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Estimating and Mapping Chlorophyll *a* Concentration as a Function of Environmental Changes of Manzala Lagoon, Egypt Using Landsat 7 ETM+ Images

[1]Islam Abou El-Magd and [2]Elham M. Ali

[1]National Authority for Remote Sensing and Space Sciences, Cairo, Egypt
[2]Department of Biological and Geological Sciences, Faculty of Education,
Suez Canal University, Al-Arish, Egypt

Abstract: This study is aiming at developing a robust methodology for estimating Chlorophyll-a (Chl *a*) concentration in one of the largest costal lagoon of Egypt, Lake Manzala, using Landsat 7 ETM+ data. The method based on band ratioing and regression modelling established from *in-situ* measurements and the optical satellite images. The Landsat data was geometrically and radiometrically corrected, which subsequently converted into irradiance at sensor. Single band ratioing, particularly the visible bands 1, 2 and 3, were used to establish a logarithmic regression model. Ratio of ETM+ band 1 and ETM+ band 3 shown the most significant ratio in estimating chlorophyll-*a* with a maximum correlation coefficient of $R^2 = 0.75$. This ratio is then used to estimate the spatial distribution of Chl *a* along the lake. The methodology and environmental factors are detailed in the paper.

Key words: Remote Sensing, Phytoplankton, Chlorophyll-a, Lake Manzala, Egypt,

INTRODUCTION

Healthy environmental conditions and water quality of coastal lakes are of great importance in most countries in arid region. These coastal lakes constitute Egypt's most important wetland, which show a great public interest for fisheries, aquaculture, recreation, industry and support to most of the local communities. Unfortunately, most of these lakes are aggressively affected by the environmental changes due to both natural processes and anthropogenic activities; therefore improved timely monitoring of these lakes are urgently required. Conventional water quality measurements are based on water sampling and laboratory measurements, which surely give accurate values. It is, however, time consuming and not cost effective. More importantly, field sampling always fails to give the synoptic view together with the complete spatial coverage of the water quality parameters such as chlorophyll-*a* (Brivio *et al.* 2001)

Phytoplankton blooms in such environment is merely due to the amount of sewage and fertilizers (e.g. nutrients and phosphorous) discharged from both urban settlement and agricultural surroundings. The interaction of Chl *a* and the electromagnetic radiation gives scattering or/and absorption with strong absorption between 400 - 500 nm (which correspond to ETM+ Band 1) and at 680 nm (which correspond to ETM+ Band 3) and maximum reflectance at 550 nm (which correspond to ETM+ Band 2) (Dekker *et al.* 1991, Han. 1997).

Optical remote sensing techniques are widely applied in water quality studies nowadays, for example, measuring water clarity, surface temperature and Chl *a* (Giardino *et al.* 2001, Lathrop 1992, Zhang *et al.* 2003). Band ratioing models are recently introduced to this field as an advantageous method to measure Chl *a*. The strength of this ratio models is reducing the influence of atmospheric illumination (Jensen 2005, Han & Jordan 2005). Due to the relationship between absorption and scattering of the visible spectrum and Chl *a* concentrations; therefore it is more efficient to use a ratio between two bands that have such interaction with the spectra (Gin *et al.* 2002).

Corresponding Author: Islam Abou El-Magd, National Authority for Remote Sensing and Space Sciences, El-Nozaha El-Gedidah, PO.Box 1564 Alf Maskan, Cairo, Egypt
Email: imagd@narss.sci.eg Telephone: +2 02 26225801 Fax: +2 02 26225800

Using remote sensing technology in aquatic research worldwide is an emerging capability that can greatly replace traditional *in-situ* methods (Mittenzwey *et al*. 1992, Braga *et al*. 2003, Chang *et al*. 2004). However, it is considered to be a relatively new approach especially in addressing optically complex water bodies, satellite remote sensing potentially offers a promising alternative for scientists and practitioners for assessing a large water body in an economical and timely fashioned technique. The 1st GEO workshop (Group Earth Observation) held on 27th March 2007 mainly focused on the urgent need of improving the capabilities of remote sensing in assessing and monitoring inland and near shore water quality. The final report of the workshop addressed six major issues the top most of which was the satellite sensors and its improvement to help in monitoring the inland water qualities. Till then improved techniques with using optical remote sensing is urgently needed to monitor such aquatic environments.

The morphology of Lake Manzala has been transformed from an open water body to semi-closed sub-basins in the last few decades. Such morphological changes lead to great changes in water quality that consequently lead to flourishing of phytoplankton community in some basins. Dominance of some phytoplankton species might seriously affect the basin and alter its natural habitat (e.g. toxic species). Monitoring and mapping phytoplankton community (indicated as chlorophyll biomass) using optical versus flurometrical measurements helps in detecting environmental changes occurring throughout the lake and consequently helps in supporting decision makers in managing such economically valuable resources (Dewidar and Khedr 2004, Abbassy *et al*. 2003).

This research uses the visible spectrum of the Landsat 7 ETM+ data in combination with *in-situ* field sampled measurements of Chl *a* to estimate and map Chl *a* along the lake (Lake Manzala) with a sensible estimation of the lake water column.

Area of Study:

Lake Manzala is the largest of the Nile Delta lakes; it occupies the North Eastern corner of the Nile Delta. It lies between 31°N and 31°30°N and 31°45' E and 32° 15' E. It is surrounded by the Suez Canal to the east, the Nile River (Damietta Branch) to the west and the north is bounded by the Mediterranean Sea and to the south agricultural and urban settlements (Figure 1). The lake is relatively shallow with a maximum depth of 3.5 m in the north near the outlet to the Mediterranean Sea and a minimum depth of 0.6 m in the western part of the lake. The average dominant depth of the lake is 1.2 m.

MATERIALS AND METHODS

Image Processing:

Landsat 7 ETM+ satellite image (path 176 and row 38) acquired on 4th March 2007. The image was acquired under nearly clear sky with 0.15 % of cloud cover. The optical resolution of the image is the typical Landsat image of six mutli-spectral bands, which covers the visible spectrum (0.40-0.70 μm) and infrared (0.7-2.09 μm). The ground resolution is 30 meters which is adequate for such application.

The approach used in this research is focused on the visible light spectrum that give a real estimation of water column Chl *a* rather than estimation of surface Chl *a*. This is based on the fact that visible spectrum has the potential of penetrating water column (Jensen, 2000).

Satellite image was geometrically corrected to the UTM (Universal Transverse Mercator) grid reference (Zone 36N; Datum: WGS84). Viewer to viewer process is used to rectify the image using topographic maps with well known ground control points on both viewers. The minimum root mean square (RMS) error achieved was less than 0.5 pixel. Then, the image is radiometrically corrected using the darkest pixel theory (Campbell 1993). Last the reflectance values were converted to at-sensor irradiance and surface albedo (Irish 2000) which made the image ready for further interpretation and analysis.

A 3 x 3 window was established around each sampling location based on the UTM coordinates determined with a GPS (Global Positioning System) during the water sampling (Figure 1). The mean reflectance of the 3 x 3 window was extracted and used in the statistical modelling process (Table 1). The reasons behind the 3 x 3 window instead of a single pixel are:

Table 1: The average concentrations of Chl *a* and the corresponding reflected albedo

		Satellite Albedo		
Station	Average Chl *a* (mgm^{-3})	Band1	Band2	Band3
S1	30.5	0.173	0.081	0.101
S2	33	0.189	0.088	0.121
S3	43.1	0.197	0.091	0.092
S4	44.3	0.212	0.105	0.084
S5	53.3	0.213	0.112	0.071
S6	70.9	0.239	0.126	0.088
S7	125	0.267	0.122	0.079
S8	101.1	0.243	0.113	0.066

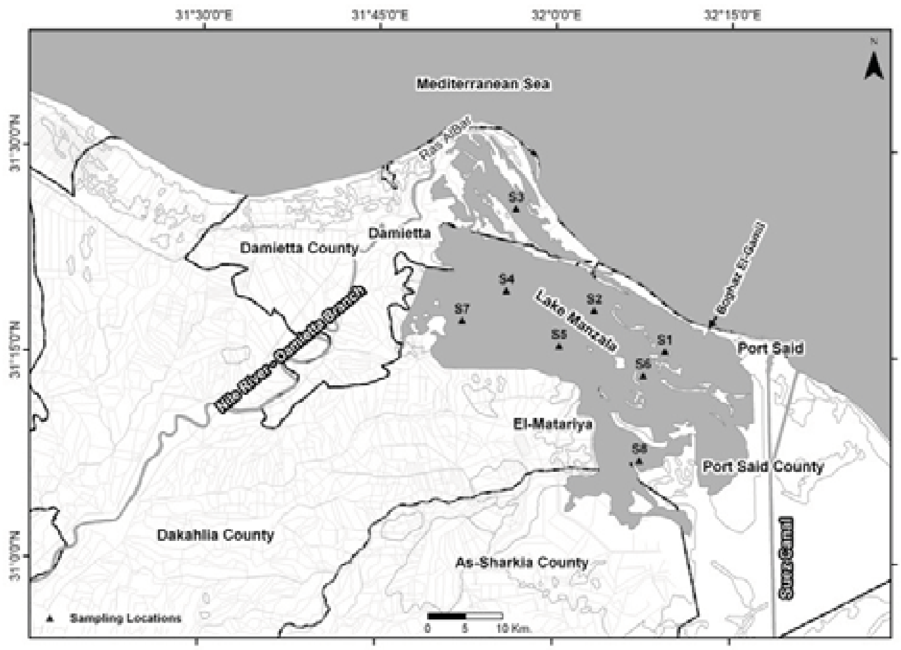

Fig. 1: Area of study and sampling locations

- To avoid the possible errors in the geometric correction and the dynamicity of the water body,
- To give spatial variability of the sampling window

In-Situ Sampling Data Collection:

Discrete water sampling was carried out during the satellite overpath with two hours discrepancies one hour before and one hour after the image capturing. Eight sampling locations distributed along the lake were chosen to represent the whole lake environment (Figure 1). Sampling locations were geographically identified using Global Positioning System (GPS) to be superimposed on the satellite image. An assumption is made that quality of water along the lake is relatively stable or at least is not changed significantly during the imaging time. Surface water (1m depth) was collected using a 1.5-L Niskin bottle from the eight selected sampling locations and taken to the laboratory prior to Chl *a* and physicochemical parameters measurements.

Chlorophyll a Estimation:

Samples for Chlorophyll *a* analysis were filtered (50 ml) through 25-mm diameter GF/F filters and immediately frozen. Chlorophyll *a* was extracted in 8 mL of 90% acetone by sonication followed by centrifugation. Chlorophyll *a* was measured using a Turner AM10 fluormeter. Chlorophyll *a* concentration was determined using Parsons' equation (Parsons *et al.* 1984) and the fluormeter calibrated against a standard Chlorophyll *a* solution (Sigma Ltd.).

Statistical Regression Model:

A regression model was established based on the albedo reflection and both single band ratioing and logarithmically transformed band ratioing with the Chl *a* concentration. Correlation coefficient was then generated from both models to map the spatial distribution and concentration of Chl *a* in the lake.

RESULTS AND DISCUSSION

Environmental Variables:

Water temperature showed slight variation between sampling sites during the sampling day with mean value of about 20.1 °C. Highest temperature values were recorded at the north western sites (site 3, 4 and 7) and was also relatively high at the southern site (site 8).

pH values ranged between 8.42 and 9.19 on the sampling day. Highest pH values were generally recorded at eastern sites; however the maximum values (8.9 & 9.1) were recorded at sites number S4 and S5 (Figure 1).

A noticeable variation in surface water salinity (as measured by salinometer, PSU) was recorded between sampling sites during the sampling day with a mean value of about 5.1. Minimum salinity values were recorded at the eastern and western sites (see Figure 2) however the northern and north eastern sites represents the more saline water bodies. This shows the contribution of the Mediterranean sea via the lake tidal inlet (Boghaz El-Gamil). Similar patter was recognised for Total Dissolved Salts (TDS) data. Results showed that TDS varied from a minimum of 4.0 gL^{-1} to a maximum of 15.7 mgL^{-1} with a spatial distribution pattern similar to the salinity.

Dissolved Oxygen varied between (8.0 - 18.2 mgL^{-1}) with a mean value of 13.1 mgL^{-1}. The maximum dissolved oxygen value was recorded at the eastern part of the lake (site 8, 11.6 - 18.2 mgL^{-1}) with a mean value of 10.6 mgL^{-1} compared to the western side (site 7), which showed a mean value of 10.8 mgL^{-1}.

Water transparency data showed a remarkable variation between sampling sites during the sampling day (24.0-90.0). The northern and the eastern part of the lake showed homogenous water body with a relatively similar transparency level. Two highly transparent water bodies were recorded southwards (site 5 and site 8)

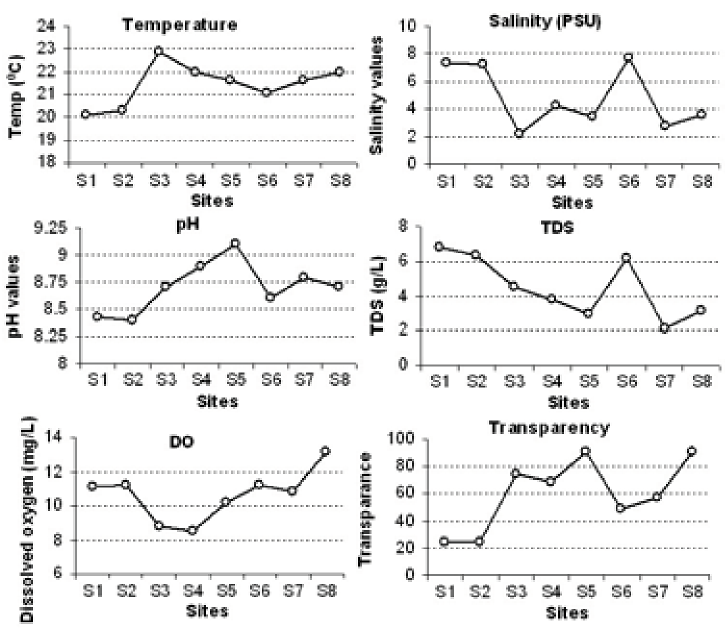

Fig. 2: *In-Situ* physico-chemical parameters on 4th March 2007

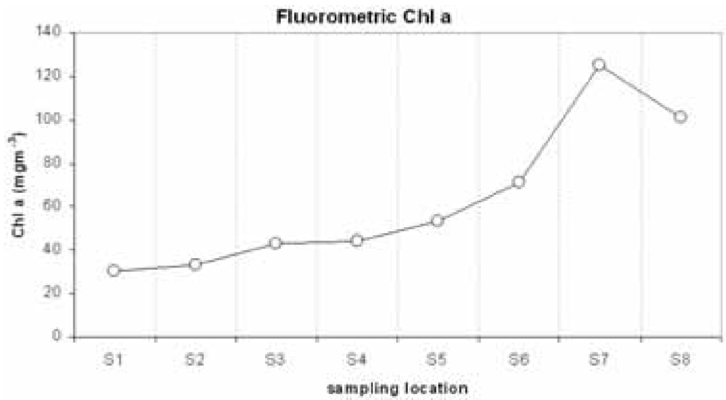

Fig. 3: Chlorophyll a in the sampling locations within Lake Manzala

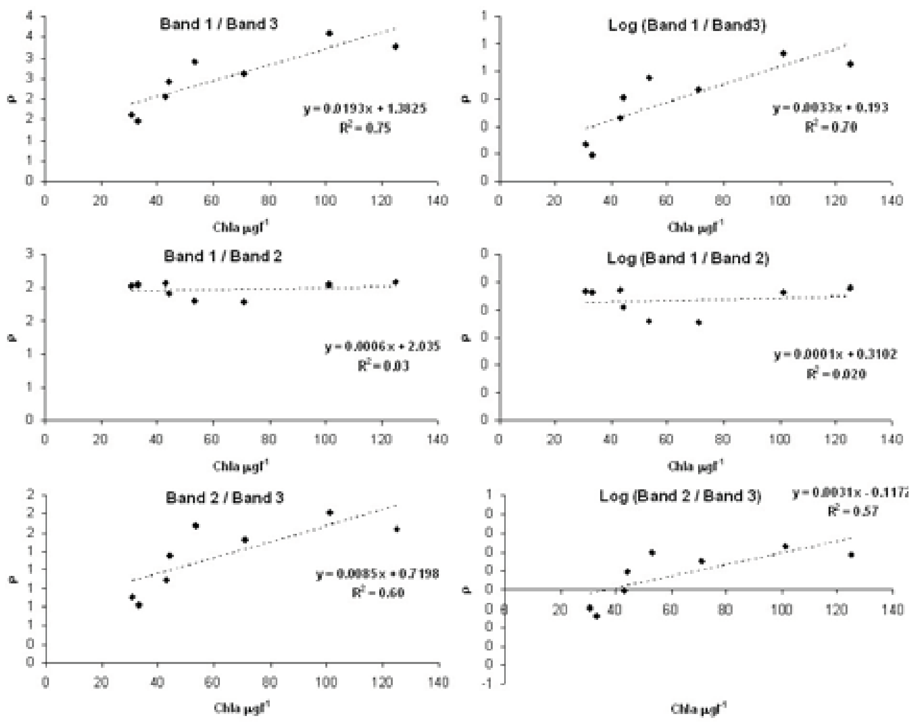

Fig. 4: Single and Logarithmic band ratio regression models between *in-situ* Chl *a* data and satellite image reflection

Chlorophyll a Dynamics: Chlorophyll *a* is a universal indicator of phytoplankton and showed wide variations on the sampling date throughout the eight sampling sites with a mean concentration of about 62.65 mgm^{-3}. Lower Chl *a* levels (flurometrically measured) were measured in the northern strip of the lake at sites 1, 2, 3 (Figure 3 and Table 1). This low level of Chl *a* concentrations at these sites is attributed to the regular tidal flushing of the Mediterranean seawater via Boghaz El-Gamil inlet. However, higher levels were recorded in other locations along the lake. The maximum concentrations of Chl *a* recorded were 101.1 mgm^{-3} and 125 mgm^{-3}, at sites 7 and 8 respectively (Figure 3 and Table 1). Both sites receive significant amount of wastes. Site 7, in the western corner, receives high amount of agricultural and sanitary wastes via El Serw drain. On he other hand, site 8 in the south-eastern corner receives mixed amount of sanitary, agricultural and industrial wastes from Bahr Hadous and Bahr El-Bakar drains.

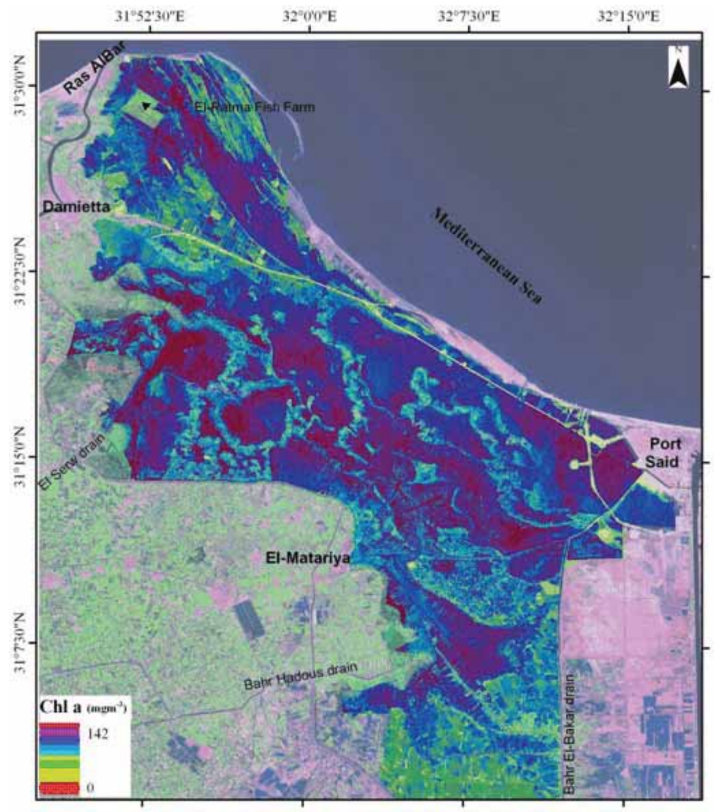

Fig. 5: Spatial distribution map of chlorophyll-a of lake Manzal

Two types of linear regression models were established; the first is a single band ratio and the second is a logarithmic band ratio, which derived from flurometrically measurements of Chl *a* values and satellite albedo (Chang *et al*. 2004). The scatter plot (Figure 4) shows both types of regressions (left is the single band ratio and the right is the logarithmic band ratio).

This approach is based on the correlation between the reflection and absorption of Chl *a* in the visible spectrum bands. Both regression types show different correlation, the least correlation was the single band ratio between ETM+1 and ETM+2 (R^2 = 0.03) as well as the log band ratio for the same two bands (R^2 = 0.02). However, ETM+1 (blue range of the visible light) and ETM+3 (red range of the visible light) show a significant absorption which increases with the increase of Chl *a* values (Figure 4). This probably explains that the rate of decrease in ETM+3 is faster than the decreasing rate in ETM+1. This could be interpreted due to the possible contribution of inorganic suspended sediments and dissolved organic matter to the reflection and absorption of the visible spectrum. The ratio of ETM+1 and ETM+3 might work more effectively in estimating Chl *a* when the Chl *a* concentration is above a certain level (35 mgm^{-3}) and the water is not much turbid. Comparing the single ratio with the logarithmic ratio, the later shows that the ratio between Log ETM+1 and Log ETM+3 produce good correlation with R^2 0.70.

A Chl *a* concentration map (Figure 5) was then generated by using the single regression model. The map shows the spatial distribution pattern of Chl *a* in lake Manzala on the sampling day, which reflects the environmental conditions of the lake. The map shows steady low pattern of Chl *a* in the northern strip, however some higher values (red color) appears close to El-Ratma fish farm. This may be attributed to the flourishing of the phytoplankton due to high level of organic matter resulted from fish deeding residue.

On the other hand, medium and high levels of Chl *a* in other parts of the lake is attributed to the degree of discharge of pesticides and/or wastes together with the characteristics of the water basins. As shown in Figure (5) lake Manzala has changed from an open water body to semi-closed basins, which in due course has a direct impact on the water quality. The size of the basin and the water circulation together with its physico-chemical properties, which play a significant role in the flourishing of phytoplankton. The smaller the size of the basin and less of water circulation together with convenient environment of low salinity, high temperature and higher organic matter help in flourishing the Chl *a* (e.g. south western and south eastern corner). Indeed, this reflects the environmental conditions of lake Manzala and how much the changes in the morphology of the lake has contributed to the changes in the water quality.

Conclusions: Specific processing of landsate satellite images may play a significant role in mapping the costal lake's water quality in general and Chl *a* in particular. The ratio of ETM+1 / ETM+3 and Logarithmic of ETM+1 / ETM+3 show high correlation with Chl *a* concentration. It seems that this regression model is more realistic to estimate and map the chlorophyll-a in the water column. There are, however, some limitations which could be tackled and therefore improve the results. Among these, the method is applied once with limited number of sampling locations, which does need more sampling locations for more confidence with the correlation.

The environmental conditions of lake Manzala is unique where it is not an open water body that might help predicting the distribution easily. So, this regression models need to be applied on other lakes in Egypt to see the applicability of this regression model. Also, further research is required to assess the applicability of this method in recognizing the toxic algae, since it is occurred in lake Manzala.

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