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Remote sensing method and field data to measure chlorophyll-a in surface waters of Chabahar Bay, Iran

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Abstract

Remote sensing is typically the most efficient and cost-effective method to measure chlorophyll-a (Chl-*a*). This study was designed to perform remote sensing of Chl-*a* in Chabahar Bay, located in the northern part of the Gulf of Oman, Iran, based on the light absorption coefficient of phytoplankton. Surface water has been sampled at six stations in Chabahar Bay during 2013-2015. Chl-*a* was extracted by acetone (90%) and the absorption (750, 664, and 630 nm) was read using the spectrophotometry method. These values were compared with data acquired by the Landsat 8 satellite to estimate the concentration of Chl-*a*. The results showed that Chl-*a* concentration was at the range of 5 to 30 mg/m^3 and a positive correlation was found between the field data and satellite prediction algorithms. Generally, this study showed that Landsat satellite data can provide useful information on the spatio-temporal variations in Chabahar Bay and establish general trends that are difficult to be determined through routine ground measurements.

Keywords: Chlorophyll-*a*; Eutrophication; Remote sensing; Chabahar Bay.

1. Introduction

Chlorophyll is an important component in photosynthesis, a critical process in which sunlight energy is used to produce life-sustaining oxygen. This pigment is abundant in phytoplankton, a bioindicator for the water quality assessment, with an important and essential role. Algal growth can be monitored by measuring chlorophyll level. Algal bloom occurs in surface waters with high nutrient, total nitrogen, and phosphorus. This rapid population growth changes environmental conditions, destroys algae, and decreases dissolved oxygen

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levels, resulting in killing fish. High levels of nitrogen and phosphorus can be indicators of pollution from anthropogenic sources, such as septic system leakage, poorly functioning wastewater treatment plants, or fertilizer runoff. Thus, chlorophyll measurement can be utilized as an indirect indicator of nutrient levels (Almuktar *et al*., 2018). The measurement of chlorophyll has been interesting for researchers, scientists, and aquatic resource managers for decades, and provides information about the quality of water, its composition, and ecological status.

Eutrophication, extremely high abundance of nutrients in water environment, decreases water quality by increasing the excessive growth of algae and suspended organic material, resulting in unpleasant odors and tastes. Furthermore, micro-organisms associated with eutrophication may pose health risks to consumers. Water resource managers try to find the most efficient way for the identification of this situation, especially when the water quality risk management involves wide areas and field measurements may be time-consuming, costly, and limited logistically. Increases in water quality parameters such as Chl-*a*, total suspended solids (TSS), nutrients, and turbidity are symptomatic of eutrophic conditions. Concentrations of these parameters can indicate the level of eutrophication, the potential impact on aquatic biota, and overall water quality. It would be advantageous for resource managers to be able to diagnose eutrophic conditions using multiple sites in a bay without relying on field measurements (Savari *et al*., 2016).

There are various methods to measure chlorophyll, including fluorometry, high-performance liquid chromatography (HPLC), and spectrophotometry. Spectrophotometry is a classical method to assess chlorophyll in aquatic ecosystems and involves sampling water, concentrating the chlorophyll-containing organisms through the filtration of this sample, rupturing these cells by mechanical methods, and extracting the chlorophyll using the organic solvent acetone. Then, the extract is analyzed by the spectrophotometric technique (fluorescence or absorbance) using the optical properties of chlorophyll. This method (Rice and Bridgewater, 2012) is valid with high accuracy and has been extensively used in the scientific literature.

Satellite remote sensing with high spatial and temporal resolution offers ways to monitor wide areas and to obtain relevant bio-optical parameters with reasonable cost. Besides, in situ measurements are needed to validate and improve the used methods as well as to develop new methods. The quantitative ocean color remote sensing has attracted the attention of researchers to estimate Chl-*a* concentration in the coastal waters. Estimating water quality using satellite data has had widespread applications, especially in oceanography. For example, Landsat's Thematic Mapper images have been used to produce maps of TSS, turbidity, chlorophyll-*a*, and other parameters (Hellweger *et al*., 2004).

Satellites analyze the color of the ocean to determine the amount of chlorophyll. The ocean color is often blue, but satellites can detect very small changes in the ocean color as a result of variation in the chlorophyll of phytoplankton. Satellite measurements need to be compared with field data to calibrate its measurements and allow us to look at a very large part of the ocean at the same time (Blondeau-Patissier *et al*., 2014).

The concentration of chlorophyll in the water column is mainly caused by the abundance of phytoplankton (Yoder *et al*., 2001). Chl-*a* can be observed through a satellite sensor by analyzing the ocean color data (Radiarta and Saitoh, 2008).

Field data obtained from a routine sampling program are compared with the Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) imagery. Several previous studies (Dekker, 1993; Gitelson *et al*., 1993; Jupp *et al*., 1994a, Jupp *et al*., 1994b) have developed empirical regression formulas for the prediction of the bay and lake water quality parameters using spectrometer data and spectral ratios, typically reflectance ratios, as independent variables. Chl-*a* concentration is usually one of the predicted water quality parameters.

Although several studies have been carried out to measure chlorophyll at the Chabahar bay based on field methods (Fazeli and Zare, 2011; Fazeli *et al*., 2015), there is no study to use the satellite information in this area. The present study aimed to compare the field data and the satellite data to each other, predict the amount of chlorophyll in the water by utilizing the Regression Calibration of Algorithms as well as the MATLAB and GIS software, and produce detailed and informative images.

2. Materials and methods

2.1. Study area

Chabahar Bay is located on the northeast of Oman Gulf in Iranian waters along with the Sistan and Baluchestan province (25° 17’ 45” N and 60° 37’ 45” E) and is connected to the Indian Ocean by the Oman Gulf (Figure 1). It is the largest bay along the Iranian coastline, and the total area and perimeter of this bay are 320 Km^2 and 68 Km, respectively (Kabiri, 2017). The Bay surface area is 290 km^2 with 14km width located between Chabahar and Konarak. The average depth of this bay is 6m while its deepest part is about 19m (Owfi *et al*., 2007). As shown in Figure 2 and Table 1, the sampling was conducted at 6 stations, defined by coordinates and in the depth of less than 1m.

Table 1. Geographical coordinates of sampling sites in Chabahar Bay.

Sampling stations	Geographical coordinates
1	25° 21' 46.25" N 60° 35' 40.16" E
2	25° 22' 0.79" N 60° 33' 59.78" E
3	25° 26' 3.52" N 60° 30' 13.95" E
4	25° 22' 50.09" N 60° 26' 3.60" E
5	25° 22' 27.92" N 60° 28' 30.31" E
6	25° 17' 44.69" N 60° 32' 11.98" E

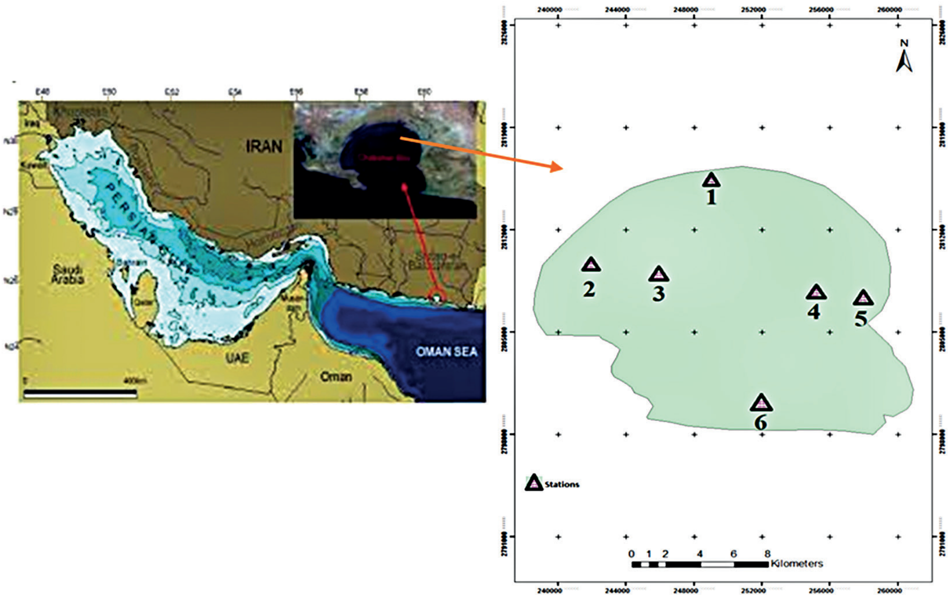

Figure 1. The study area sampling stations, Chabahar Bay

2.2. Data collection

Field campaigns were conducted on November 18, 2013 (6:29:17), November 21, 2014 (6:27:46), and November 24, 2015 (6:27:46) simultaneous with satellite overpass. Landsat 8- OLI sensor was used to monitor chlorophyll concentration, the imagery of which is an ideal medium to provide information on this environment.

A polyethylene bottle, covered with aluminum foil, was used for the sampling. Water (1 L) from the surface layer and near the seafloor was obtained from the specific stations, kept in a cool and dark place, and filtered under vacuum pump pressure (Millipore 0.45 micron filter) in the laboratory. Chlorophyll was extracted using 90% acetone and then the sample was kept in the refrigerator for about 24 h, stirred, and centrifuged at 3000 rpm. The absorbance of the transparent solution was read at the wavelengths of 750, 664, and 630 nm, and its amount was calculated in mg/m^3 using Equation 1 (Rice and Bridgewater, 2012).

$$\text{Chl-}a\ (\text{mg/m}^3) = (C*v) / (V*L) \qquad (1)$$

where:

v= volume of 90% acetone added (ml)

V= volume of filtered water (L)

C= absorbance

L= diameter of spectrophotometer cells (cm)

SPSS 23 software was used to correlate field data with satellite data got from the website of Earth Explorer (http://earthexplorer.usgs.gov) for 2013 to 2015. The ArcGIS software was used to mask the determined zone; the image was cropped and then used in the MATLAB program. Chl-*a,* was measured by algorithms and the regression between the information of Landsat 8's bands 1-2 (Equation 2). Data of MATLAB images were used in the ArcGIS (layer properties and symbology).

Chl-*a* Prediction Algorithm for Landsat 8 Bands:

$$(110-24.3*(B1./B2)-65.17*(B2./B1)-0.448*B2) \qquad (2)$$

B= Band

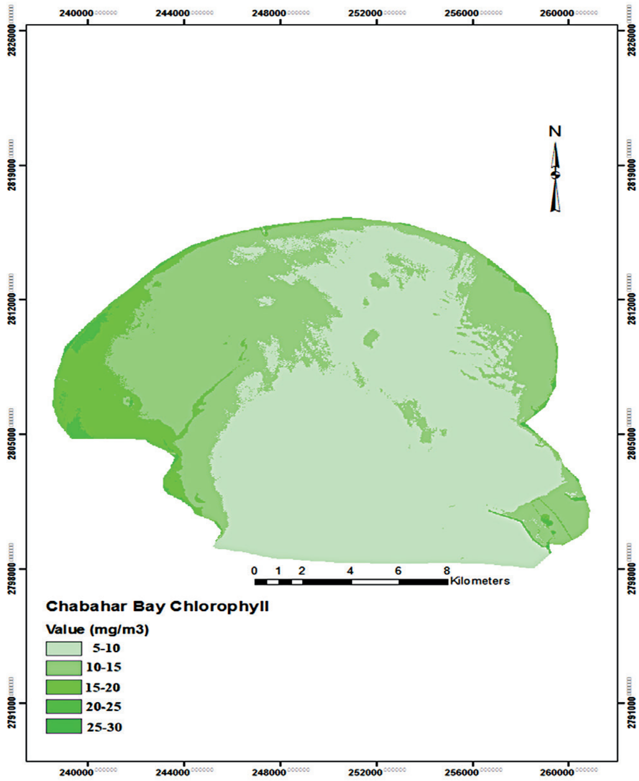

Figure 2. Chl-*a* measured by remote sensing in Chabahar Bay in 2013

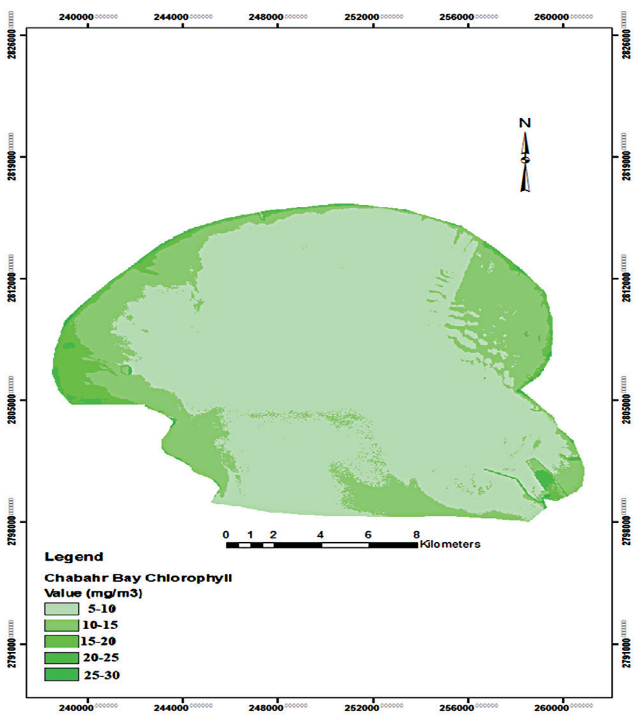

Figure 3. Chl-*a* measured by remote sensing in Chabahar Bay in 2014

3. Results

Variability of Chl-*a* was intensively investigated in the coastal water in Chabahar Bay. Data of Chl-*a* derived from Landsat satellite with a 1 km spatial resolution from 2013 to 2015 was processed to climatological images.

The data followed by the Tukey and Duncan test in SPSS was analyzed for finding the correlations and validating the results. These tests showed that there was a good correlation (90%) between field data and satellite data. In addition to these tests, the regression analysis was used. The results (R^2= 0.95) indicated a significant relationship between the field data and remote sensing data.

Satellite data can now be used to show the spatial patterns of the coastal area and ocean water properties, especially surface Chl-*a* concentration, on the scales covering from kilometers to the entire globe. The repeated coverage shows weekly, seasonal, and longer-term variability, and provides a unique resource for regions where in-situ measured data sources are scarce (Figures 2, 3, and 4).

4. Discussion

This study indicated that the variability of remotely-sensed chlorophyll-α in Chabahar Bay can be explained by Landsat images because the upwelling signal in the spectral regions carries precious information about the phytoplankton absorption and total backscattering coefficients in such waters. Results imply that the existing data archive of Landsat images could be used to study quantitatively the dynamics of Bay waters. Estimation of Chl-*a* accurately from satellite data using traditional blue-green empirical band ratio algorithms in complex coastal water bodies is a challenging task due to optical

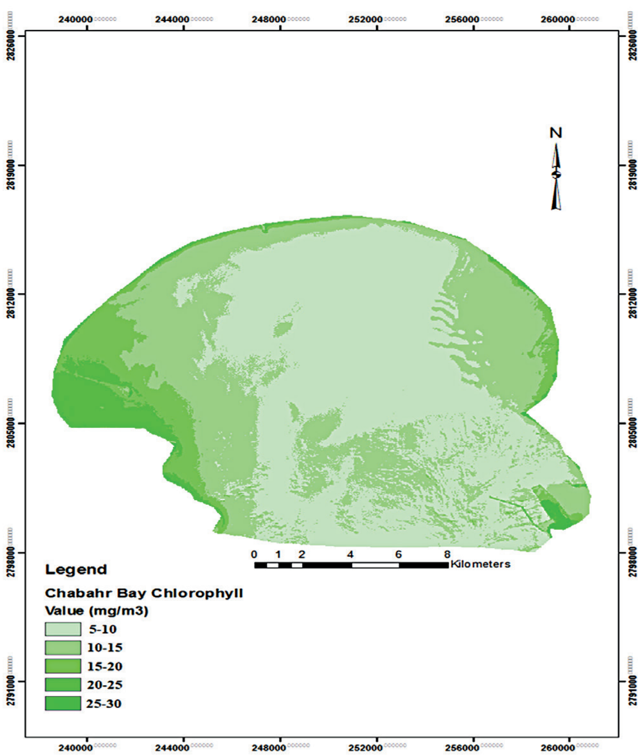

Figure 4. Chl-*a* measured by remote sensing in Chabahar Bay in 2015

complexity, contribution of non-algal particles in significant light absorption, and atmospheric correction uncertainties (Le *et al*., 2016).

The chlorophyll concentrations obtained from regression show good correlation (R^2=0.95) with the in situ measurements of chlorophyll concentrations.

The Figures 3 to 5 show the concentration of Chl-*a* in the Bay. The bloom of phytoplankton and high concentration of Chl-*a* can be seen around the Bay and the lower concentration of Chl-*a* in the middle of Bay due to waves effects and the lack of foods.

Field data showed that the level of Chl-*a* was in the range of 5 to 30 mg/m^3 at stations and was identical with satellite data. Fazeli *et al*. (2015) reported field data and information about chlorophyll that were identical to the findings of the present study. The satellite data and the field data were the same, had a good range, and regression parameters showed that satellite analysis and remote sensing is good for assessing Chl-*a* changes. Moradi and Kabiri (2019) found similar chlorophyll concentrations in the Chabahar Bay using MODIS data.

One limitation of field data to determine the distribution of phytoplankton over a large area is the spatial coverage per day that is relatively small. Extending the duration of study over several weeks or more in a physically dynamic area increases the possibility of obtaining error data related to the synoptic distribution of chlorophyll-*a*. This can be overcome by the use of satellite data because it can provide synoptic information on the distribution of Chl-*a* over an entire study area (Holm-Hansen *et al*., 2004).

The results of this study indicate that bio-optical algorithms are capable of determining the quantitative estimation of surface Chl-*a* using remotely sensed optical data in Chabahar Bay. Chlorophyll has two absorption peaks, including the blue region (440 nm) and the red (665 nm) region of the electromagnetic spectrum. In an estuarine environment, other substances such as iron oxide, dissolved organic pigments, and some algal pigments (e.g. carotenoids) also absorb blue and green light, resulting in significantly masking the response of this wavelength to Chl-*a*. Phytoplankton, in which Chl-*a* and other pigments with various predominances are found, is combined with other factors to produce the water's spectral reflectance (Savari *et al*., 2016).

Conclusion

This study explored the use of Landsat 8 satellite data to study the spatio-temporal changes in chlorophyll-α concentration in Chbahar Bay. The chlorophyll-α concentration images derived from Landsat satellite data indicate the annual spatial variation in chlorophyll-α concentration during 2013 - 2015. This study showed that Landsat satellite data provide useful information on the spatio-temporal variations in Chabahar Bay and establish general trends that are more difficult to determine through routine ground measurements.

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