Mapping of Chlorophyll-A in the Dubai Creek Area Using WorldView-2 Imagery and Field Data

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Abstract

Occurrences of harmful algal blooms (HAB) in coastal regions have been increasing both in frequency and magnitude in the last few decades. The coasts of United Arab Emirates UAE have been affected by massive HABs in 2008 and 2009 that lasted for months and encouraged frequent monitoring of algae and nutrient concentrations in the area. Other small scale algal blooms were also observed in recent years as well. The increasing anthropogenic activities in the Dubai area have led to increased growth of algae in the Dubai Creek. This paper presents the results of a study aimed at mapping of chlorophyll-a, which is a direct indicator of algal growth in the creek. A spectral model of chlorophyll-a was developed from WorldView-2 data of the creek that was acquired in July, 2012. Field data of chlorophyll-a collected at the time when the WorldView-2 image was acquired, have been used for calibration and verification of the spectral model, which showed an 82.7% correlation with field data. Development of such a model is useful for spatiotemporal mapping of algae in the area. Such information is essential for monitoring of the levels of pollution in the Emirate of Dubai coastal area and for planning and decision making activities related to the sustainability of the creek.

Keywords: Chlorophyll-a, Dubai Creek, Remote sensing, Water quality, WorldView-2.

Introduction

Water bodies, global and regional, have been polluted and endangered in many ways in the last few decades. Pollution of water bodies comes from many sources such as oil spills, garbage dumping, untreated or partially treated sewage, toxic wastes, algal blooms, and many others. These pollutants affect aquatic life in many ways which in turn, may directly or indirectly, affect the health of human beings. The algal bloom is one such important case of water pollution. The presence of algae in water bodies is expected. However, the increase of its concentrations is a source of concern. Algae accumulate on the surface of the water body forming a nontransparent layer that prevents passage of sunlight into deep water and reduces oxygen levels as well as plants consume it to produce food. The end result of this process is an imbalance in the aquatic system, which can lead to death of fish and shellfish. Algal blooms have increased both in frequency and size in recent years. The main cause of algal blooms is the increase in nutrients concentrations in the water column. The increase in nutrients concentrations may happen due to coastal upwelling (Victor, 2012) or other natural causes such as temperature and light availability (Davis *et al.*, 2009). Unfortunately, it’s understood that the main reason for the increase of nutrients such as nitrogen and phosphorus in water bodies is due to the increase in the agricultural and industrial activities in the last years.

Introduction of remotely-sensed imagery in environmental studies allowed researchers to study water hazards and sources of pollution more accurately. Given their devastating impact on the environment, algal bloom events are one of the major phenomena that are being under extensive studies utilizing remote sensing technology. Chlorophyll-a is a pigment found in all green plants and is the main indicator of the presence of algae in an area. Chlorophyll-a retrieval with remote sensing can be achieved utilizing analytical or empirical algorithms. Analytical algorithms model remote sensing reflectance using radiative transfer modelling through forward and inverse processes (Matthews, 2011). Empirical algorithms are simple to derive when compared to analytical algorithms. However, most of the empirical algorithms are time and site specific. In other words, applying empirical algorithms at different locations or even at the same location, but at a different time(s) may result in imprecise estimations of chlorophyll-a concentrations. Empirical algorithms can be subdivided into algorithms that utilize narrow-band sensors or broad-band sensors. Narrow-band models specify reflectance at certain wavelengths as input of the model. Obtaining such values isn't possible unless one of the bands of the satellite is centered on the specified wavelength. Such models include the Maximum Chlorophyll Index which is only applicable to the Medium Resolution Imaging Spectrometer (MERIS) imagery due to the use of the band centered at 708.75nm which is only found in MERIS imagery and the Floating Algae Index (FAI) which is only applicable to the Moderate-resolution Imaging Spectroradiometer MODIS (Blondeau-Patissier *et al.*, 2014). Broad-band satellites such as SPOT, LandSat, IKONOS, and WorldView-2 don't have focused narrow-bands and therefore application of the narrow-band algorithms is not possible. Current studies that utilize broad-band satellites either use multiple linear regression to relate in-situ data to reflectance values (Nas *et al.*, 2009; Ormeci *et al.*, 2009, Ali *et al*., 2013) or use some form of band ratios regression with measured data (Brivio *et al.*, 2001; Han, 2005). This study is an empirical broad-band one that utilizes high resolution WorldView-2 multispectral imagery.

The coasts of United Arab Emirates including Dubai have been affected by the catastrophic HABs- sometimes termed red tide that occurred in 2008 and 2009 and have resulted in massive fish kills and disturbance of the aquatic life (Richlen *et al.*, 2010). These occurrences alerted researchers in the region to the importance of the problem; initiating studies that have addressed different aspects of the problem. (Ali *et al.*, 2013; Zhao, 2014). Currently, Dubai Creek and Dubai Coast are monitored by numerous monitoring stations installed by Dubai Municipality. It measures water quality parameters such as chlorophyll-dissolved oxygen, total nitrogen, phosphates, pH, nitrate, salinity, and turbidity. Although these monitoring stations provide accurate data, they are costly and represent the point of measurement only. Water quality modeling using remote sensing can provide a cheaper alternative and produce continuous representations. Dubai Creek is a saltwater body that is 14 km in length and has an average depth of 3 meters. It extends from Dubai coast upstream and forms a lagoon downstream as shown in Figure 1. The Creek passes under Al-Gharhoud Bridge and The Floating Bridge and passes by Port Saeed, Ras Al Khor Wildlife Sanctuary, and other malls and hotels. The creek is characterized with poor flushing, which results in stagnant waters especially in the lagoon section of the creek.

There are many sources of nutrients to Dubai Creek such as wastes from Port Saeed, Dubai Ship Docking Yard (DSDY), and the many other hotels and malls located along the creek. However, the major source of pollution is the effluent of the treated sewage from Al Awir wastewater treatment plant. The daily discharge of this plant into the creek is about 100,000 metric tons, which includes phosphate and nitrate with average concentrations in the range from 10 to 25 mg/l (Saunders *et al.*, 2007). The in-situ data provided by Dubai Municipality shows an increase in nutrients and chlorophyll-a levels year over year. Increased concentrations of nutrients especially nitrogen- and phosphorus- based in a water body can cause accelerated growth of algae and other forms of plants, a situation scientifically known as eutrophication.

The objective of this study was to map chlorophyll-a concentrations at Dubai Creek using remote sensing. A band ratio model was developed using a WorldView-2 satellite image and assessment of model accuracy was based on in-situ data provided by Dubai Municipality. Comparison of chlorophyll-a concentrations in the creek in recent years was conducted to highlight the importance of taking measures to limit these concentrations in the creek.

Materials and Methods

Materials

The satellite image for this study was acquired on 24th of July, 2012 WorldView-2 images are 11-bit images with 8 multispectral bands and one panchromatic band. The pixel size is 2 meters in the multispectral bands and 0.5 meters in the panchromatic band.

There are 10 stations located along Dubai Creek that are used by Dubai municipality to monitor water quality parameters quarterly (Table 1). Locations of the 10 monitoring stations are shown in Figure 1. The water quality parameters monitored by these stations include chlorophyll-a, total nitrogen, and phosphates concentrations in addition to other parameters. Two out of the 10 were excluded from the study. Hyat Regency station was excluded due to being outside the scope of the satellite image. Al-Gharhoud Bridge station was excluded because the station is located under the bridge so the pixel at the location of the station doesn't represent a water column; instead it represents a concrete barrier pixel of the bridge above.
Due to the unavailability of specified dates for the measurement of in-situ data by Dubai Municipality, it was decided to linearly interpolate chlorophyll-a to produce corresponding values of water quality parameters that match the image acquisition time (column 4 of Table 1). Interpolation was carried out using the following linear equation assuming that each data set represents the mid-way point of the quarter.

$$\mathrm{Y} = \mathrm{Yo} + (\mathrm{Y1} - \mathrm{Yo})\,\frac{X - Xo}{\mathrm{X1} - \mathrm{Xo}}$$

Where Yo, Y1, and Y are the chlorophyll-a concentrations in quarter 2, quarter 3, and at image acquisition date respectively and Xo, X1, and X are quarter 2 midpoint date, quarter 3 midpoint date and image acquisition date respectively.

Figure 1: Stations positioned on the WorldView-2 image.

Table 1: Chlorophyll-a data.

Station	Chl-a Quarter 2, 2012	Chl-a Quarter 3, 2012	Interpolated Chl-a value
Creek Mouth	4.6	1.3	2.13
Hyat Regency	15.3	6	8.33
Abra	5.9	42	32.98
Wharfage	4.6	4.8	4.75
Floating Bridge	57.5	18.8	28.48
Al Gharhoud Bridge	57.8	33.9	39.88
Dubai Festival City	69.5	34.5	43.25
STP Outfall	69.3	36.8	44.93
Jaddaf	74.8	37.9	47.13
Sanctuary	92.6	18.8	37.25

Methods

The WorldView-2 image was corrected geometrically and atmospherically to obtain correct ground-reflectance values. The scene was provided by Digital Globe projected to Universal Transverse Mercator (UTM) zone 40 North with WGS1984 as Datum.
The scene was re-projected to Dubai Local Transverse Mercator (DLTM). The parameters needed to re-project the image to DLTM are shown in Table 2.

Table 2: DLTM projection parameters.

Name	DLTM (Dubai Local Transverse Mercator)
False Easting	500000
False Northing	0
Central meridian	55.33333
Scale factor	1
Latitude of Origin	0
Linear Unit	Meter

WorldView-2 image was delivered free of radiometric errors (Upkide, 2010). Therefore, there was no need for radiometric correction to be conducted. Conversion of DNs (Digital Numbers) to TOA (Top-Of-Atmosphere) spectral radiance was performed using the formula provided by Digital Globe as shown in the following section.

$$L\lambda pixel, band = \frac{Kband * qpixel, band}{\Delta\lambda band}$$

Where $L_{\lambda pixel,band}$ is the top-of-atmosphere spectral radiance for a band, K_{band} is the absolute radiometric calibration factor, $q_{pixel,band}$ is the radiometrically-corrected image pixels, and $\Delta\lambda_{band}$ is the effective bandwidth for a band. The absolute radiometric calibration factor and the effective bandwidth for each band were provided by Digital Globe with the image.
The cosine of solar zenith angle (COST) model was selected to perform atmospheric correction due to its simplicity and the successful results it produces. The COST model is expressed mathematically as following,

$$\rho\lambda pixel, band = \frac{(L\lambda pixel, band - L\lambda haze, band) * dES2 * \pi}{Esun\lambda, band * \cos(\theta s)} + 0.01$$

Where $\rho_{\lambda pixel,band}$ is atmospherically-corrected reflectance, $L_{\lambda pixel,band}$ is top-of-atmosphere spectral radiance calculated in Equation 2, $L_{\lambda haze,band}$ is radiance of dark object at a certain band, d_{ES} is Earth-sun distance, $Esun_{\lambda, band}$ is band-averaged solar spectral irradiance, and θ_s is solar zenith angle in radians. Selection of $L_{\lambda haze,band}$ values for each of the eight bands was based on the first radiance value with 100 or more pixels in the image histogram. $Esun_{\lambda, band}$ values were provided by Digital Globe along with the procedure for the calculation of d_{ES}. Conversion of DNs to radiance and atmospheric correction were done using ERDAS Imagine 2011 software.

In order to develop the chlorophyll-a model, different simple band ratios of ground-leaving reflectance values of the eight WorldView-2 bands were used and in each time tested against the field values of chlorophyll-a in column 4 of Table 1. The band rationing included two-band, three-band, and four-band ratios. The strength of the correlation between model-based and field-based values were determined based on R-squared values.

Results and Discussion

The band ratio of WorldView-2 that produced the highest R-squared value (82.7%) is shown in the equation below,

$$\text{Spectral chlorophyll} - \text{a} = 243.06\,\frac{\text{CB} + \text{NIR1}}{\text{NIR2}} - 429.6$$

Where CB, NIR1, and NIR2 are the ground-leaving reflectance values in the coastal blue, near infrared 1, and near infrared 2 bands; respectively. The characteristics of these three bands as it relates to detecting chlorophyll specifically and vegetation in general are listed in Table 3 below (Digital Globe, 2010).

Table 3: Description of the three bands used for chlorophyll-a mapping. (Digital Globe, 2010)

Band	Description
Coastal Blue	Absorbed by chlorophyll in healthy plants and aids in conducting vegetative analysis
Near Infrared 1	Effectively separates water bodies from vegetation
Near Infrared 2	Enables broader vegetation analysis and biomass studies

The chlorophyll-a concentration map produced over the entire creek is shown in Figure 2. The map shows that chlorophyll-a concentrations are evidently higher than 30 ug/l in the lagoon segment of the creek. This result is expected because of poor circulation and flushing of water compared to upstream segments of the creek. The high concentrations of chlorophyll-a in this part of the creek are attributed mainly to the effluent of the treated sewage disposal from Al Awir treatment plant.

Spectral-based and in-situ chlorophyll-a concentrations at the eight stations utilized in the study are shown in Figure 3. These results are tabulated along with the difference between the two values in Table 4. The difference between the spectral-based and in-situ chlorophyll-a concentrations has a maximum of 10.37 ug/l. This difference may appear to be considerable. However, it looks normal when observing the big range of in-situ chlorophyll-a concentrations and the ranges of in-situ data in the other studies (Brivio *et al.*, 2001; Han, 2005).

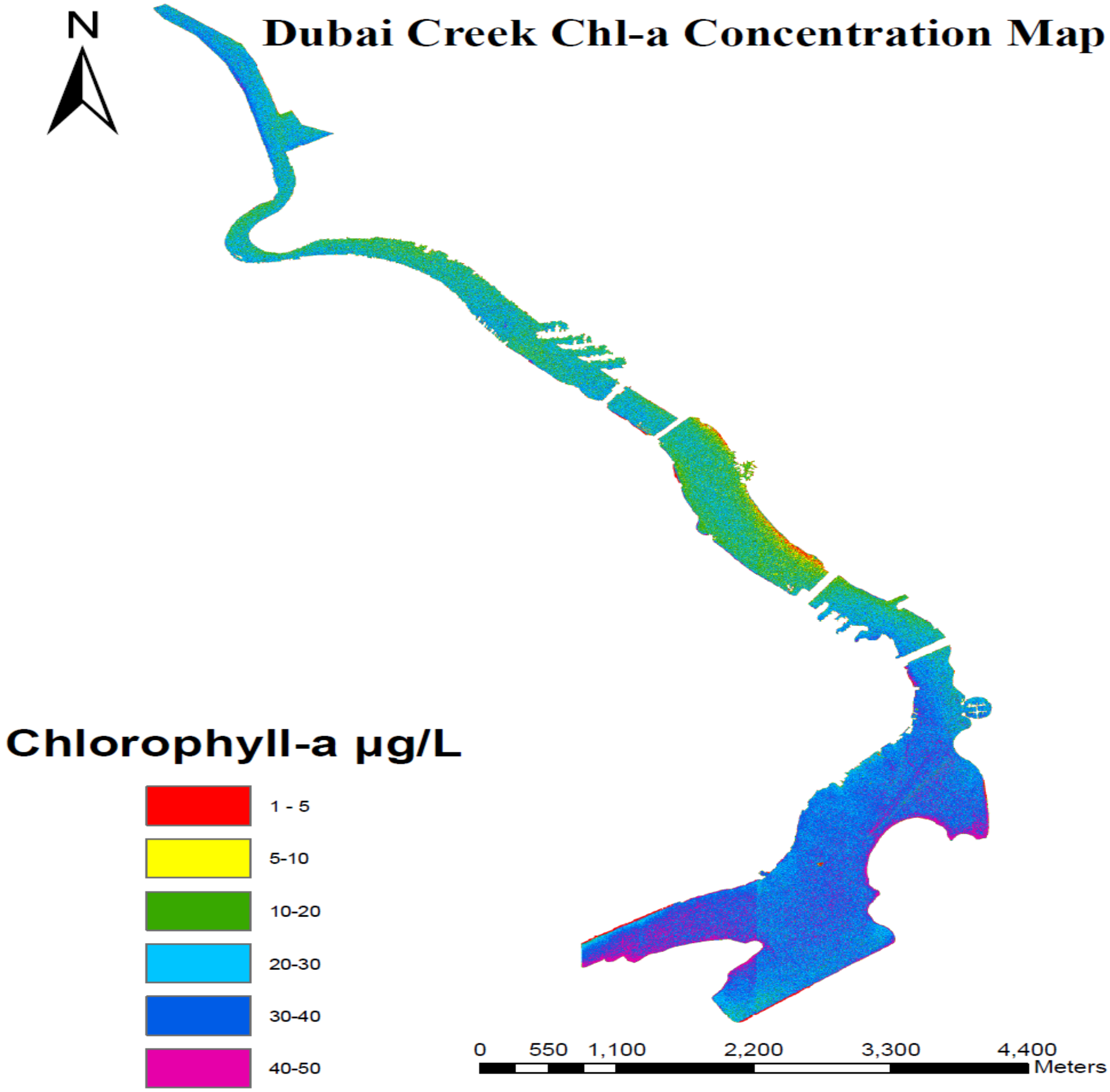

Figure 2: Spectral chl-a concentration map of Dubai Creek, 2012.

An important observation during the period of study was the change in chlorophyll-a levels in the creek over the last few years. Table 5 shows chlorophyll-a concentrations in ug/l in quarter 2 in 2010, 2011, and 2012 at five monitoring stations. The first two columns are taken from (Ali *et ali*, 2013). It was noticed that the absolute maximum value of chlorophyll-a is increasing year over year. Averages of concentrations at the five stations are not increasing year over year, however, in both 2011 and 2012 (20.86ug/l and 17.64ug/l respectively) they are much higher than in 2010 (6.84 ug/l). It is important to note that these values exceed the mean threshold value of 8ug/l of chlorophyll-a established by the Organization for Economic Cooperation and Development (OECD) for assessing eutrophic status (OECD, 1982).

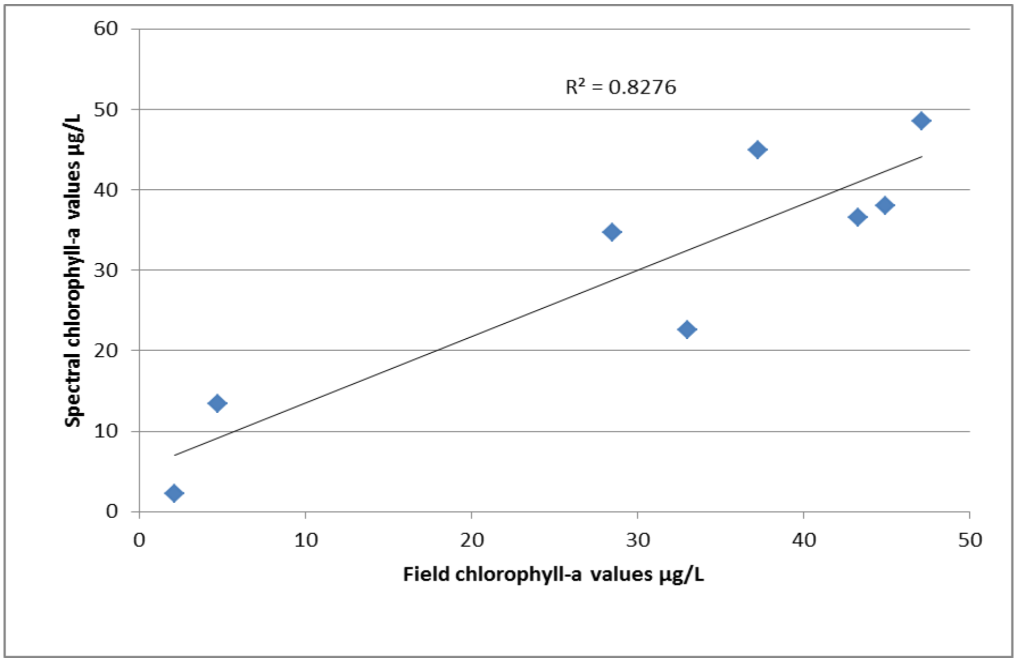

Figure 3: Spectral-based vs. in-situ chlorophyll-a concentrations.

Table 4: Spectral-based and in-situ chlorophyll-a stations at the eight stations.

Station	Field chlorophyll-a ug/l	Spectral chlorophyll-a ug/l	Difference ug/l
Creek Mouth	2.13	2.24	0.11
Abra	32.98	22.61	10.37
Wharfage	4.75	13.4	8.65
Floating Bridge	28.48	34.65	6.17
Dubai Festival City	43.25	36.6	6.65
STP Outfall	44.93	38.01	6.92
Jaddaf	47.13	48.48	1.35
Sanctuary	37.25	44.98	7.73

Table 5: Comparison of chlorophyll-a concentrations year over year.

Station	Chl-a Q2, 2010 (ug/l)	Chl-a Q2, 2011 (ug/l)	Chl-a Q2, 2012 (ug/l)
Creek Mouth	0.1	8.1	4.6
Hyat Regency	10.8	11.2	15.6
Abra	6.4	29.8	5.9
Wharfage	9.2	32.8	4.6
Floating Bridge	7.7	22.4	57.5

Conclusions

Mapping chlorophyll-a in the creek using remote sensing shows that chlorophyll-a concentrations are at high levels especially downstream in the lagoon part of the creek.

Furthermore, comparison of chlorophyll-a concentrations over the last few years showed an increasing trend that would be problematic if not addressed soon. Based on OECD criteria, most parts of the creek are eutrophic; a situation that calls for an urgent mitigation plan in order to reduce these high levels of chlorophyll-a.

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