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Assessment of Chlorophyll-a Concentrations in the Lagoon, Lagos State, Nigeria

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Abstract:
Remote sensing data is another possible option for mapping chlorophyll-a (Chl-a) present in all phytoplankton species. This study estimates chlorophyll-a concentration in Lagos Lagoon using Landsat 7 (ETM+) and Landsat 8 (OLI) data. Landsat data were first geometrically corrected. The techniques used were band rationing and regression modelling. The brightness values were converted to reflectance through the radiometric correction process, while the regression models, logarithmically transformed chlorophyll-a was used as the dependent variable. The single bands, band ratios and logarithmically transformed band ratios were used as the independent variables. Subsequently, the R^2 values were computed and calculated using the results generated from regression models. The Chl-a concentration generated showed reasonable results but the concentrations across the study lagoon was impacted by the ocean current with distance from Atlantic Ocean. The study concluded that the Landsat 7 and 8 images were effective in estimating chl-a concentration and producing chl-a spatio-temporal map.

Keywords: Water quality, Chlorophyll-a, Assessment, Laboratory, Remote sensing, and Satellite imagery

Introduction

Photosynthesis in green plants including algae is the critical process in which the energy from sunlight is used to produce life-sustaining oxygen; it is brought about by chlorophyll 'a' which is the primary molecule. Algal communities possess many attributes as biological indicators of spatial and temporal environmental changes (Wan-Omar, 2010; Stevenson, 2014, Wehr *et al.,* 2015; Ezat, *et al.*, 2016; Friederike *et al.,* 2016) and phytoplankton can be used as an indicator organism for the health of a particular body of water while monitoring chlorophyll 'a' levels which is a direct way of tracking algal growth. Measuring chlorophyll concentration is also a step in the process of monitoring nuisance algal blooms that may influence the taste and odor of drinking water (Kudela *et al.,* 2015; Anderson-Abbs *et al.,* 2016; Otten *et al.,* 2016). These blooms may actually create conditions that are toxic to fish, wildlife, livestock, and humans. Thus, chlorophyll measurement can be utilized as an indirect indicator of nutrient levels. Surface waters that have high chlorophyll conditions are typically high in nutrients, generally phosphorus and nitrogen. These nutrients cause the algae to grow or bloom.

According to Hestir *et al.* (2015), freshwater ecosystems underpin global water and food security, yet are some of the most endangered ecosystems in the world because they are particularly vulnerable to land management change and climate variability. It is widely noted that, surface freshwater ecosystem are among the most anthropogenically modified ecosystems on earth and are exceptionally vulnerable to climate change (Woodward *et al.,* 2010; Carpenter *et al.* 2011; Xia *et al.,* 2016). The lack of spatio - temporally representative water quality data to monitor these activities which can damage the species diversity and undermine the ecological stability has become a problem in many water quality monitoring programs. For instance, land-based runoff into Lagos lagoon resulting from anthropogenic eutrophication and human activities have remained the most common ecological problems about coastal water and therefore enrich water bodies with nutrients, which often degrade the water quality and at the same time destroy water ecosystem (Lohrenz *et al*., 1999; Kim and

Montagna, 2009; Arismendez et al., 2009; Novoa *et al.*, 2012; Oribhabor, 2016). These ecological problems intensify the pollutant effects of the quality of the water and the impacts on human when used for domestic purposes. The pollutant loading into the Lagos lagoon is mainly from non-point source which is difficult to measure and quantify using traditional water quality measurement methods. In particular, eutrophic conditions have become a recurring threat to coastal waters in the Lagos lagoon, largely owing to human land use and nutrient loading (His *et al.*, 1999; Vandeweerd, 2006; Solidoro *et al.*, 2010; Burkett, and Davidson, 2012; Oribhabor, 2016; Osunla and Okoh 2017). These anthropogenic impacts, combined with projected changes in climate, may have significant impacts upon the health and characteristics of lagoon ecosystems along the Lagos coast. Even when eutrophic conditions are not prevalent, primary producers form the base of the food web and changes in abundance result in altered productivity and biomass at higher trophic levels (Kim and Montagna, 2009; Alberti *et al., 2017*; Ullah, *et al.,* 2018). Given the importance of primary productivity to lagoon ecosystems, it is thus important to understand what the controlling factors are and to monitor current and past concentrations. Thus, there is the need to determine methods to retrieve water quality parameters accurately using satellite estimates.

Yang, 2005 and Hestir *et al.* (2015) stated that the potential of satellite remote sensing for freshwater inventory and monitoring has long been recognized by the scientific community and found widespread application, especially in marine and aquatic studies. Optical satellite datasets have been used to detect freshwater systems for decades however traditionally, satellite remote sensing of freshwater systems has been limited by sensor technology as well as its current and past missions have not provided the measurement resolutions needed to fully resolve freshwater ecosystem properties and processes (Hestir *et al.* 2015; Kudela *et al.,* 2015).

Nevertheless, integration of earth observation products derived from satellite imageries that may improve water quality monitoring is one of the feasible methods (Vignolo *et al.,* 2006; Vandeweerd, 2006; Guzinski *et al.,* 2014). With an improvement in sensor capabilities over the years, the use of earth observation products in monitoring water quality has become an increasingly popular and promising technique as well as a major component that can now accurately estimate water quality variables (Harkvoort *et al.,* 2006; Barrett and Frazier, 2016; Vihervaara *et al.,* 2017; Zheng and DiGiacomo, 2017). This is because of lack of comprehensive and reliable in-situ datasets generated from the inadequacies of traditional methods. The earth observation (satellite imagery) data allows for synoptic estimates over large areas including water quality in remote and inaccessible areas as well as estimation of historical water quality when laboratory and in situ measurements are not performed.

Studies by Kishino *et al.,* (2005), Werdell *et al.,* (2005) and Gholizadeh *et al.,* (2016) demonstrated the relationship between optical properties (reflectance) of water to other water parameters' properties such as suspended sediments, chlorophyll concentrations, dissolved organic matter, pigment load, temperature, Secchi disc depth and other laboratory based water quality results. Satellites sensors can measure the amount of solar radiation at various wavelengths reflected by surface water, which can be compared to water quality parameters for instance, total suspended solids which constitutes an alternative means of estimating water quality.

Remote sensing therefore, offers a credible means of estimating water quality measurement. In a comparative study to assess the ability of satellite based sensors to monitor suspended sediment concentration, Secchi disc depth, and turbidity, it was discovered that predictions based on optical measures of water quality are slightly better when using earth observation data (Harrington Jr *et al.,* 1972; Hua-Dong 2017). In addition, apart from extremely demanding time and capital investments of traditional methods, its monitoring also requires sequential laboratory and unreliable in situ measurements and analysis (Wang *et al.,* 2004; Al-Fahdawi *et al.,* 2015).

Nonetheless, remote sensing application is limited to its ability to distinguish among the various water constituents; the problem of depth which is limited to surface, uncontrollable and varies with water clarity, and finally, the spatial and temporal resolution could be inadequate and difficult to control. Since conventional and satellite estimates approaches have their merit and demerit, this study uses satellite imagery to extrapolate and complement ground measurements to areas and times with little or no coverage. This will reduce the number of ground samples and increases the spatial and temporal coverage of the assessment.

It is based on the aforementioned that this study aims at assessing Chlorophyll-a concentrations in the Lagos Lagoon using satellite data (Landsat-7 ETM+ and Landsat-8 OLI/TIRS) and field observation / laboratory methods.

The Study Area

The Lagos Lagoon is a lagoon sharing it name with the city of Lagos, Nigeria (the second fastest growing city in Africa and the seventh fastest in the world). Lagos lagoon cuts across the southern part of the Lagos metropolis and empties into the Atlantic Ocean via Lagos Harbour, a main channel through the heart of the city – 0.5km to 1km wide and 10 km long in the southwest of Lagos State. It lies within longitudes 6°25 and 6°43E and latitudes 3°22 and 3°40N, and covers an area of about 589.sqkm (Figure 1). The lagoon provides places of abode and recreation, means of livelihood and transport, a dumpsite for residential and industrial discharge and a natural shock absorber to balance forces within the natural ecological system. The untreated domestic and industrial wastes from the Metropolitan Lagos are discharge into the Lagos lagoon through the following 13 points (Ibeshe, Egbin, Oworoshoki, Makoko, Okobaba, University of Lagos (UNILAG) front, Iddo, Ijora, Apapa, Five Cowries Creek, Commodore Channel, and Tincan Creek) of which the main 7 (Ibeshe, Egbin, Oworoshoki, University of Lagos-UNILAG front, Ijora, Five Cowries Creek, and Commodore Channel) form the focus of the study and sampling points (Figure 1).

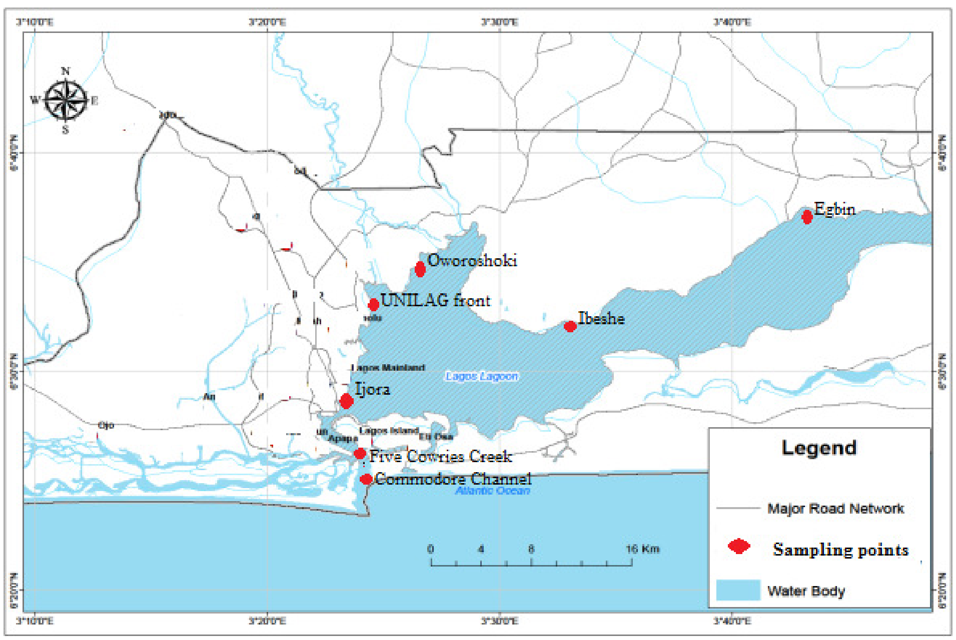

Figure 1: Lagos Lagoon showing sampling points
Source: GIS Lab, Department of Geography, University of Lagos

Methodology

Estimation of chlorophyll-a from the laboratory

Chlorophyll 'a' was determined using a Fluorometer equipped with filters for light emission and excitation (Golterman, 1975). Water sample measured 200ml was filtered through a 0.45µm fibre membrane filter, after which the residue on the filter was transferred to a tissue blender, covered with 3ml of 90% aqueous acetone and macerated for 1min. the sample was then transferred to a centrifuge tube, capped and allowed to stand for 2hr in the dark at 4˚C (in a refrigerator). Thereafter, it was centrifuged at 5000rpm for 20mins and the supernatant was decanted. Volume left after decanting was noted. Different readings were taken from the Fluorometer (which had been pre-calibrated with 2, 5, 10 and 20µg standard chlorophyll solutions) at

×1, ×3, × 10, and × 30 sensitivity settings and noted. The calibration factors to convert fluorometric reading for each sensitivity to concentration of chlorophyll-*a* was derived as follows:

$$\frac{Fs}{Rs} = Ca \quad \text{Equation 1}$$

Where;
Fs = Calibration factor sensitivity settings
Rs = Fluorometer reading for sensitivity setting
Ca = Concentration of chlorophyll-a

Image data processing

In this study, the Landsat 7 ETM+ and Landsat 8 Operational Land Imager (OLI) of paths and rows 191 and 055/056 covering Lagos Lagoon were used.

Landsat-7 ETM+ image is superior to its predecessors (e.g. Landsat -5), with significant improvement of on-flight geometric and 5% absolute radiometric calibration, and consist of improved panchromatic band with 15m spatial resolution (band 8), visible (reflected light) bands in the spectrum of blue, green, red, near-infrared (NIR); mid-infrared (MIR) with 30m spatial resolution (bands 1-5, 7), and a 60m thermal infrared (band 6) spatial resolution.

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The resolution for Band 8 (panchromatic) is 15 meters. In addition, it also has two Thermal IR bands with a spatial resolution of 100m (later resampled into 30 m). Since the spectral bands of Landsat ETM are very similar, this study used similar methods for of 2007 and 2010 imageries. Using the image metadata, the radiometric calibration was conducted to convert digital numbers into top-of-atmosphere radiance (Watanabe *et al.*, 2015; Center for Earth Observation, 2016). The surface reflectance retrieval was accomplished using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH), an atmospheric correction module, implemented in the ENVI software. This tool adopted the MODerate resolution atmospheric TRANsmission (MODTRAN4), an atmospheric radioactive transfer code (Richter, 1996; Atmospheric Correction Module, 2009; Liu *et al.,* 2003; Fernanda *et al.,* 2015; Center for Earth Observation, 2016; Ayeni and Adesalu, 2018) environment and a shape file covering the Lagos lagoon was superimposed on the images and used to extract the Region of interest (ROI). The extracted images were then stretched using the histogram equalization technique and filtered to remove haze, cloud cover and noise using the Quick atmospheric correction tool in Envi 5.0 software (Richter, 1996; Gitelson *et al.,* 2003; Mathias *et al.,* 2007; Ayeni and Adesalu, 2018).

Landsat ETM+ data pre-processing followed standard specification including radiometric and geometric calibration and terrain correction (Irish 2000; Yang *et al.*, 2003); conversion from digital number to at satellite reflectance (for six reflectance bands) or at satellite radiance temperature (the thermal band), and referencing to the National Albers equal-area map projection and resampling using cubic convolution to 30m resolution. After initial pre-processing, tasselled-cap brightness, greenness, and wetness were derived using at satellite reflectance-based coefficients (Huang *et al.,* 2002; Yang *et al.,* 2003)

Estimation of chlorophyll-a using Landsat satellite imageries: Two different Landsat 7 images with acquisition dates of November 08 2007 & November 06 2010 and Landsat 8 with acquisition dates of November 11 2015 image used for this study were acquired from USGS Earth Explorer. The data were in GeoTiff format with 16bit radiometric resolution (ranges from 0-65535).

Landsat 7: The band ratios among the first four ETM+ bands as proposed and tested in the literature were computed (Gitelson *et al.*, 1996; Chavez1996; Baban 1997, Woodruff *et al.,* 1999, Braga *et al.,* 2003; Jensen 2005; Ayeni and Adesalu, 2018). In the regression models established, the logarithmically transformed chlorophyll-a concentration was used as a dependent variable (Chang *et al.,* 2004). The three types of independent variables were tested: reflectance of a single band, logarithmically transformed band ratios, and ratios of logarithmically transformed single band. Subsequently, R^2 values were computed and calculated using the results generated from regression models (Han and Jordan, 2005). The results were used to generate maps of chlorophyll-a distribution and concentration in Lagos Lagoon.

DN was then converted to TOA reflectance using the Landsat 8 processing toolbox of ArcGIS 10.3. Radiometric calibration and atmospheric correction for Landsat 8 required to achieve the purpose of chlorophyll a concentration retrieval (Chengkun and Min, 2015; Ayeni and Adesalu, 2018) were conducted using the ENVI software in for this study. After radiometric calibration, the un-calibrated digital numbers (DN) were converted to radiance values through the formula:

$L_\lambda = M_L Q_{cal} + A_i$, ………… Equation 2

where
L_λ is the top-of-atmosphere (TOA) spectral radiance, M_L is band specific multiplicative rescaling factor from the metadata, A_i is the band specific additive rescaling factor from the metadata, and then the dimensionless top-of-atmosphere reflectance ρTOA can be calculated as:

$$\rho_{TOA} = \frac{\pi L_\lambda d^2}{ESUN_\lambda \cos\theta_s} \quad \text{… Equation 3}$$

Where
$L\lambda$ is the spectral radiance at the sensor, d is the Earth-sun distance in astronomical units. ESUN is the mean solar exoatmospheric irradiance for each band and θcos is the solar zenith angle in degrees and all the parameters can be acquired in the header files (Chengkun and Min, 2015).

Band Ratio using band 4 and band 5 reflectance: The reflectance band 4 (NIR) and band 5 (MIR) were divided to correct for atmospheric distortions in the images and to obtain a band ratio of the both images.
Estimation of chl-a content: The band ratio (3_4.tif) was then divided by π to obtain the chlorophyll-a content using the raster calculator in ArcGIS and the regression method. The FLAASH module subsequently outputs a bottom-of-atmosphere reflectance value for each pixel and an average scene visibility and water amount were therefore estimated (Tebbs *et al.,* 2013; Ayeni and Adesalu, 2018). The images used in this study were processed with FLAASH atmospheric correction which produced Landsat image individual bands with reflectance values (Ayeni and Adesalu, 2018).

Results and Discussions

Landsat 7 and 8 images were used to study Lagos lagoon chl-a concentration for 2007, 2010, and 2015. Their results showed that the images spatial resolution and signal noise ratio was suitable to study the Lagoon chl-a concentration. The findings of the analysis are shown in Table 1 and Figures 2 – 5 (Ayeni and Adesalu, 2018).

Table 1: Remote sensing and Laboratory estimation of Chl-a.

Locations' information			**Landsat Imageries (µg/l)**			**Laboratory (µg/l)**
Latitude	**Longitude**	**Locations**	**2007**	**2010**	**2015**	**2015**
6°25'14.5''	3°24'25.7''	Commodore Channel	0.45	0.48	0.25	0.32
6°26'17.4''	3°23'48.0''	Five Cowries Creek	0.51	0.32	0.24	0.44
6°27'54.0''	3°22'37.3''	Ijora	0.32	0.32	0.23	0.22
6°30'37.5''	3°24'14.1''	Unilag Water Front	0.24	0.32	0.20	0.014
6°32'54.0''	3°24'24.6''	Oworonshoki	0.21	0.21	0.19	0.02
6°'32'48.9''	3°28'36.1''	Ibeshe	0.35	0.32	0.23	0.16
6o25'37.8''	3°35'55.1	Egbin	0.33	0.29	0.21	0.13

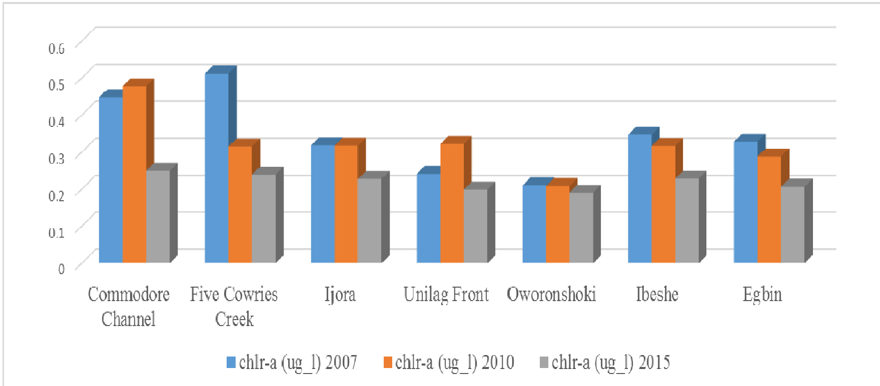

Fig. 2: Comparison of Chl-a estimation of 2007, 2010 & 2015 Landsat data

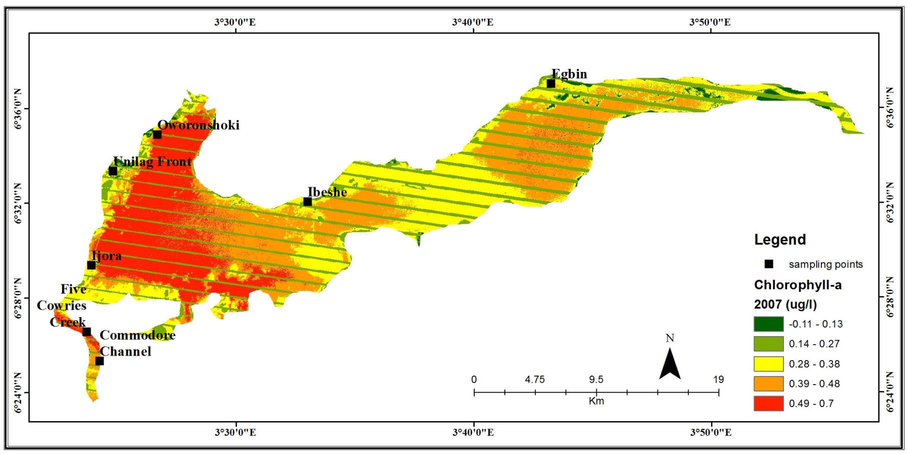

Fig. 3: Chlorophyll-a distribution in the Lagos Lagoon, 2007

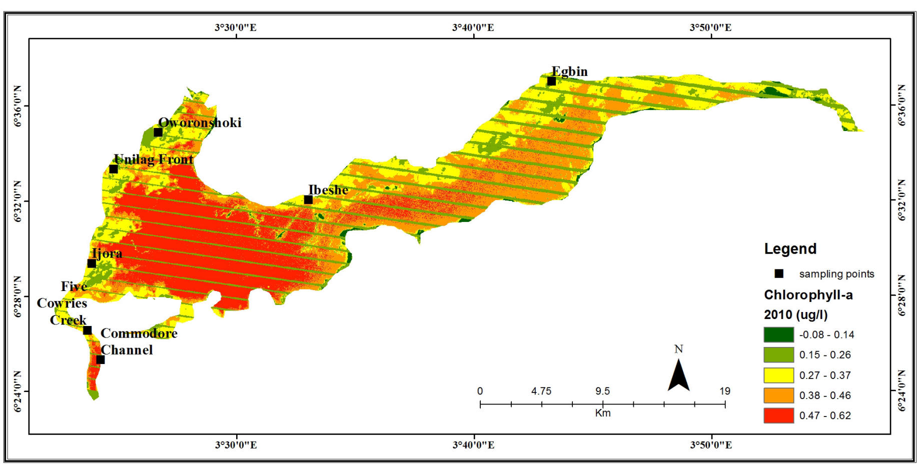

Fig. 4: Chlorophyll-a distribution in the Lagos Lagoon, 2010

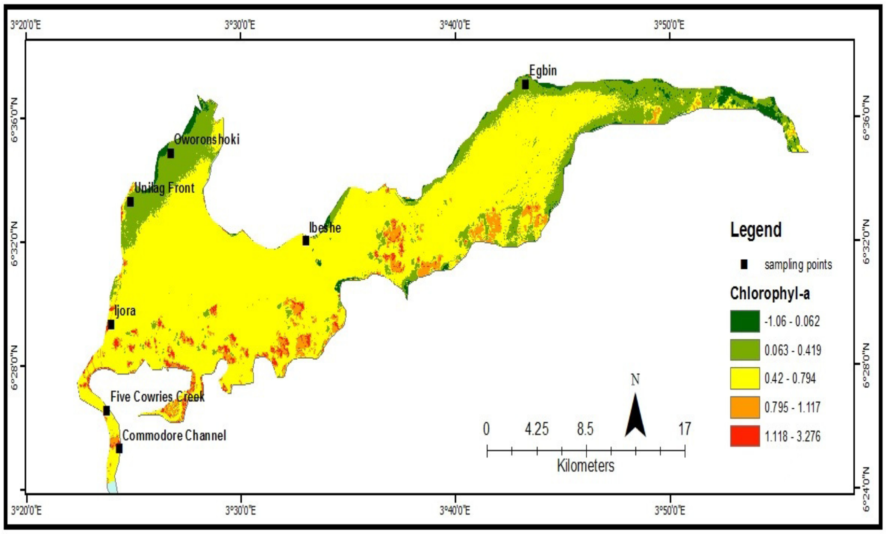

Fig. 5: Chlorophyll-a distribution in the Lagos Lagoon, 2015

The results revealed that the concentration of chlorophyll-a was highest at the Five Cowries Creek in 2007 and Commodore channel in 2010 and 2015. The lowest concentration of Chlorophyll a was observed at Oworonshoki for the whole period. The inter-annual variabilities of chlorophyll-a in Lagos Lagoon between 2007 and 2015 are shown in Table 1 and Figures 2 – 5. Concentrations decrease predominantly with distance from Lagoon to Atlantic Ocean. These findings may indicate constant yearly patterns of chlorophyll-a distribution, even though data from the rainy season are not included in this study. The results of chlorophyll-a estimation from the Landsat 7 and 8 revealed that there was correlation with laboratory result of 2015 with r^2-value of 0.79 (significant at $p < 0.05$). This indicates that the Landsat and laboratory results generated for Lagos Lagoon were positively related.

The highest value of Chlorophyll-a observed at the Five Cowries Creek in 2007 and Commodore channel in 2010 and 2015 could probably due to their closeness to Lagos harbour which eventually showed in the depth of the lagoon (Adesalu *et al.,* 2010; Nwankwo *et al.,* 2012). In this case, there will be less mixing of bottom sediments which aggravate turbidity and eventually affect the rate of light penetration for photosynthesis to take place (Adrie *et al.,* 2008; Pedersen *et al.,* 2013). The lowest concentration of Chlorophyll-a was observed at Oworonshoki for the whole period and this may be attributed to the fact that Oworonsoki and other locations (Ijora, Unilag Water Front, Ibeshe, and Egbin) are shallow water body which allow the mixture of the bottom sediments (Zakonnov *et al.,* 2007; Adrie *et al.,* 2008; Kogelbauer and Loiskandl, 2015; Mimier and Żbikowski, 2016). In addition, most of the domestic wastes from settlements around these locations find their way directly into the water body thereby increasing the surface water turbidity and decreasing the light penetration which then resulted in low photosynthesis rate (Nwankwo and Akinsoji, 1989; Ajao and Fagade, 1991; Adesalu *et al.,* 2010; Nwankwo et al., 2013; Uwadiae, 2016). Considering the fact that Lagos lagoon is used for so many things in which transportation of man and goods is the most common, this can also bring about the mixture of the bottom sediment due to the shallowness of these parts of the lagoon (Nwankwo *et al.,* 2013).

It should be noted that the effects of large amounts of suspended sediment or coloured dissolved organic matter (CDOM) on the remotely sensed data in these areas were not considered in this study. For detail understanding of the Lagos Lagoon chlorophyll-a concentration and distribution pattern for various years, data from the rainy season may be needed but unfortunately the Landsat data for rainy season for the study region are always hindered with cloud cover. Furthermore, errors may originate from haze and cloud during the rainy season which may shadow parts of the lagoon (Liu *et al.,* 2003; Sass, *et al.,* 2007). Increased knowledge on the Lagos Lagoon temporal chlorophyll-a distribution may help for an improved description of the main features of annual nutrient cycling in the Lagoon. The study finally observed the coastal waters of the study area have a high trend of eutrophication during dry season but appear to be normal during rain. Also, the effect of ocean current was noted to have had impact on Chl -a distribution.

Conclusion

Chlorophyll-a is an indicator of the abundance of phytoplankton, which make an important contribution to overall primary productivity of coastal water bodies. The in-situ results used in this study were limited by spatio-temporal samples sizes. As a result, using remote sensing techniques to estimate and map chlorophyll-a concentration is quite significant for improving the monitoring and assessment of water quality in water bodies. This study estimates and map Chl-a concentration using Landsat ETM and OLI images with linear regression methods. The result of OLI 2015 showed high accuracy when comparing with the in-situ measurement of December 2015. The distribution map of Chl -a concentration could be useful in analysing the Chl-a source, as well as the transport processes. It is therefore concluded that as Lagos is continuously under the influence of rapid economic development and pressures on aquatic resources continue to increase, future monitoring of eutrophication trends of Lagos Lagoon should continue to be cause of concern to researchers and more effort should be towards analysing of spectral characteristic and the water quality parameters for future comprehensive sampling examination.

The one season and 6 sampling stations of in-situ is the limitation to this study while the spectral resolution of Landsat 7 ETM+ is relatively low in estimating chlorophyll-a compared Landsat 8 OLI. Nevertheless, the estimation from the ETM+, OLI and in-situ are comparable and justifiable for real time chlorophyll-a assessment and mapping.

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