Using Earth Observation (EO) Technique for Monitoring Water Quality in Lake Burullus

Hanan A. Farag[1]

[1] Researcher, Environment and Climate Research Institute (ECRI), National Water Research Center (NWRC); Hanan_Farag@yahoo.com

Abstract

The knowledge of the impact of pollution source on the water resources is essential in environmental water studies as well as for resource management. Earth Observation (EO)-based water quality monitoring service will close this knowledge gap by providing a set of comprehensive water quality products derived from satellite imagery. The objective of this research is to explore the water quality characteristics of the brackish water in lakes using earth observation (EO) techniques to maintain of conserve water environment of lake and introduce and recommend a simple approach to formulate a guide line for stockholders.

Lake Burullus is one of the northern lakes, is the central of five principal coastal lagoons of northern Egypt. It is considered as shallow brackish water basin. It receives drainage waters from surrounding agricultural areas through seven drains. The amount of the drainage water discharged annually into the lake fluctuates from one year to the other, with the average of about 2.5 billion m^3/year (Samaan *et al.*, 1989).

Lake Burullus was declared a nature reserve under Law 102/1983 in May 1998. The lake and its surroundings are subject to ecological constraints that relate to excessive use of resources: land reclamation, fish farming, over-fishing, over-hunting, overwhelming flow for drainage water, etc.

MEdium-spectral Resolution Imaging Spectrometer MERIS (FRS) imaginary are acquired at spatial resolutions 300 m concurrently with field observations have done. A correlation coefficient has been investigated by using statistics software MINITAB between the four water quality parameters (TSS, Turbidity and TDS and transparency). It was found that the correlation of TSS and TDS is strong with R^2=0.6, (P= 0.017). The correlation between TSS concentration measured and MERIS reflectance's bands have been investigated. There is a significance correlation between three MERIS reflectance's bands (7,8 and 9). The best correlation was obtained with MERIS band 9 (700–710 nm) with correlation coefficients reach to 0.59 with (P = 0.05). Linear trend between the average reflectance in MERIS band 9 and TSS measurements is investigated. It was recommended to increase the number of water quality sampling and it should be covered all over lake basins to get a real picture of the water quality status. In addition, more EO data with reduced resolution should be calibrated and fine tuning using the high resolution and in situ measurements to get regular EO monitoring in reasonable cost.

Key words: Earth Observation (EO); Water Quality Monitoring;, Lake Management; Lake Burullus, MERIS data.

1. BACKGROUND

Remote sensing is a suitable technique for large-scale monitoring of inland and coastal water quality and its advantages has long been recognized. Remote sensing provides a synoptic view of the spatial distribution of different biological, chemical and physical variables. Therefore, recent years have seen increasing interest and research in remote sensing of water quality of inland and coastal waters (Dekker *et al.*, 1995; Doerffer,1992; Lindell *et al.*,1999).

The knowledge of the impact of pollution sources on the water resources is essential in environmental water studies as well as for resource management. Earth Observation (EO)-based water quality monitoring service is expected to close this knowledge gap by providing a set of comprehensive water quality products derived from satellite imagery while relying on existing in-situ measurements for calibration and validation.

2. PROBLEM DEFINITION

The population growth and expansion of urbanization in the Nile delta is an important problem affecting to deterioration of water resources. Although, the urban areas are considering as economic backbones of the development, they are also exerting an enormous stress on natural resources and the environment. The Northern lakes in Egypt serve as reservoirs for drainage waters, which are contaminated, with anthropogenic materials (El-Sammak and El-Sabrouti, 1995).

Lake Burullus is one of the northern lakes of Egypt. It is a shallow brackish water basin. It receives drainage waters from surrounding agricultural areas through seven drains in addition to the fresh water from Brembal Canal situated in the western part of the lake. The amount of the drainage water discharged annually into the lake fluctuates from one year to the other, with the average of about 2.5 billion m^3/year (Samaan *et al.,* 1989). During winter period, seawater may also enter the lake and increasing the salinity of water. Many investigators had studied the hydrographic and chemical characteristics of Lake Burullus water and sediments. Organic carbon distribution and preservation of the lake sediments was studied by (El-Sammak and El-Sabrouti, 1995a).

In many developing countries the standard traditional mapping and monitoring techniques of lakes have already become too expensive compared with the information achieved for environmental use. A solution could be to optimize our efforts and more frequently base our surveillance on remote sensing techniques to improve the information contented limit the costs.

In addition, the water quality measurements are used in models to predict future trends and examine, compare and evaluate the impact of water management and cropping patterns scenarios. The current system of water quality monitoring is constrained by limited resources and falls short of delivering a complete picture on lakes water quality.

3. OBJECTIVE

The objective of this research is to explore the water quality characteristics of the brackish water in lakes using earth observation (EO) techniques. Such investigations way lead to maintaining and conservation water environment of lake. The research would introduce and recommend a simple approach to formulate a guide line for stockholders.

4. MATERIAL AND METHOD

Integrating EO-derived information into the water quality monitoring program is expected to have a positive impact on the integrated management and sustainable use of water resources in Egypt in the long term.

The suspended matter is defined as a combination of: inorganic particles and detritus, present due to re-sedimentation and advection processes, the upward radiance at any visible wavelength is composed of contributions from all these substances (Ritchie et al. 1976, 1990; Curran and Novo 1988). Significant relationships have been shown between suspended sediments and radiance or reflectance from spectral wave bands or combinations of wave bands on satellite

Kallio et al., (2005) investigated the suitability of channel configuration of three satellite instruments for the estimation of optically active substances concentrations of lakes using the inversion method and empirical algorithms. The dataset, consisting of data from 11 lakes located in Finland, has a wide range of water quality. The study was focusing on three parameters in developing the algorithm these are: the sum of chlorophyll a and phaeophytin a ($C_{Chl\text{-}a}$) total suspended solids concentration (C_{TSS}) and the absorption coefficient of coloring dissolved organic matter (CDOM). The results indicated that MODIS and MEdium-spectral Resolution, Imaging Spectrometer (MERIS) have nearly optimum channel configurations for the estimation of accuracy for total suspended solids concentrations (C_{TSS}) and the absorption coefficient of CDOM at 400 nm $a_{CDOM}(400)$ in the lakes have been studied.

Another study has been conducted to El-Manzala Lake (C-Core, 2007), it was integrated the EO data lake water monitoring service focusing on water constituents and surface cover products. Three types of ENVISAT imagery have been used (MODIS, MERIS and ASAR) and three parameters were investigated (Turbidity, TSS, and chlorophyll CHL-a).

The review and data available it was found that the suitable satellite imagery that used in the analysis, should have high temporal resolution and a sufficiently high spatial resolution to allow capture the high temporal variability of water constituents. Among the range of operational EO systems currently available, these conditions are met by the MERIS which are operating in the solar reflective spectral range images.

MERIS imagery is available at spatial resolutions ranging from 300 m to 1200 m, fifteen spectral bands are available at full (300 m) and low (1,200 m) resolution as the same. The fifteen bands in the visible and near-infrared portion of the electromagnetic spectrum, these bands cover wavelength from 412.5 nm to 900 nm (ESA, 2006). MERIS images which were analyzed have been provided by European Space Agency ESA through the tiger second initiative project.

4.1. Applying an Empirical Algorithms

Many studies have developed algorithms for the relationship between the concentration of suspended sediments and radiance or reflectance. A few studies have taken the next step and used these algorithms to estimate suspended sediments for another time or place (Ritchie and Cooper 1988, 1991). The extraction of water constituents from EO data is frequently based on empirical algorithms where water quality variables are estimated from the reflectance at one wavelength or from ratios between reflectance's measured at two wavelengths. Estimation of empirical algorithms methods can be divided into purely empirical and semi-empirical. Semi-empirical algorithms is considered the most common for applying information about the optical properties of water constituents affect reflectance at different wavelengths. In this study it is concerning with exploring the best correlation of the total suspended solids.

MERIS eutrophic lakes processor which is a plug-in processor of BEAM software (applied. This processor has been developed as a joint effort between different specialist research institutes and universities in Finland, Spain, Norway and Germany under a certain protocol with the European Space Agency ESA.

The task of this developed processor is to produce Level 2 data from MERIS Level 1b data for eutrophic lakes water. This includes an algorithm for atmospheric correction and an algorithm to derive properties of the water such as the inherent optical properties (IOP's) absorption and scattering and the concentrations of total suspended matter (TSM) and chlorophyll from the water leaving radiance reflectance spectra (i.e. after atmospheric correction). Input to the The algorithms of the lake processors are estimated the water leaving radiance reflectance of 8 MERIS bands. These data are the output of the atmospheric correction. The algorithms derive data of the inherent optical properties total scattering of particles (total suspended matter, tsm) b_tsm, the absorption coefficient of phytoplankton pigments a_pig and the absorption of dissolved organic matter a_gelb (gelbstoff), all at 443 nm (MERIS band 2), (cited from BEAM documentation cited from http://www.brockmann-consult.de/cms/web/beam).

The field measurements have been used also for calibration and validation. MERIS image processing has been done using the BEAM software ver.4.8 which has been developed by brockmann-consult group to view and convert the MERIS data to other formats. ENVI ver.4 was also used for classification and developing the water mask while ArcGIS ver.9.3 software used for developing a TSS map.

In the pre-processing stage, EO data are subjected to applicable corrections and preparatory processing, such as corrections for atmospheric effects, geo-referencing to specified projection and coordinate system, and the masking of land, water. Information extraction is concerned with converting observed reflectance values to water constituents (TUR, TSS). The flow chart of proposed methodology used in this study is provided in Figure (1).

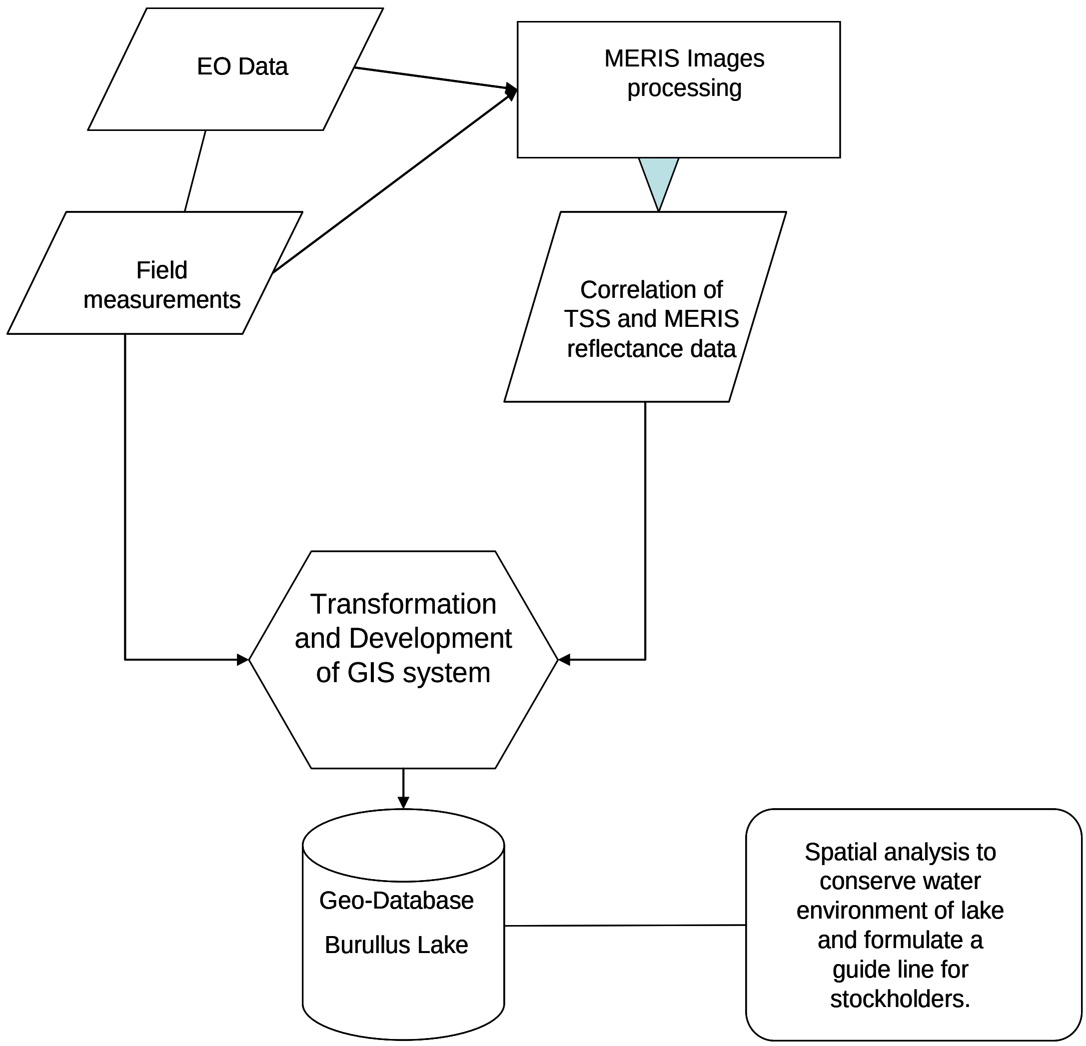

Figure 1: Overall research methodology

5. STUDY AREA AND DATASETS

Lake Burullus is the central of five principal coastal lagoons of northern Egypt. To the east are Lake Manzala and Lake Bardawil, to the west are Lake Idku and Lake Maryut. Figure (2) shows the general layout of the lake and the drains discharged to it.

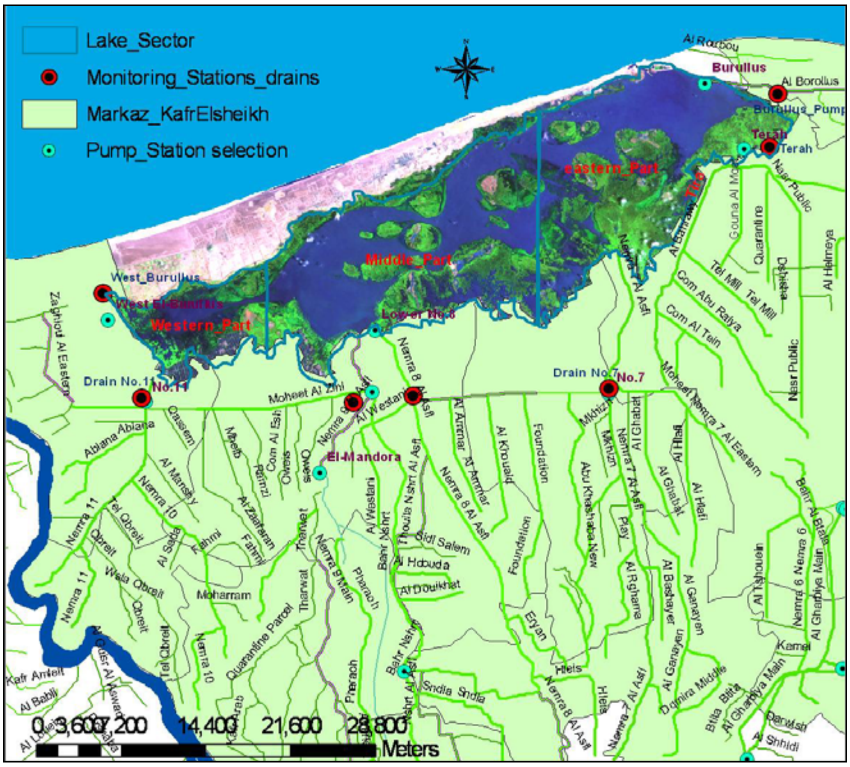

Figure 2: General Layout of El-Burullus Lake

It is a part of the Governorate of Kafr El-Sheikh in the northern part of the Delta that lies between the two branches of the Nile. It was declared a nature reserve under Law 102/1983 in May 1998. Lake Burullus is separated from the sea (the Mediterranean) by a 65 Km long sand bar, the middle section of the bar is narrow and is cut by an inlet (Bughaz) that connects the sea and the lake (EEAA, 2005).

The Lake and its surroundings are subject to ecological constraints that relate to excessive use of resources: land reclamation, fish farming, over-fishing, over-hunting, overwhelming flow for drainage water, etc. Another future constraints was related to the impact of new development projects, including: the international coastal highway that runs along the sand bar, fishing port to the west of the Bughaz, future sea-side resorts, etc. (Okbah,2005).

5.1. Remote Sensing Data

The amount of EO data acquired concurrently with field observations was limited. Therefore, several images acquired prior to or after the field survey were included in the analysis. Two MERIS full resolution (FRS) are acquired during the field campaign. One only scene, acquired on July 29, coincided with the field survey.

LANDSAT imagery archives have been used to provide a source of medium resolution imagery to supplement the high resolution EO data. This imagery consists of visible and near infrared (VNIR) bands 1, 2, 3, 4 and 8 (PAN) with a spectral range between 0.4 and 1.0 μm. Two LANDSAT images have been used, acquisition dates were July 2003 and July 2010 (ETM), Path/Row (177/38).

5.2 Water Quality Data

According to generating water constituent products require the integration of EO and in-situ measurements to formulate empirical models linking the relative brightness variations observed in the EO data to physical ground measurements, a preliminary field observations had been done. In-situ data for validation and calibration was collected between July 27 and July 29, 2010.

Based on the results of the literature review and interpretation of relative water constituents products, a total of sampling locations were identified prior to the field campaign. The planned locations were used to guide the field campaign, and modifications to the sampling locations were implemented where dictated by local conditions and access limitations.

As a result, a total of 30 locations were planned sampled. In most cases, sampling was carried out by boat, but where boat access was not possible, water samples were drawn from the shore. 23 point were surveyed and covered the two large basins in El- Lake Burullus (Eastern and middle), eight points were not associated with areas of open water and were therefore not used in the calibration and validation of water constituent products. However, observations and measurements at these locations were helpful in getting an overall picture of the lake and for the interpretation of surface cover products. A total of fifteen locations over the two day's sampling collection were used in the analysis of water constituents. At each sampling location, the following observations and measurements have been done, the in-situ measurements, Temperature, pH, Turbidity, TDS, Transparency, Dissolved Oxygen (DO), Water depth, while the laboratory measurements included TSS and Turbidity. In addition the observations of land use and land cover were explored and supported by photographs. Figure (3) represents the planned and actual water quality monitoring locations all over lake Burullus.

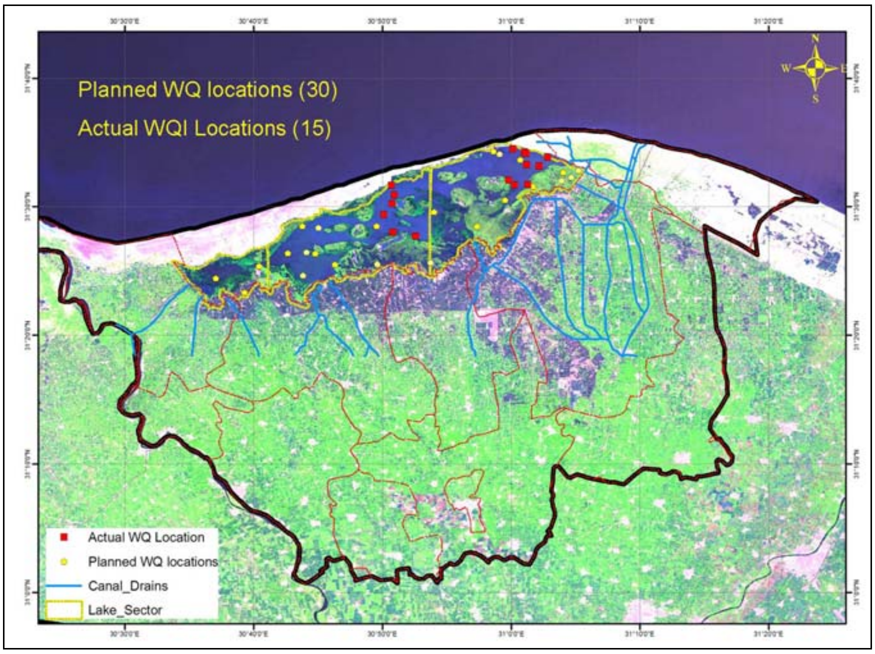

Figure 3: Planned and actual water quality locations at Lake Burullus

6. RESULTS

Kallio et al., (2005) were reported that the correlation between CTSS and reluctances is increased with longer wavelengths (until the 700–730 nm). The best correlation was obtained with MERIS channel 700-710 nm. While in another study on Lake Manzala, it was found that a good correlation exists with TSS and MERIS band 7 (665 nm), (C-Core, 2006).

A correlation coefficient has been investigated between four water quality parameters (TSS, Turbidity and TDS and transparency) that have been measured at 15 locations by using statistics software MINITAB. It was found that the correlation of TSS and TDS is strong with R^2 = 0.6, (P= 0.017) Table (1) shows the correlation matrix between the four selected parameters.

Table 1: Correlation matrix results of the selected parameters

WQ_Parameters	*TSS (mg/l)*	*Turbidity (NTU)*	*TDS (mg/L)*	*Transparency (cm)*
TSS (mg/l)	1			
Turbidity (NTU)	0.130	1		
TDS (mg/L)	0.606	0.122	1	
Transparency (cm)	0.319	0.043	-0.037	1

MERIS eutrophic lakes processors are applied to Lake Burullus water mask. The most significance correlation between the band reflectance's values and in situ measurements are investigated. It was found that the Case-2 Regional processor has higher significance correlation between MERIS bands reflectance's (7, 8 and 9) and measured TSS concentration then the two other processors. Eight water quality sampling was concurrent the MERIS imaginary acquired. Figure (4) represents the output results of lakes Case-2 Regional processor (BEAM 4.8).

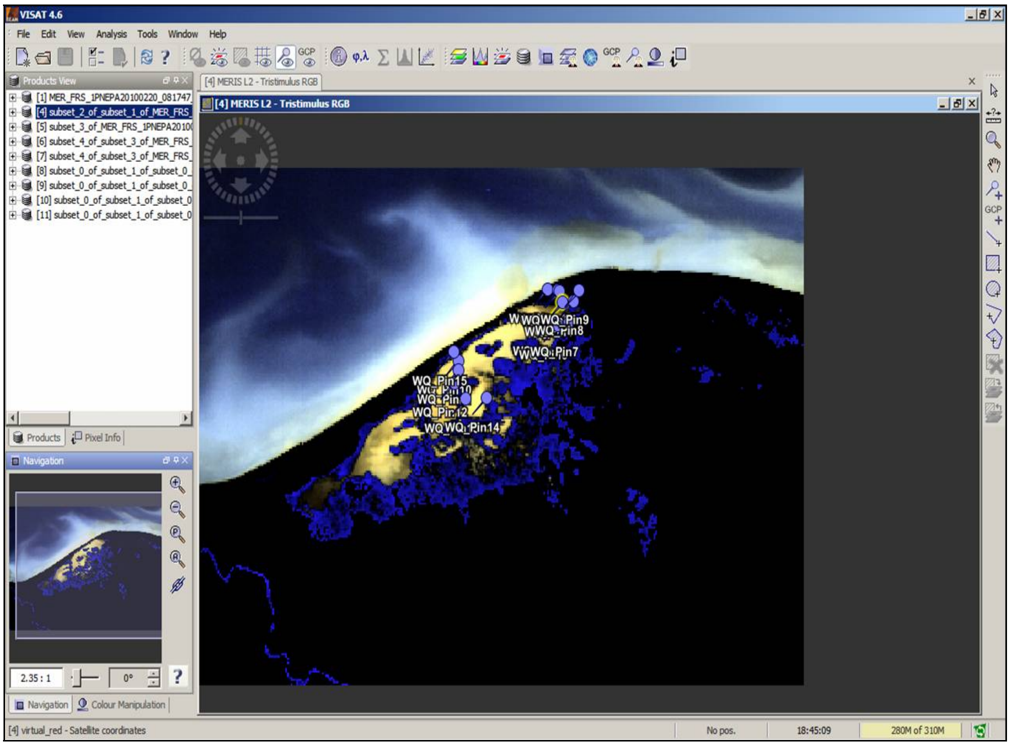

Figure 4: Case -2 Regional processor output

The correlation between TSS concentration measured and MERIS bands reflectance has been investigated. There is a significance correlation between three MERIS bands (7, 8 and 9). The best correlation was obtained with MERIS band 9 (700–710 nm) with correlation coefficients reach to 0.63 with (P = 0.05). Figure (5) represents a clear linear trend between log reflectance in MERIS band 9 and log (TSS) measurements. Empirical relationship between the Log (TSS) concentration and MERIS band (9) reflectance is estimated from linear regression model.

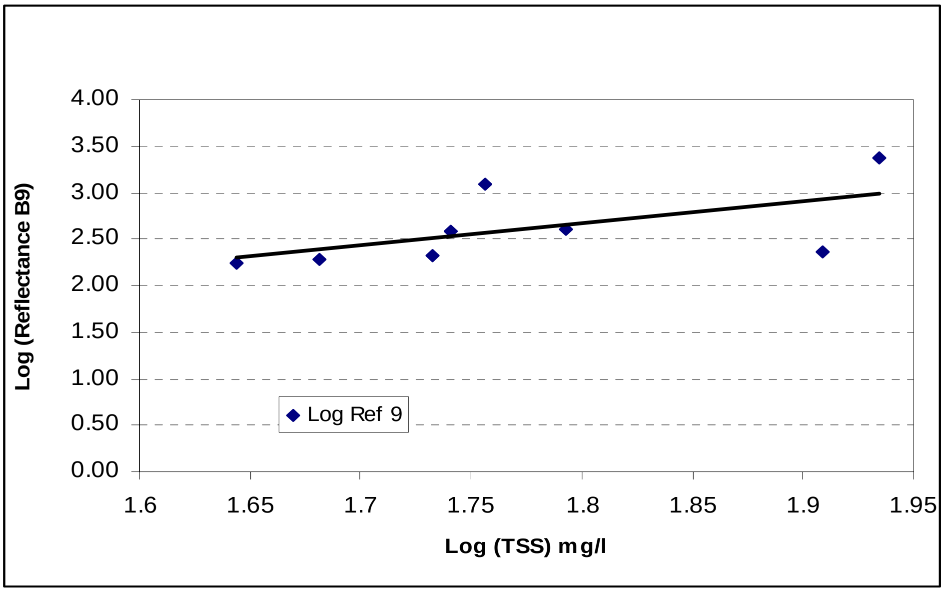

Figure 5: Average Reflectance of MERIS Band 9 and TSS

The general formulation of the empirical relationship was:

$$C_i = aX + b \quad (1)$$

Where C_i is the concentration of water quality parameter (i), a and b are empirical parameters and X is an independent variable (reflectance of single channel or reflectance ratio of two channels (Kallio et al., 2005). The accuracy characteristics of reflectance result of lake processors were defined by R^2 and root mean squared error (RMSE). The linear regression model was developed for TSS and MERIS band 9 (700-710 nm). The estimated algorithm as represented in equation (2) with significant R^2 accuracy (R^2=0.56), (P<0.05) and RMSE = 14.0%.

$$\log(TSS)mg/l = 1.40 + 0.144\log(B_9) \quad (2)$$

The comparison of the TSS measured and the estimated values at the same location presents in Figure (6).

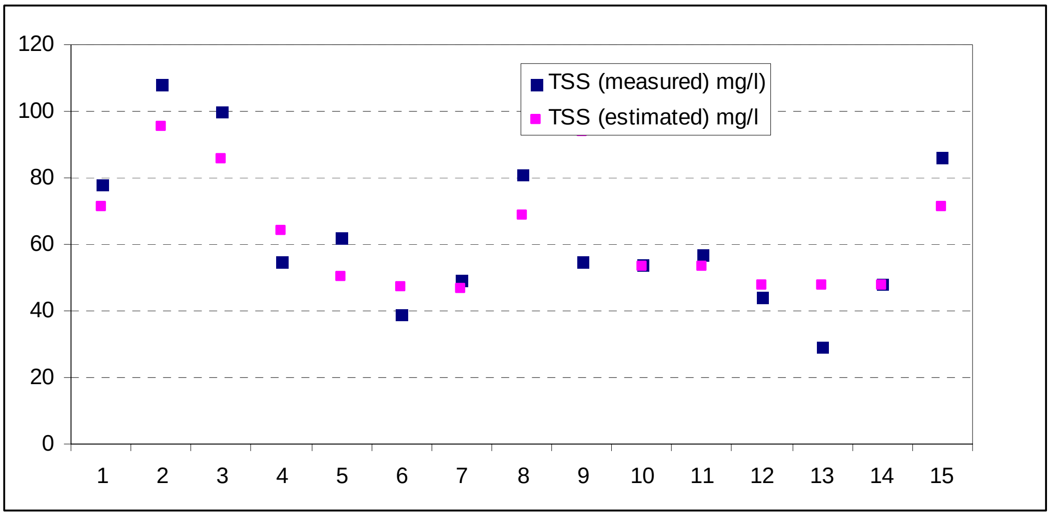

Figure 6: Comparison between the TSS concentration measured and estimated

TSS surface is developed by applying the developed algorithm. Figure (7) shows the resulting average TSS superimposed over LANDSAT image July 2010. It is clear that in TSS surface; high TSS values at the eastern part while the TSS concentrations are decreased from the right to left side at the second large basin. There are also, high TSS concentrations values at the third basin at the lower western part of the lake.

For TDS surface is developed also based on the correlation and regression model with TDS and TSS concentrations. Figure (8) shows the distribution of TDS concentration along the lake basins. The TDS concentrations is relatively high values at the middle basin near to the drains outfalls and fish ponds.

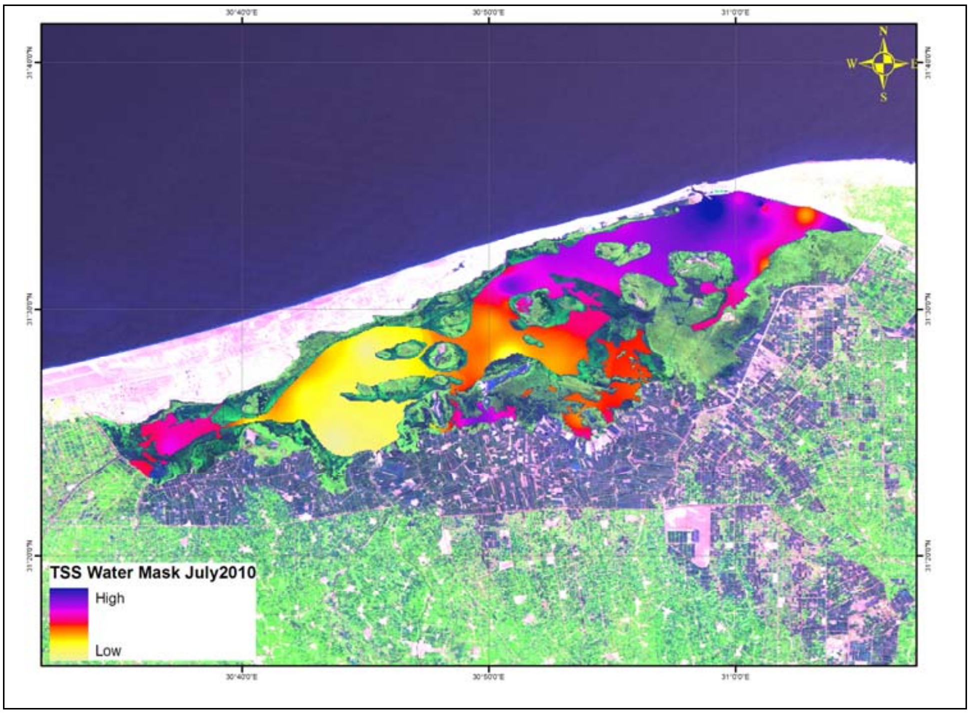

Figure 7: Average TSS concentration at Lake Burullus

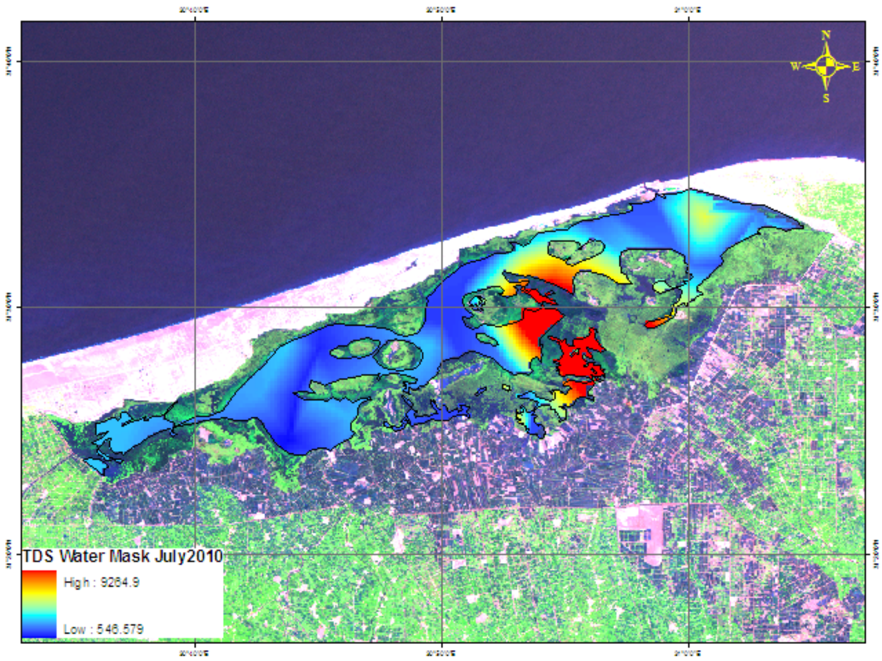

Figure 8: Average TDS concentration at Lake Burullus

7. CONCLUSIONS AND RECOMBINATION

It was concluded that earth observation technique was suitable for exploring the impact of drainage water discharged to the lake and the expansion of fish ponds. In spite of, earth observation saves time and provides us with continuous data of water quality status but it also, needed well trained staff for preprocessing and evaluating the results. MERIS imaginary (B_9) has a good correlation with TSS measurements with RMSE reached to 14%. The root mean square error (R2) between the TSS measured data is relatively low value due to the limitations of the measured data used for calibration and validation and the EO are acquired concurrently at the same time of field investigation.

From the previous work, it was recommended to increase the number of water quality sampling which should cover all lake basins to get a real picture of the water quality status. In addition, more EO data with reduced resolution should be calibrated and fine tuning using the high resolution and in situ measurements to get regular EO monitoring at reasonable cost.

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