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# Estimation of Chlorophyll-A Concentration in Aquatic Ecosystems Northwest Arabian Gulf Using Remote Sensing

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**Abstract** - One of the essential components of life is water, and that is why its monitoring is fundamental. The purpose of this research, therefore, was to estimate the concentration of chlorophyll-a using remote sensing data. Chlorophyll-a concentration in water is an indicator of phytoplankton density and, consequently, water quality, which in turn is crucial, as it represents the base of the ecological life in seas and oceans. Any increase or decrease in the number of phytoplankton may contribute to the disruption of the ecological cycle in the seawater. The study area was located in the northwest Arabian Gulf. The concentration of chlorophyll-a was mapped based on images captured by the Medium Resolution Imaging Spectroradiometer on Aqua Satellite (MODIS) and Operational Land Imager (OLI) sensor. The images were acquired in 2022. Chlorophyll-a concentration was estimated using an algorithm based on Band 4 and Band 5 of Landsat 8,9 OLI. The concentration of chlorophyll-a was found throughout the seasons of the year 2022, and it was found that its highest value is in the winter season and its lowest value is in the spring.

## تقدير تركيز الكلوروفيل-أ في النظم البيئية المائية شمال غرب الخليج العربي باستخدام الاستشعار عن بعد

عادل جاسم الفرطوسي [1] ، معتصم ابراهيم ملك [2] و حامد مجيد عبد الجبار [3]
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**المستخلص** - يُعد الماء أحد المكونات الأساسية للحياة، ولذلك يُعد رصده أمرًا بالغ الأهمية. لذا، كان الغرض من هذا البحث تقدير تركيز الكلوروفيل-أ باستخدام بيانات الاستشعار عن بُعد. يُعد تركيز الكلوروفيل-أ في الماء مؤشرًا على كثافة العوالق النباتية، وبالتالي على جودة المياه، وهو أمر بالغ الأهمية، لأنه يمثل أساس الحياة البيئية في البحار والمحيطات. قد يُسهم أي زيادة أو نقصان في مقدار العوالق النباتية في اختلال الدورة البيئية في مياه البحر. تقع منطقة الدراسة في شمال غرب الخليج العربي. رُسمت خريطة تركيز الكلوروفيل-أ بناءً على الصور الملتقطة بواسطة مطياف التصوير متوسط الدقة على القمر الصناعي المائي (MODIS) ومستشعر تصوير الأرض التشغيلي (OLI) . تم التقاط الصور في عام 2022. قُدِّر تركيز الكلوروفيل-أ باستخدام خوارزمية تعتمد على النطاقين 4 و5 من القمر الصناعي Landsat 8,9 OLI. تم العثور على تركيز الكلوروفيل-أ طوال فصول عام 2022، ووجد أن أعلى قيمة له في فصل الشتاء وأقل قيمة له في فصل الربيع

**الكلمات المفتاحية:** شمال غرب الخليج العربي ، المياه البحرية العراقية ، MODIS ،الكلوروفيل-أ

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## Introduction

To monitor the spatial and seasonal variations of near-surface phytoplankton, as well as provide data for the study of oceanic primary production, other biogeochemical cycles and fisheries research, satellite ocean color information is a practical tool (IOCCG, 2000). Since phytoplankton is the basis of ecological life in seas and oceans, the concentration of chlorophyll-a in water is a good indicator of phytoplankton density (Muller *et al.,* 2005).

The ecological cycle of seawater may be disturbed due to an increase or decrease in the amount of phytoplankton. Also, Phytoplankton density is another important pointer on water quality (O'Reilly *et al.,* 1998). Specimens of water are gathered traditionally in the field and examined in a lab. to measure phytoplankton density in a specific volume of water.

Recently, advanced methods have been developed in detecting phytoplankton density by extracting near-surface chlorophyll-a concentrations, using remote sensing (O'Reilly *et al.,* 1998). For many years, have been examining how phytoplankton affects seawater color. Ocean color research started in the late 1970s using data gathered between October 1978 and June 1986 using the Coastal Zone Color Scanner (CZCS) on board the Nimbus7 satellite (Acker, 1994) .

Passive CZCS measurements over the oceans have been successfully used to determine the in situ chlorophyll-a concentration because phytoplankton is the main contributor to marine waters' color (Evans and Jorden, 1994). The Sea-Viewing Wide Field of View Sensor (SeaWiFS; 1997–2010), the Medium Resolution Imaging Spectrometer (MERIS; 2002– 2012), and the Moderate Resolution Imaging Spectroradiometer (MODIS; 2000 to the present for the Terra satellite and 2002 to the present for the Aqua satellite) are examples of the subsequent generation of ocean color sensors. These more advanced sensors have been made to overcome some of the disadvantages of CZCS because they contain more wavebands and higher resolution (Hooker *et al.,* 1993).

Every two days, the Terra and Aqua satellites' MODIS instrument scans the entire surface of the planet, collecting data in 36 spectral bands that can be utilized to study the dynamics and processes that take place in the lower atmosphere and on land oceans (Hattab *et al.,* 2013). Instead, the characteristics of the water quality, such as the concentration of chlorophyll-a, suspended particulate matter (SPM), colored dissolved organic matter (CDOM), etc., were measured using satellites dedicated to terrestrial surveillance with a relatively high spatial resolution, such as Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper plus (ETM+) (Cardille *et al.,* 2013; Menken *et al.,* 2006).

When a new generation of satellites Landsat-8 with previously unparalleled-of capabilities was launched, this situation was transformed (Franz, 2014). The current sensors have a 30 m spatial resolution of Operational Land Imager (OLI). For making precise estimates of chlorophyll-a form satellite radiance data, improvements in bio-optical algorithms have been necessary, along with improved sensors. Algorithms for ocean color inverting (spectral radiance or ocean surface reflection) have been developed to extract chlorophyll-a concentration (in mg $m^{-3}$), these algorithms are based on the remote sensing reflectance spectral ratio (Rrs) (Chuanmin *et al.,* 2012).

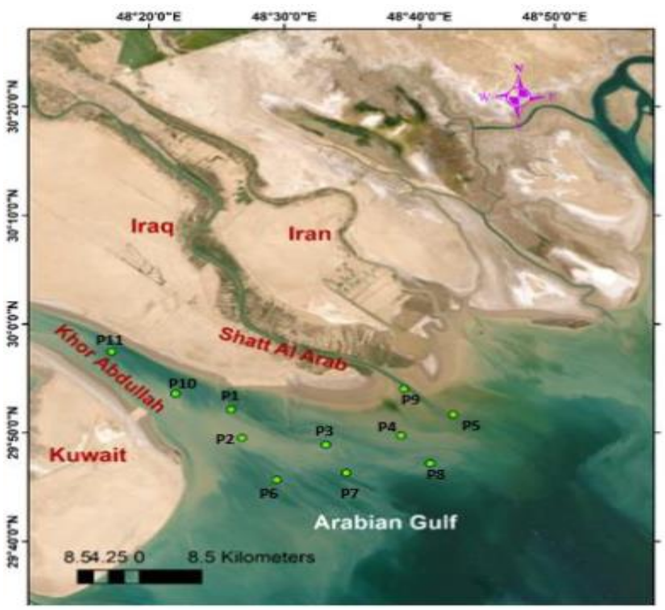
The purpose of the study was to use satellite data to investigate and extract the values of chlorophyll-a concentrations at points with coordinates distributed in marine waters.

## Study Area:

The study was conducted in the Iraqi territorial waters northwest of the Arabian Gulf because of its great importance in economic, environmental, and geopolitical terms. It represents one of the most important natural borders of the country, in addition to being the only marine artery and a window for direct communication with the outside world by sea, and the presence of many Iraqi oil ports, floating export platforms, and Al-Faw large port in the future.

The study area is located in the far northwest of the head of the Arabian Gulf, so its physical, chemical, and biological properties are mainly affected by the characteristics of the Arabian Gulf. The northwestern part of the Arabian Gulf is characterized by the presence of a network of marine channels, which are locally called Lagoons, such as Khor Abdullah. In addition, the study area is affected by the hydrology of the Shatt al- Arab River and Bahmanshir Channel, Figure (1).

Among the studies conducted in the area, but not limited to (Mussa *et al.*, 2023a ; Mussa *et al.*, 2023b), there is also the study (Al-Fartusi *et al.*, 2023a ; Al-Fartusi *et al.*, 2023b) that used remote sensing to study some of the physical factors of the region.




.Figure 1. Research Region (Researcher's work)

## Data and Methods

Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua Satellite and the Landsat-8 OLI sensor were used to measure the concentricity of chlorophyll-a and compare its value calculated from the two sensors, because field measurements were not available. The chlorophyll-a image was downloaded on 19 Jan. 2022 from the NASA Ocean Color website Level 3 (http://oceancolor.gsfc.nasa.gov). NASA Ocean Color is a platform supported by

NASA's Goddard Space Flight Center's Ocean Biology Processing Group (OBPG). Since 1996, NASA has offered a range of products to the scientific community that are related to the marine environment and water quality. The level 3 products have a 4 or 9 square km spatial resolution. In the current study, the 4 km$^2$ product was used. The image was processed by SeaDAS Software v.8.2, to extract the data of chlorophyll-a. Level-1 data product for Landsat (8, 9) OLI was used. To retrieve chlorophyll-a from satellite sensors over the study area, four steps are necessary.

(i) The top of atmosphere (TOA) reflectance is calculated from scaled DN values for each band that is needed.

(ii) The dark object subtraction technique (DOS technique) is used, by which the bottom of the atmospheric reflection or the surface reflection (originating from the land's surface) can be determined.

(iii) The surface reflectance is converted to the corresponding remote sensing reflectance (Rrs) at these bands, finally.

(iv) Ocean Chlorophyll (OC) algorithm is used to retrieve chlorophyll-a from the Rrs (Shukla *et al.,* 2019).

The formulations below are used to calculate TOA Reflectance ($\rho_p$) for Landsat (8, 9 ) OLI (NASA , 2011):

$$L_\lambda = \left(\frac{Lmax_\lambda - Lmin_\lambda}{Q_{calmax} - Q_{calmin}}\right) * (Q_{cal} - Q_{calmin}) + Lmin_\lambda \quad \text{.........(1)}$$

$Lmax_\lambda$ is Radiance _Maximum_Band_x, where x is the band number
$Lmin_\lambda$ is Radiance _Minimum_Band _x, where x is the band number

$Q_{calmax}$ is Quantize _cal_Max_Band

$Q_{calmin}$ is Quantize _cal_Min_Band

$Q_{cal}$ is Pixel values (DN)

$$\rho_p = \frac{(\pi * L_\lambda * d^2)}{(ESUN_\lambda * \cos(\theta s))} \dots\dots\dots\dots\dots.(2)$$

Where: $\rho_p$ is the TOA Reflectance, $L_\lambda$ is the spectral radiance at the sensor's aperture (at-satellite radiance), d is the EarthSun distance in astronomical units, $ESUN_\lambda$ is the mean solar exo-atmospheric irradiances,

θs is the Solar zenith angle in degrees, which is equal to $\theta s = 90^\circ - \theta e$, where θe is the Sun elevation, and $\pi = 3.142$.

Among the image-based atmospheric corrections, is dark object subtraction (DOS). (Shukla *et al.,* 2019) explains that “the basic assumption is that some pixels in the image are completely in shadow, and their radiances received by satellite are due to atmospheric scattering (haze effect).

This assumption is combined with very few elements on the Earth's surface having an absolute black color, so an assumed reflectance of one percent is better than zero percent." It is important to note that corrections based on physical measurements are usually more accurate than image-based techniques, they are beneficial when atmospheric measurements are not available that can improve the estimation of the reflectance of the earth's surface.

The atmospheric scattering or path radiance (haze effect) (Lp) is provided by (Chavez, 1996 ; Sobrino *et al.*, 2004):

$$L_p = L_{min} - L_{DO1\%} \dots\dots\dots\dots (3)$$

Where:

$L_{min}$ is a radiance that corresponds to a digital value such that the total of all pixels in the image under consideration with digital values of 0.01% or less fall within this range (Sobrino *et al.*, 2004), therefore, the radiance obtained with that digital count value ($DN_{min}$).

$L_{DO1\%}$ is the dark object's radiance by a reflectance value of 0.01

In particular, for Landsat images:

$$L_{min}=M_L * DN_{min} + A_L \quad \dots\dots\dots\dots\dots (4)$$

Dark Object Radiance was found by (Moran etal, 1992):

$$L_{DO1\%} = \frac{0.01 * [(ESUN_\lambda * \cos(\theta s) * T_z) + E_{down}] * T_v}{(\pi * d^2)} \dots\dots\dots . (5)$$

Therefore, the haze effect is:

$$Lp = (M_L * DN_{min} + A_L) - \frac{0.01 * [(ESUN_\lambda * \cos(\theta s) * T_z) + E_{down}] * T_v}{(\pi * d^2)} \quad \dots\dots\dots\dots\dots (6)$$

Numerous DOS techniques are available, each depending on different values of $T_v$, $T_z$, and $E_{down}$. The simplest technique is where the following assumptions are made (Zhaoming *et al.*, 2012):

$$T_v = 1, T_z = 1, E_{down} = 0$$

Therefore, the haze effect is:

$$L_p = (M_L * DN_{min} + A_L) - \frac{[0.01 * ESUN_\lambda * \cos(\theta s)]}{(\pi * d^2)} \dots\dots\dots\dots . (7)$$

Then, using TOA Reflectance for the sensor at the required bands (λs), land surface reflectance (ρ) is calculated (Moran *et al.*, 1992):

$$\rho = \frac{\left[\pi * \left(L_\lambda - L_p\right) * d^2\right]}{\left[T_v * \left(\left(ESUN_\lambda * \cos(\theta s) * T_z\right) + E_{down}\right)\right]} \dots\dots\dots(8)$$

where $T_v$ is the atmospheric transmittance in the viewing direction, $T_z$ is the atmospheric transmittance in the illumination direction, and $E_{down}$ is the down welling diffuse irradiance.

As a result, the land surface reflection (DOS1) is given by:

$$\rho = \frac{\left[\pi * \left(L_\lambda - L_p\right) * d^2\right]}{\left(ESUN_\lambda * \cos(\theta s)\right)} \dots\dots\dots(9)\ (\text{Zhaoming } etal., 2012)$$

$ESUN_\lambda$ values from: $ESUN_\lambda = (\pi * d^2) *$ RADIANCE_MAXIMUM / REFLECTANCE_MAXIMUM (Hereher, 2020).

Where:

RADIANCE_MAXIMUM and REFLECTANCE_MAXIMUM are provided by image metadata.

Remote sensing reflection ($R_{rs}$) is obtained to correct for atmospheric effects of hyperspectral ocean color data or as expressed by the water-leaving radiance from the land surface reflection following ( Moses *etal.*, 2015), submitted by:

$$R_{rs}\ (\lambda) = \rho / \pi \dots\dots\dots(10)$$

The $R_{rs}$ obtained for the bands are then used in the bio-optical algorithms for retrieval of chlorophyll-a.

Using an equation adapted from (Bhirawa *et al.*, 2015), chlorophyll-a was calculated from the Landsat (8,9) OLI images. Equation 11 was applied using the Map Algebra function of the ArcGIS 10.8.1 software.

$$\text{Chl- a} = 0.9889\ (Rrs4 / Rrs5) - 0.3619 \dots\dots\dots(11)$$

where:

$R_{rs}4$ and $R_{rs}5$. The reflectance of Band 4 and Band 5, respectively, of Landsat 8 OLI

## Results and Discussion

The study was conducted to investigate the presence of chlorophyll-a and then know its spatial distribution, the concentration of chlorophyll was calculated in distributed points with known coordinates in the Iraqi territorial waters during 2022.

The ideal way to monitor the primary productivity of the marine environment is through satellite remote sensing in areas with a dearth of oceanographic data, such as in the Arabian Gulf.

Table 1 shows the values of chlorophyll-a concentrations obtained from the Aqua Modis satellite image and the Landsat-8 OLI for the day 19/1/2022.

Table 1. Shows the values of chlorophyll-a concentrations (19/1/2022).

| No.point | Coordinate of points (DD) | | Aqua Modis(mg/m$^3$) | Landsat 8 (mg/m$^3$) |
|---|---|---|---|---|
| P1 | 48.448 | 29.879 | 4.37 | 3.7 |
| P2 | 48.444 | 29.833 | 3.54 | 4.01 |
| P3 | 48.551 | 29.822 | 3.45 | 3.19 |
| P4 | 48.637 | 29.833 | 3.33 | 3.77 |
| P5 | 48.708 | 29.865 | 2.7 | 2.51 |
| P6 | 48.483 | 29.761 | 3.03 | 4.02 |
| P7 | 48.573 | 29. 768 | 2.73 | 4 |
| P8 | 48.676 | 29.786 | 2.63 | 3.79 |
| P9 | 48.644 | 29.908 | No Data | 3.55 |
| P10 | 48.366 | 29.9 | 4.09 | 3.9 |
| P11 | 48.283 | 29.968 | No Data | 3.55 |

It is noted that the concentration values differ, and this is normal because the accuracy of the Landsat-8 is 30 meters, while the Aqua Modis satellite is 4 km for level 3. In the shallow regions of the Arabian Gulf. The value of satellite sensors is affected by seafloor reflections. So, the spatial coverage of moderate satellite sensors is weak for marginal seas such as the Arabian Gulf.

This was evident when analysing MODIS data, as the coverage of narrow coastlines and waterways is relatively bounded.

This has emerged from the lost data that was observed at the entrance to the Khor Abdullah and Shatt al-Arab, which agrees with (Reilly *et al.*, 2000).

Landsat-9 images were relied upon to calculate and know the change in the values of chlorophyll-a concentrations during the seasons of the year 2022, as satellite images were downloaded in the fourth, seventh, and tenth months, to represent the seasons of spring, summer, and autumn, respectively table 2 shows satellite image information.

Table 2. Satellite image information.

| Satellite Name | Sensor Type | Path _Row | Date Acquired | Scene Center Time (AM) | Spatial Resolution (m) |
|---|---|---|---|---|---|
| LANDSAT 8 | OLI | 165-39 | 2022-01-19 | 07:15:48 | 30 |
| LANDSAT 9 | OLI | 165-39 | 2022-04-01 | 07:15:33 | 30 |
| LANDSAT 9 | OLI | 165-39 | 2022-07-06 | 07:15:28 | 30 |
| LANDSAT 9 | OLI | 165-39 | 2022-10-10 | 07:16:00 | 30 |

The results of the Chlorophyll-a distribution analysis of the year 2022 in Iraqi marine waters showed that the focus increases in the winter and decreases in the summer and fall, and its lowest values in the spring. As shown in Table 3. This agrees with (Albanai, 2021).

Table 3. Values of chlorophyll-a concentrations in the seasons of the year 2022

| No. point | Winter (mg/m$^3$) | Spring (mg/m$^3$) | Summer (mg/m$^3$) | Fall (mg/m$^3$) |
|---|---|---|---|---|
| P1 | 3.7 | 1.23 | 1.66 | 2.82 |
| P2 | 4.01 | 1.27 | 1.68 | 3.27 |
| P3 | 3.19 | 1.24 | 1.47 | 3.12 |
| P4 | 3.77 | 1.27 | 1.68 | 3.65 |
| P5 | 2.51 | 1.14 | 1.46 | 2.4 |
| P6 | 4.02 | 1.13 | 1.90 | 2.49 |
| P7 | 4 | 1.05 | 1.12 | 3.39 |
| P8 | 3.79 | 1 | 1.10 | 3.61 |
| P9 | 3.55 | 1.3 | 1.51 | 3.29 |
| P10 | 3. 9 | 1.17 | 1.92 | 2.42 |
| P11 | 3.53 | 1.19 | 1.79 | 2.67 |

The low Chlorophyll-a concentration in spring is likely due to the phytoplankton bloom in winter depleting nutrients. Such seasonal cycles are common in tropical and subtropical oceans, claim (Al-Naimi *et al.*, 2017 ; Nezlin *et al.*, 2007), where nutrient deficiency brought on by a strong pycnocline formation restricts phytoplankton growth. This is related to thermal stratification, which stabilises the water column by reducing vertical mixing and, as a result, the supply of nutrients to the surface (Doney, 2007). Our findings are consistent with another study of the spatiotemporal variations of phytoplankton biomass in the Arabian Gulf using the chlorophyll-a dataset (Moradi and Kabiri, 2015), where they reported that both spring and summer saw chlorophyll-a concentrations lower compared to winter in the open waters of the Gulf.

**Conclusions:**

1-The retrieval of chlorophyll-a concentration is only the first step in monitoring water ecosystems.

2- The distribution and dynamics of chlorophyll-a concentration in Iraqi waters is the key indicator towards understanding the density of phytoplankton, as well as Iraq’s marine ecosystem environment.

3- Results showed that the used algorithm was able to estimate Chlorophyll-a in the northern Arabian Gulf coastal region well.

4- Seasonal variability of Landsat-derived Chlorophyll-a was analyzed and it was observed that Chlorophyll-a was lowest in April and highest in January (winter season). Inter-comparison of

Chlorophyll-a retrieved from the two sensors (Landsat-8 OLI and MODIS) was then carried out during the year 2022.

5- The current analysis shows that ongoing coastal water (case-2 water) monitoring is very necessary.

**Recommends;**

1- Installing buoys equipped with sensors and distributed in Iraqi marine waters to measure turbidity and chlorophyll-a concentration.

2- Conducting a study for at least a decade, taking into account climate change, which in turn affects the sea surface temperature and thus the dissolved oxygen concentration, and then knowing the spatial and temporal distribution of chlorophyll-a in Iraqi marine waters.

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