# *ESTIMATION OF WATER QUALITY PARAMETERS IN LAKE NASSER USING REMOTE SENSING TECHNIQUES*

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## ABSTRACT

The main objective of this research is to use remote sensing to estimate water quality parameters (WQPs) in Lake Nasser which is considered the sole strategic storage of fresh water in Egypt. The estimation of WQPs will support an integrated water management for lake Nasser and provide decision makers with the status of Lake water. The main problem for water quality monitoring in lake Nasser is that it is performed annually using traditional sampling where it is difficult to take more repetitive measurements in different seasons due to high cost of the field trips. So that, this research will provide a technique based on both field data and remote sensing to evaluate WQPs in Lake Nasser. Data of six field missions, executed in different seasons, are used with Envisat/MERIS match-up images to create and validate a regression model for various water quality parameters. The correlation between the different WQPs, optical and non-optical parameters, were calculated to show their behavior with the change of optical parameters. The correlation values indicate that non-optical WQPs have a strong correlation with the optical ones. Regression models can, therefore, be created to estimate many WQPs using remote sensing techniques. The stepwise regression was conducted between different WQPs and reflectance extracted from atmospherically corrected match-up MERIS images. Variation in WQPs resulted in different regression models for each water quality parameter depending on the season of measurement. Regression models was validated using statistical performance measures to select the suitable model for each water quality parameter, one for each season. The results indicated that bands 5 and 6 are found to be the common predictors for both optical and non-optical WQPs. It is recommended to make use of the regression models in studying the time series variation of WQPs in different seasons.

**Keywords:** Remote Sensing, Envisat/MERIS, Water Quality, Lake Nasser, regression models.

## 1 INTRODUCTION

The High Aswan Dam (HAD) has its great impacts on the economic development of Egypt by means of storing water during flood in the upstream reservoir, known as High Aswan Dam Reservoir (HADR), to supply water needed for irrigation, producing hydroelectric power and protecting the downstream reaches from flood damage. The reservoir is extended in Egypt and Sudan, the Egyptian part is known as Lake Nasser while the Sudanese part is known as Lake Nubia. Protection of water in HADR from pollution is a big challenge. The Egypt government has therefore taken some important measures to protect it against pollution. The following ministerial decrees were issued to protect the lake from human activities. Decree 203/2002 identified a 2 km buffer zone around, where it is not allowed to have any agricultural, industrial and tourist activities. Wadi Alaqi, as a part of Lake Nasser was considered as a Biosphere Reserve of international importance according to Law 102/1983 which stated that this area should remain free of any development, changes and disturbance in land-use or activity that may affect the natural site (Zaghloul et al., 2012).

The Ministry of Water Resources and Irrigation represented in Nile Research Institute (NRI) and High Aswan Dam Authority (HADA) do a great effort in monitoring the HADR water quality. An annual field trip is taking place to monitor sedimentation and water quality in both the Egyptian and Sudanese parts of the lake. Physical, chemical and microbiological parameters were measured in order to monitor water quality in Lake Nasser, these parameters were measured vertically by means of sampling or in-situ measurements at specific points along lake. The total number of monitoring points or section in Lake Nasser is 29 sections (14 in Egyptian part of lake and 15 in Sudanese part), (EL Sammany, 2002). The monitoring program is used to have an overview of the status of the lake at the sampling point, but when it is needed to know the status of water quality at any other location it can be done by means of linear interpolation between measurements.

Remote sensing has introduced useful tools for studying water bodies with large spatial extents, such as Lake Nasser. Many researches were found in literature that studying water quality in inland lakes, such as Lake Naivasha in Kenya (Ndungu et al., 2015) or coastal lakes, such as Lake Burullus in Egypt (Farag, 2011).

The Medium Resolution Imaging Spectrometer (MERIS) is a multispectral sensor found on board of Envisat which launched by European Space Agency (ESA) on 1 March 2002 water (ESA, 2006). MERIS is designed to acquire 15 spectral bands in the 390-1040 NM range of the electromagnetic spectrum. The primary mission of MERIS is the measurement of sea color in the oceans and in coastal areas and consequently this color converted into other geophysical measurements. MERIS are Images available for period of ten years starts from December, 2002 to March, 2012, where the connection between Envisat and its ground stations was lost in that date. The available MERIS data will help in understanding of the long-term change pattern of water quality in Lake Nasser and hence helps in water management in future.

Hussein and El Shafi (2005) studied the water quality in Lake Nasser, and carried out physical and biological analysis for WQPs at 25 section distributed along total length of lake. Number of regression models were constructed to describe the status of WQPs in lake before flood and during it. The total number of regression models were 3300 equations which are very large to use. Generally, remote sensing was used to study Lake Nasser in many disciplines. Mostafa and Soussa (2006) used remote sensing and GIS techniques to study the change in lake shape using three Landsat images in different dates to identify the agriculture areas around the lake. Ebaid and Ismail (2010) estimated evaporation using aerodynamic method, while Hassan (2013) estimated it using Surface Energy Balance Algorithm for Land (SEBAL). In field of water quality, Hassan and Fahmy (2005) estimated surface suspended sediment by applying the second order polynomial equation developed by Ritchie et al., 1991, two Landsat images represent the high and low water levels. They found that the equations were valid only in the low water level seasons. Hamed et al. (2015) estimate both Total Suspended Solids (TSS) and Chlorophyll (Chl-a), for the surface layer of Lake Nasser, using remote sensing techniques. The research validated three water quality processors (Case2 Regional [C2R], Eutrophic Lake and boreal Lake) in different seasons using statistical techniques. The validation results showed that, depending on the season, one or more processors can be used. For example, Eutrophic lake processor can be used to estimate TSS during maximum water level season, while C2R and eutrophic lake processors can be used to estimate TSS during falling period.

Despite most of researches that estimate WQPs using remote sensing have focused on optical variables where its concentration affects the color of water and interact with light by changing the reflected radiation spectrum (Gholizadeh et. al, 2016), such as chl-a, Colored Dissolved Organic Matter (CDOM), TSS, and turbidity, it is founded that other non-optical parameters, such as Total phosphorus (TP) and Silica ($SiO_2$), have also a good correlation with the remote sensing reflectance. Many researches that estimates Total phosphorus (TP) were summarized by Chang et al. (2015), where linear and multiple regression and genetic programming were used with correlation factor ranging from 0.41 to 0.78. Also, Total Dissolved Solids (TDS) can be estimated using remote sensing techniques (Abdelmalik, 2016).

The first aim of this research is to find the correlation between measured WQPs, where Pearson correlation matrix will be calculated to check whether the non-optical WQPs have been influenced by the optically active parameters or not. While the second aim is to construct and validate regression or retrieval models to estimate different optical and non-optical WQPs of Lake Nasser using remote sensing techniques where MERIS image will be used.

## 2 STUDY AREA

Nasser Lake is the second largest man-made lake in the world, extending from the southern part of Egypt to the northern part of Sudan, about 500 km length, and 7000 km circumference. The level of water oscillates between 147 to 182 meter Above Mean Sea Level (AMSL). Lake Nasser has an area of about 6,600 $km^2$ out of which 5,600 $km^2$ in Egypt at the storage level of 182 m AMSL. The study area of HADR was defined by bounding box has the following coordinates, Figure (1a):

- Lower Left Corner (21° 00' 00" N, 30° 34' 10" E)
- Upper Right Corner (23° 46' 44" N, 33° 28' 18" E)

## 3 MATERIAL AND METHOD

### 3.1 Field data

Data used through this research were collected during annual field survey for Lake Nasser carried out by High Aswan Dam Authority (HADA) incorporation with Nile Research Institute (NRI). This research used data collected in Lake Nasser from 2003 to 2011. Table (1) shows measured parameters and dates of different six survey missions. Eight WQPs were measured during the six field missions, but, as indicated in Table (1), not all parameter measured in all mission. For instance, Chl-a was measured only during third and fourth missions. So that, the monitoring of lake water quality was not be made for all parameters using water sampling analysis, which reflects the importance of elaborating a technique to estimate water quality for all parameters using the correlation between remote sensing images and field data. Figure (1a) shows the locations of the samples taken for water quality monitoring, and the location of each sample upstream HAD was shown as well, in addition to its geodetic coordinates. The indicated location is for all survey missions except 2010 mission as the survey team decided to follow a different plan in taking samples. Samples, for 2010, were taken every five kilometers from the Egyptian-Sudanese border until reaches near Allaqi section as indicated in Figure (1b). Water samples were collected vertically to represent water column at each sampling point, five vertical samples were taken at 0.50 m below water surface, 25%, 50%, 65% and 80% of water depth at each location. Water sample at depth 0.5 m under water surface is used through this research as it is the effective in remote sensing. Analyses of TSS and Chl-a were done as per the Standard Methods for the Examination of Water and Wastewater (APHA).

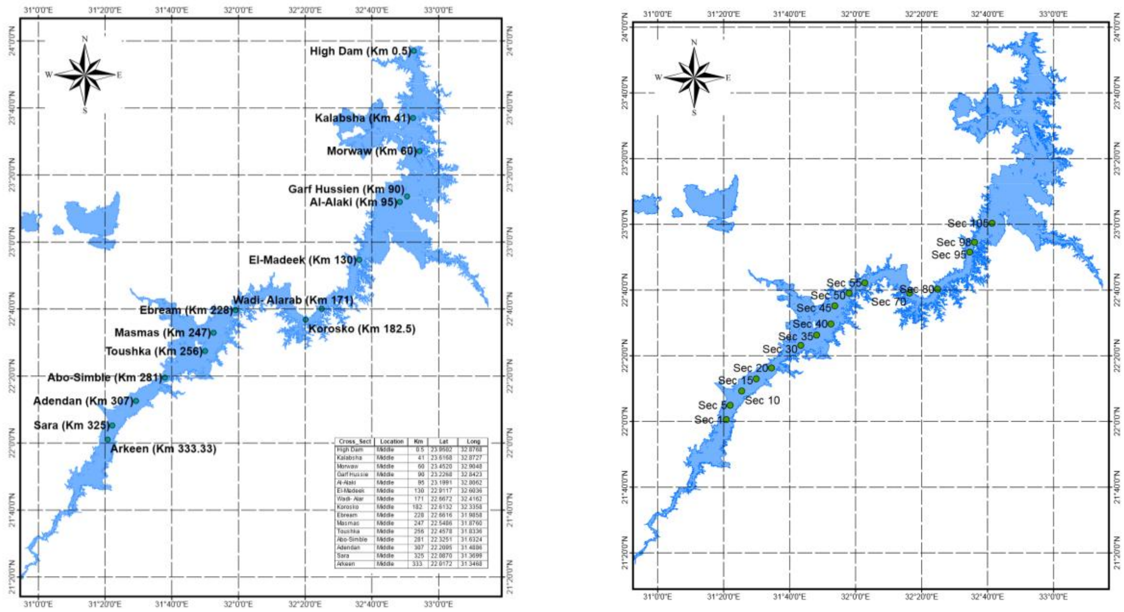
**Table (1) Measured Parameters for each mission**

| | Dates | No. of Samples | TSS | Chl-a | Turbidity | Transp. | SD | TP | $SiO_2$ | TDS |
|---|---|---|---|---|---|---|---|---|---|---|
| First Mission | 23Oct 03<br>15 Nov 03 | 10 | ● | | ● | ● | | ● | ● | ● |
| Second mission | 27 Nov06<br>15 Dec 06 | 12 | | | ● | ● | | ● | ● | ● |
| Third Mission | 15 Nov 07<br>24 Nov 07 | 11 | ● | ● | | | ● | ● | ● | ● |
| Fourth Mission | 24 Apr 09<br>08 May 09 | 12 | ● | ● | | | ● | ● | ● | |
| Fifth mission | 21 Aug 10<br>31 Aug 10 | 16 | ● | | ● | ● | | ● | | ● |
| Sixth Mission | 04 Oct 11<br>10 Oct 11 | 9 | ● | | | | | | | |

## 3.2 Remote sensing data

The Medium Resolution Imaging Spectrometer (MERIS) will be used through this research. The primary mission of MERIS is the measurement of water color in the oceans, coastal areas and lakes. Knowledge of water color can be converted into a measurement of WQPs such as chlorophyll pigment concentration, suspended sediment concentration and of atmospheric aerosol loads over water (ESA, 2006). MERIS was found in three main spatial resolutions; Full-Resolution (FR), Reduced Resolution (RR) and Low Resolution (LR). The description of MERIS resolutions and processing levels can be found in (ESA, 2006). The temporal resolution of MERIS Images is about three days, while its view angle is 68.5 and the swath width is about 1150 Km. Table (2) indicates the primary application for the 15 bands as found in MERIS Product Handbook (ESA,2006).

MERIS full resolution (FR) level 1B quarter and full scenes were used in this research. Each pixel of full resolution image covers an area of 260 m × 290 m, which is suitable for studying large water bodies like Lake Nasser, especially for water quality monitoring. The match-up Images used in this current research taken at 07-Nov-03, 01-Dec-06 19-Nov-07, 01-May-09, 21-Aug-10 and 10-Oct-11, one image per each field trip was selected, the specific dates were chosen taking into account to select the clearest and cloud free images and to be at the middle of the mission period as much as it can.




a) b)

**Figure 1. Water Quality Samples' Locations**

**Table 2. MERIS spectral bands and applications (ESA, 2006).**

| No. | Band center (nm) | Band width (nm) | Applications |
|---|---|---|---|
| 1 | 412.5 | 10 | Yellow substance and detrital pigments |
| 2 | 442.5 | 10 | Chlorophyll absorption maximum |
| 3 | 490 | 10 | Chlorophyll and other pigments |
| 4 | 510 | 10 | Suspended sediment, red tides |
| 5 | 560 | 10 | Chlorophyll absorption minimum |
| 6 | 620 | 10 | Suspended sediment |
| 7 | 665 | 10 | Chlorophyll absorption & fluorescence reference |
| 8 | 681.25 | 7.5 | Chlorophyll fluorescence peak |
| 9 | 708.75 | 10 | Fluorescence reference, atmosphere corrections |

| No. | Band center (nm) | Band width (nm) | Applications |
|---|---|---|---|
| 10 | 753.75 | 7.5 | Vegetation, cloud, O2 absorption band reference |
| 11 | 760.625 | 3.75 | O2 R- branch absorption band |
| 12 | 778.75 | 15 | Atmosphere corrections |
| 13 | 865 | 20 | Atmosphere corrections |
| 14 | 885 | 10 | Vegetation, water vapor reference |
| 15 | 900 | 10 | Water vapor |

# 4 METHODOLOGY

Remote sensing methods usually use correlation techniques between field data and remote sensing images for estimating various parameters. The research methodology includes the acquisition of MERIS images, in addition to regression analysis between the atmospherically corrected MERIS images. More than one regression model is constructed for each parameter. The selection of the best model that represent each parameter will be based purely on some statistical performance measures.

## 4.1 Acquisition of MERIS images

The spatial coverage of MERIS image is greater than the current study area, so that, subset process for images was performed to reduce image spatial coverage to the bounding box coordinates of Lake Nasser, hence, the time needed for image processing was reduced. Regression gives, in many cases, strong and best relationships between surface reflectance and different optical WQPs. Many examples can be found in the remote sensing literature that claim the ability to measure water quality variables that do not directly affect light reflectance or are present in natural waters at such low concentrations that they do not affect reflectance signals measured by satellite sensors. According to Table (2) which shows bands application it can be noticed that bands from 11 to 15 contain data for $O_2$ absorption and it can be used in atmospheric correction (ESA, 2006). Therefore, only the first ten bands will be used in regression analysis. The method of analysis can be described as follows:

1- Surface reflectance will be calculated by applying a Simplified Model for Atmospheric Correction (SMAC) to the raw match-up images. SMAC is found also as plugin in a tool called Basic ENVISAT Toolbox for (A)ATSR and MERIS (BEAM).

2- Extracting surface reflectance from the atmospherically corrected MERIS images at the location of in situ measurements.

3- Pearson correlation matrix between measured WQPs will be calculated to check influence of optical WQPs such as TSS and Chl-a on other parameters.

4- Regression analysis will be applied separately for each field mission. stepwise regression techniques will be used in order to automate the choice of variable and regression model.

5- Classifying field mission according to its timing relative to flood seasons as not all mission preformed in the same season. flood seasons are described as rising, end of flood, and falling periods.

6- Validating the resulted regression model, the validation will be performed to select the most suitable regression model for the end of flood as this period has different measurements during this period.

The validation procedure was based on several statistical performance measures such as Fractional Bias, Correlation Coefficient, Normalized Mean Square Error, Geometric Mean Bias, and Geometric Mean Variance (Hanna et. al, 1993).

### 4.2 Statistical Performance Measures

Two types of performance measures will be used in selection of the best regression model for each WQP in different seasons, the first is the measure of difference which represent a quantitative estimate of the size of difference between predicted ($C_P$) and observed values ($C_O$). While the second is the measures of correlation, which is a quantitative measure of association between predicted and observed values. The correlation coefficient between the observed and predicted values became a popular way of looking at the performance of a model. A perfect correlation coefficient is only a necessary, but not sufficient, condition for a perfect model.

Statistical measures used in the evaluation process are shown in Table (3). The criteria of good model were suggested by Kumar et al. (1993) for Normalized Mean Square Error (NMSE), Fractional Bias (FB), and Factor of two (FAC2) as shown in Table (3). Also, there are two additional criteria, for Geometric Mean Bias (MG) and Geometric Mean Variance (VG), were suggested by Ahuja and Kumar (1996) could be useful to test the reliability of the model.

## 5 RESULTS

Seven WQPs are measured during the indicated field mission. The parameters are Total suspended sediment (TSS), Chlorophyll-a (Chl-a), Turbidity, Transparency, Total phosphorus (TP), Silica ($SiO_2$), Total dissolved Solids (TDS).

Figure (2) shows the period of each survey with changing water levels in Lake Nasser during the period 2001- 2011. The first three survey missions and the sixth mission were conducted in the period in which lake is in the case of maximum level after the end of flood. The fourth mission was conducted during the Lake level falling period, while the fifth mission was in the rising period. Figure (3) shows the longitudinal profile for all WQPs upstream HAD. The concentration of TSS is increased as with distance from HAD, especially in during rising period (fifth mission). this behavior can be found for turbidity and TP. While the concentration of both transparency and TDS decreases with distance from HAD. There is no significant change in the concentration of $SiO_2$. While, Chl-a don't have a specific change pattern.

**Table 3. Formulation of used statistical measures and its criteria**

| Statistical Measure | Formula | Criteria of good model |
|---|---|---|
| Correlation Coefficient (R) | $r = \frac{\overline{(C_O - \overline{C_O})(C_P - \overline{C_P})}}{\sigma_{C_P}\ \sigma_{C_{Po}}}$ | ---- |
| Mean Normalized Bias (MNB) | $MNB = \frac{1}{N}\overline{\left(\frac{C_p - C_o}{C_o}\right)} \times 100\%$ | ---- |
| Fractional Bias (FB) | $FB = 2 \times \left(\frac{\overline{C_O} - \overline{C_P}}{\overline{C_O} + \overline{C_P}}\right)$ | $-0.5 \leq FB \leq +0.5$ |
| Normalized Mean Square Error (NMSE) | $NMSE = \frac{\overline{(C_O - C_P)^2}}{\overline{C_O} \times \overline{C_P}}$ | $NMSE \leq +0.5$ |
| Geometric Mean Bias (MG) | $MG = \exp\left(\overline{\ln C_O} - \overline{\ln C_P}\right)$ | $0.75 \leq MG \leq 1.25$ |
| Geometric Mean Variance (VG) | $VG = \exp\overline{\left[\ln C_O - \ln C_P\right]^2}$ | $0.75 \leq VG \leq 1.25$ |
| Factor of two (FAC2) | Fraction of data that satisfy $0.5 \leq MG \leq 2.0$ | $FAC2 > 0.80$ |

Table (4) presents descriptive statistic for all missions. The table shows the maximum and minimum values for each parameter in addition to its standard deviation and mean. Also, it shows the total number of samples taken during each field mission.

The relation between reflectance values and measured water parameters can be found by three approaches empirical, analytical, semi analytical. Through this research, the empirical approach will be used; regression analysis will be conducted between different WQPs and reflectance of different bands of MERIS image. The regression analysis will not only be for optical parameters but it will also include the non-optical parameters. Pearson correlation matrix will be calculated to find the effect of optical parameter on others; strong correlation can be an evident that non-optical parameter can be correlated to different bands' reflectance.

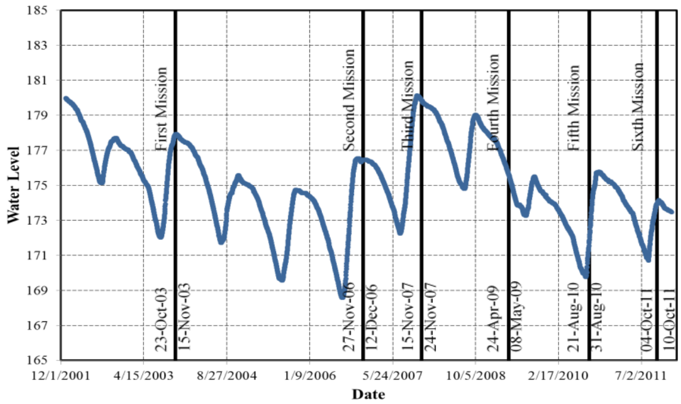



**Figure 2. Survey mission with respect to water level change in period from 2002 to 2011**

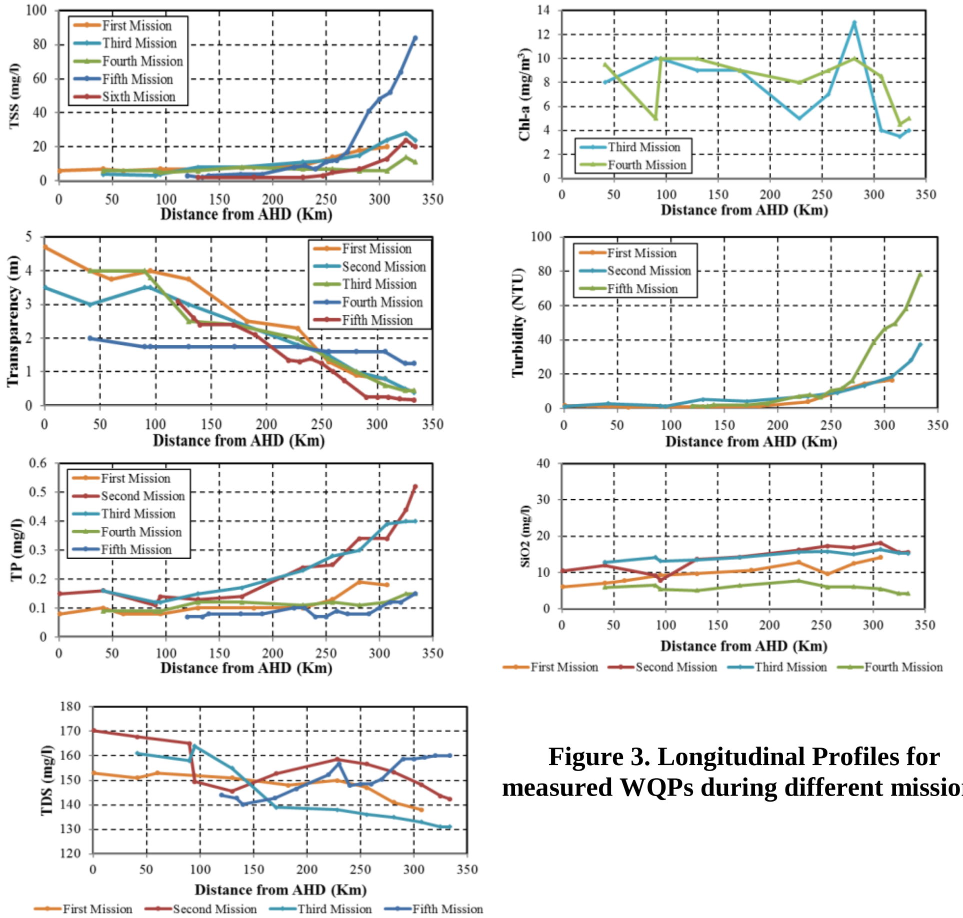



**Figure 3. Longitudinal Profiles for measured WQPs during different missions**

**Table4. Descriptive statistics of measured WQPs**

| | | First Mission | Second Mission | Third Mission | Fourth Mission | Fifth Mission | Sixth Mission |
|---|---|---|---|---|---|---|---|
| TSS (mg/l) | n | 10.00 | 12.00 | 11.00 | 11.00 | 16.00 | 9.00 |
| | Max | 20.00 | - | 28.00 | 14.00 | 84.00 | 24.00 |
| | Min | 6.00 | - | 3.00 | 5.00 | 2.00 | 2.00 |
| | Mean | 10.20 | - | 12.82 | 7.45 | 23.06 | 8.67 |
| | Std Dev. | 5.20 | - | 8.87 | 2.70 | 25.99 | 8.40 |
| Chl-a ($mg/m^3$) | Min | - | - | 13.00 | 10.00 | - | - |
| | Max | - | - | 3.50 | 4.50 | - | - |
| | Mean | - | - | 7.50 | 8.05 | - | - |
| | Std Dev. | - | - | 3.07 | 2.16 | - | - |
| Transparency (m) | Min | 0.80 | 0.40 | 0.45 | 1.25 | 0.17 | - |
| | Max | 4.70 | 3.50 | 4.00 | 2.00 | 3.10 | - |
| | Mean | 2.80 | 2.08 | 2.05 | 1.64 | 1.30 | - |
| | Std Dev. | 1.43 | 1.22 | 1.41 | 0.22 | 0.97 | - |
| Turbidity (NTU) | Min | 0.75 | 1.06 | - | - | 1.35 | - |
| | Max | 16.50 | 37.30 | - | - | 78.40 | - |
| | Mean | 5.13 | 10.77 | - | - | 21.27 | - |
| | Std Dev. | 6.07 | 11.67 | - | - | 24.54 | - |
| TP (mg/l) | Min | 0.08 | 0.11 | 0.12 | 0.09 | 0.07 | - |
| | Max | 0.19 | 0.52 | 0.40 | 0.15 | 0.15 | - |
| | Mean | 0.11 | 0.25 | 0.25 | 0.12 | 0.09 | - |
| | Std Dev. | 0.04 | 0.14 | 0.11 | 0.02 | 0.02 | - |
| $SiO_2$ (mg/l) | Min | 6.10 | 7.90 | 12.80 | 4.20 | - | - |
| | Max | 14.20 | 18.10 | 16.40 | 7.80 | - | - |
| | Mean | 9.97 | 13.93 | 14.67 | 5.74 | - | - |
| | Std Dev. | 2.61 | 3.34 | 1.17 | 1.04 | - | - |
| TDS (mg/l) | Min | 138.0 | 142.35 | 131.00 | - | 140.16 | - |
| | Max | 153.0 | 170.30 | 164.00 | - | 160.00 | - |
| | Mean | 148.4 | 154.48 | 143.73 | - | 151.08 | - |
| | Std Dev. | 5.13 | 9.40 | 12.92 | - | 6.99 | - |

## 5.1 Correlation between measured parameters

The linear correlation (Pearson correlation) between different WQPs is shown in Table (5). The analysis will be shown below, for each water quality parameter, to show its behavior with the change of optical parameters such as TSS and Chl-a. The interpretation of correlation coefficient and to how extent the parameters were linearly correlated will be described using the guidelines suggested by Hinkle et al. (2003) as illustrated in Table (6).

Turbidity is a measure of water clarity and how much the suspended material in water decreases the passage of light through the water. So that, a very strong positive relationship between TSS and Turbidity was found, the correlation factor is 0.994 and 0.999 for First and fifth missions respectively.

Transparency means how deep sunlight penetrates through the water and measured with a Secchi disk. It is also considered as measurement of water clarity as it depends on the amount of particles in the water. These particles can be algae or suspended sediments, the more particles, the less water transparency. So that, transparency has a strong negative correlation with TSS as shown in Table (6), Pearson correlation factor ranging from a minimum value of -0.807 in fifth mission to -0.928 in third mission.

Pearson correlation factor between Total phosphorus (TP) and other WQPs is shown in Table (6), the correlation between TSS and TP is a positive strong to very strong relation for second to fifth mission, it ranges from 0.846 for fourth mission and 0.974 in third mission while first mission indicates correlation factor of 0.696.

Silica ($SiO_2$) indicates a positive correlation with TSS for first, second and third missions as the values of correlation factor are 0.759, 0.576 and 0.748 for the three missions respectively. A different behavior of $SiO_2$ is found during fourth mission, as it gives a negative correlation with TSS with a value of -0.570. According to the indicated values the relation can be described as strong to moderately strong relationship.

Total Dissolved Salts (TDS) is showing, in common, a strong negative correlation with TSS, as indicated in Table (6), for first and third missions while gives a positive correlation for fifth mission. Values of correlation are -0.970, -0.837 and 0.835 for the indicated missions respectively.

The correlation between Chl-a and TSS as indicated in Table (6) is a negative correlation with values -0.687 and -0.733 for both third and fourth missions respectively. While it gives a positive correlation with transparency with correlation not exceeds value of 0.653. TP also gives a negative correlation with Chl-a with values of -0.656 and -0.498. Silica ($SiO_2$) is indicating a different behavior as it gives a negative correlation with Chl-a in third mission with value of -0.571, and a positive correlation is noted in fourth mission with value of 0.335. In general, the correlation between Chl-a can be described as a moderately strong correlation.

According to the previous analysis, it is found that there is a correlation between optical WQPs and other non-optical parameters, so that, the non-optical WQPs can be correlated to remote sensing reflectance calculated from MERIS images.

**Table 5. Pearson correlation matrix**

a- First Mission

| | *TSS* | *Turb.* | *Transp.* | *TP* | *$SiO_2$* | *TDS* |
|---|---|---|---|---|---|---|
| TSS | 1 | - | - | - | - | - |
| Turb. | 0.994 | 1 | - | - | - | - |
| Transp. | -0.917 | -0.889 | 1 | - | - | - |
| TP | 0.696 | 0.696 | -0.737 | 1 | - | - |
| $SiO_2$ | 0.759 | 0.713 | -0.839 | 0.329 | 1 | - |
| TDS | -0.970 | -0.947 | 0.897 | -0.565 | -0.799 | 1 |

b- Second Mission

| | *Turb.* | *Transp.* | *TP* | *$SiO_2$* | *TDS* |
|---|---|---|---|---|---|
| Turb. | 1 | - | - | - | - |
| Transp. | -0.882 | 1 | - | - | - |
| TP | 0.971 | -0.933 | 1 | - | - |
| $SiO_2$ | 0.576 | -0.856 | 0.644 | 1 | - |
| TDS | -0.686 | 0.617 | -0.607 | -0.431 | 1 |

c- Third Mission

| | *TSS* | *Chl-a* | *Transp.* | *TP* | *$SiO_2$* | *TDS* |
|---|---|---|---|---|---|---|
| TSS | 1 | - | - | - | - | - |
| Chl-a | -0.687 | 1 | - | - | - | - |
| Transp. | -0.928 | 0.537 | 1 | - | - | - |
| TP | 0.974 | - | -0.938 | 1 | - | - |

d- Fourth Mission

| | *TSS* | *Chl-a* | *Transp.* | *TP* | *$SiO_2$* |
|---|---|---|---|---|---|
| TSS | 1 | - | - | - | - |
| Chl-a | -0.733 | 1 | - | - | - |
| Transp. | -0.814 | 0.653 | 1 | - | - |
| TP | 0.846 | -0.498 | -0.877 | 1 | - |
| $SiO_2$ | -0.570 | 0.335 | 0.654 | -0.610 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 0.656 | | | | |
| | | - | | | | |
| $SiO_2$ | 0.748 | 0.571 | -0.831 | 0.801 | 1 | - |
| | - | | | - | - | |
| TDS | 0.837 | 0.524 | 0.943 | 0.871 | 0.878 | 1 |

e- Fifth Mission

| | *TSS* | *Transp* | *Turb.* | *TP* | *TDS* |
|---|---|---|---|---|---|
| TSS | 1 | - | - | - | - |
| Transp. | -0.807 | 1 | - | - | - |
| Turb. | 0.999 | -0.819 | 1 | - | - |
| TP | 0.852 | -0.660 | 0.847 | 1 | - |
| TDS | 0.835 | -0.902 | 0.841 | 0.750 | 1 |

**Table 6. Rule of Thumb for Interpreting the Size of a Correlation Coefficient (Hinkle et al., 2003)**

| Size of Correlation (r) | Interpretation |
|---|---|
| 0.90 to 1.00 | Very strong correlation |
| 0.70 to 0.90 | Strong correlation |
| 0.50 to 0.70 | Moderately strong correlation |
| 0.30 to 0.50 | Weak correlation |
| 0.00 to 0.30 | Negligible correlation |

## 5.2 Stepwise regression Model

Simple regression analysis between WQPs, measured during six missions, and remote sensing reflectance calculated from MERIS images will be performed using stepwise regression. Stepwise Regression is a step-by-step iterative process used to construct a regression model (Savari et.al). It is semi-automatic selection process of independent variables carried out in two ways by including independent variables in the regression model one by one at a time if they are statistically significant, or by including all the independent variables initially and then removing them one by one if they prove to be statistically insignificant. Ten MERIS bands will be used in stepwise regression. Results of stepwise regression analysis are shown in Table (7), where R-Squared function and P-value are indicated. Retrieval models for different water quality parameter are grouped by mission, where each parameter has a different retrieval model for each mission.

Retrieval models between TSS and surface reflectance show that TSS can be correlated with different bands, as indicated in Table (7). It is found that TSS can be correlated to reflec_5 for both first and fourth mission. While reflec_6 and reflec_8 can be used to predict TSS for third and fifth missions respectively. For sixth mission, TSS can be obtained by a linear equation between both reflec_1 and reflec_5. The R-squared value is very strong for all TSS retrieval models for all missions except fourth mission; it has a minimum value of 0.881 and maximum value of 0.969. While for fourth mission R-squared value is 0.578, the low value for fourth mission is attributed to conducting this mission during falling period where the influence of TSS is very low.

**Table 7. Retrieval Models for WQPs**

| Mission | Parameter | Retrieval Model | R-Sq | P-value |
|---|---|---|---|---|
| 1st | TDS | 164.488-395.906*reflec_6 | 0.808 | 0.0004 |
| | Transp. | 0.207+436.153*reflect_4-346.301*reflec_5 | 0.889 | 0.00046 |
| | $SiO_2$ | 2.082+225.371*reflec_8 | 0.47 | 0.0287 |
| | Turb. | -0.056+10.066*reflec_4-9.331*reflec_9 | 0.823 | 0.0023 |
| | TSS | -11.412+316.079*reflec_5 | 0.917 | 1.37E-05 |
| 2nd | TDS | 164.505-150.108*reflec_6 | 0.446 | 0.017 |
| | TP | -0.0124+3.275*reflec_5 | 0.878 | 6.89E-06 |
| | $SiO_2$ | 6.542+233.258*reflec_5-155.372*reflec_6 | 0.796 | 0.00077 |
| | Transp. | 2.45+50.634*reflec_2-38.832*reflec_5 | 0.983 | 1.21E-08 |
| | Turb. | 8.189-365.413*reflec_2+334.423*reflec_6 | 0.913 | 1.69E-05 |
| 3rd | Chl-a | 9.81-76.269*reflec_8 | 0.431 | 0.028 |
| | TSS | 1.914+258.003*reflec_6 | 0.969 | 4.57E-08 |
| | TP | -0.019+8.246*reflec_2 | 0.986 | 1.03E-09 |
| | Transp. | 3.297+99.144*reflec_2-71.577*reflec_5 | 0.978 | 2.50E-07 |
| | $SiO_2$ | 11.769+102.322*reflec_4-85.277*reflec_9 | 0.847 | 5.40E-04 |
| | TDS | 154.985+2038.49*reflec_2-1701.5*reflec_4 | 0.923 | 3.52E-05 |
| 4th | TSS | 0.954+120.622*reflec_5 | 0.578 | 0.00666 |
| | $SiO_2$ | 9.295-180.949*reflec_1 | 0.45 | 0.0239 |
| | TP | 0.0321+3.121*reflec_4-1.144*reflec_8 | 0.94 | 1.26E-05 |
| | Transp. | 2.336-35.723*reflec_3+19.756*reflec_10 | 0.893 | 0.000129 |
| 5th | TSS | -33.274+632.144*reflec_8 | 0.881 | 7.32E-08 |
| | TDS | 134.257+176.93*reflec_6 | 0.814 | 1.77E-06 |
| | TP | 0.052+0.437*reflec_8 | 0.55 | 0.0011 |
| | Transp. | 5.409.39.844*reflec_5 | 0.984 | 8.33E-14 |
| | Turb. | -32.166+599.642*reflec_8 | 0.889 | 4.46E-08 |
| 6th | TSS | 4.014-407.597*reflec_1+328.357*reflec_5 | 0.948 | 0.000138 |

Chl-a was measured only twice; in third and fourth missions. The results of stepwise regression show that reflec_8 can be used as a predictor of Chl-a during the third mission, but with low R-squared value (0.431). Stepwise regression is failed to get an equation for fourth mission.

Turbidity was measured in three missions; the retrieval models show that R-squared value is not less than 0.823 which indicate a very good correlation. Also, it shows that turbidity can be correlated to many bands reflectance depending on the season of the mission.

Transparency is considered as a measure of water clarity, so that, its retrieval models for it have a strong R-Squared values ranges from 0.893 to 0.984, it is noted that, retrieval models for different missions indicate that reflec_5 can be used as a predictor for transparency, it can be used alone as in fifth mission or it can be used with other band reflectance such as reflec_4 and reflec_2 for first, second and third missions. Fourth mission indicates a combination of other two bands which are reflec_3 and reflec_10.

Stepwise regression between TP and surface reflectance of different MERIS images bands indicate that reflec_8 is the suitable for TP prediction for both fourth and fifth missions. Where reflec_5 and reflec_2 are suitable for second and third missions respectively. The R-squared value is ranging from 0.55 for fourth mission to 0.986 for third mission.

Silica ($SiO_2$) was measured during four mission. Retrieval model for first mission shows that reflec_8 give R-squared value of 0.47 and fourth mission has R-squared value of 0.45 with reflec_1. This indicates that the relation is not good but still is the best to predict $SiO_2$ concentration during these two missions. While second and third mission were give an R-squared values of 0.796 and 0.847 respectively. Where the retrieval models show that reflec_5 and reflec_6 are used to estimate $SiO_2$ for second mission, while reflec_4 and reflec_9 for third mission. The resulted equation did not show correlation to a common band reflectance.

Retrieval models for TDS indicate that reflec_6 can be used as a predictor for first, second and fifth missions, the R-squared values are 0.808, 0.446 and 0.814 for these missions respectively. While both reflec_2 and reflec_4 can be used during third mission.

The overall conclusion from the previous analysis is that for each mission one can note that there are common bands suitable for predicting both optical and non-optical WQPs for each mission. For example, the retrieval models for both turbidity and transparency for second mission contain reflec_2, reflec_5 and reflec_6, where models of non-optical parameters have best correlation with reflec_5 and reflec_6. The same can be found in other mission like fifth mission.

## 5.3 Validation of retrieval model

Water quality in Lake Nasser varied along the year due to the effect of flood, especially in the southern part which influenced by suspended sediment. Variation in WQPs resulted in different regression models for each water quality parameter depending on the season of measurement, as discussed in the previous sections.

Regression models' validation will be based on selecting a model for each water quality parameter; one per each season. Missions will be categorized into groups depending on season. Each model will be validated using all collected data for the same group; statistical performance measures, such as MNB, NMSE, FB, MG, VG, Fac2 will be used to select the suitable regression model for each season.

Field missions were conducted in three seasons at the start of rising period, at end of flood season, and during the falling period. Figure (2) illustrated the timing of each mission with respect to the change in water level upstream HAD. There are four missions were conducted just after the end of flood season, first three missions and sixth mission. So that, the shared measured parameters will be validated using the proposed method. For other two seasons, it is found that only one mission was conducted per season, hence, it is not possible to validate its regression models. So that, retrieval models for these seasons need to be validated in order to have a graph for time series change for each mission.

Table (8) shows validation results for each retrieval model, different statistical performance measures are calculated for each season. The selection of the suitable retrieval model will be based giving one degree each statistical measure that comply the criteria, shown in Table (3), then divided the summation by the total number of used statistical measures which equal five. Validation process here will account for R-Squared value as additional criteria in selecting the suitable retrieval model. Bold and underlined values mean that it complies with criteria of good model. the highlighted retrieval models in Table (8) represents the best model to be used.

TSS were measured during three aforementioned seasons, during rising and falling seasons it was measured only once while during end of flood period it was measured three times. The statistical performance measures indicate that retrieval model for the third mission, conducted during November 2007, gives good comply with the criteria of good model for both NMSE and FB. Also, it has the greatest value of R-Squared.

Chl-a was measured during two missions, in November 2007 and May 2009, as indicated before, but only one mission, during 2007, gives a correlation with reflec_8, and the R-squared value for this model is 0.431.

Turbidity was measured twice during end of flood season; validation results indicate that regression model for first mission, which conducted in November 2003, is suitable to get turbidity during this season where all statistical performance measures have good comply with the criteria of good model except for VG and has a greater R-squared.

Validation of retrieval models indicate that model of second mission, conducted in 2006, is the suitable model to get transparency during end of flood, all statistical performance measures give values within limits of good model, in addition, its R-squared value is the greater between other missions.

**Table 8. Retrieval Models Validation for end of flood seasons**

| Parameter | Mission | Retrieval Model | R-Sq | MNB | NMSE | FB | MG | VG | Fac 2 |
|---|---|---|---|---|---|---|---|---|---|
| TSS | 1st | -3.954+270.496*reflec_5 | 0.913 | 80.908 | 0.633 | **-0.139** | 0.729 | 1.944 | 0.649 |
| | 3rd | 1.914+258.003*reflec_6 | **0.969** | 111.571 | **0.463** | **-0.235** | 0.596 | 1.958 | 0.702 |
| | 6th | 4.014-407.597*reflec_1+328.357*reflec_5 | 0.948 | -8.031 | 1.383 | **0.325** | 1.494 | 2.809 | 0.632 |
| | 4th | 0.954+120.622*reflec_5 | 0.578 | - | - | - | - | - | - |
| | 5th | -33.274+632.144*reflec_8 | 0.881 | - | - | - | - | - | - |
| Chl-a | 3rd | 9.81-76.269*reflec_8 | 0.431 | - | - | - | - | - | - |
| Turb. | 1st | -11.412+316.079*reflec_5 | **0.917** | 46.585 | **0.242** | **-0.174** | **0.938** | 1.933 | **0.818** |
| | 2nd | 8.189-365.413*reflec_2+334.423*reflec_6 | 0.913 | 65.850 | **0.240** | **0.031** | **0.795** | 1.789 | 0.591 |
| | 5th | -32.166+599.642*reflec_8 | 0.889 | - | - | - | - | - | - |
| Transp. | 1st | 0.207+436.153*reflect_4-346.301*reflec_5 | 0.889 | -238.301 | 5.915 | 1.129 | - | - | 0.500 |
| | 2nd | 2.45+50.634*reflec_2-38.832*reflec_5 | **0.983** | 9.430 | **0.099** | **0.061** | **0.978** | **1.123** | **0.938** |
| | 3rd | 3.297+99.144*reflec_2-71.577*reflec_5 | 0.978 | 35.766 | **0.201** | **-0.279** | **0.845** | 1.352 | **0.844** |
| | 4th | 2.336-35.723*reflec_3+19.756*reflec_10 | 0.893 | - | - | - | - | - | - |
| | 5th | 5.409-39.844*reflec_5 | 0.984 | - | - | - | - | - | - |
| TP | 1st | -0.056+10.066*reflec_4-9.331*reflec_9 | 0.823 | -15.677 | 0.558 | **0.276** | 1.685 | 9.320 | **0.848** |
| | 2nd | -0.0124+3.275*reflec_5 | 0.878 | -0.509 | **0.063** | **0.054** | **1.072** | **1.166** | **0.909** |
| | 3rd | -0.019+8.246*reflec_2 | **0.986** | 107.866 | **0.451** | **-0.482** | 0.564 | 1.901 | 0.576 |

| Parameter | Mission | Retrieval Model | R-Sq | MNB | NMSE | FB | MG | VG | Fac2 |
|---|---|---|---|---|---|---|---|---|---|
| | $4^{th}$ | 0.0321+3.121*reflec_4-1.144*reflec_8 | 0.94 | - | - | - | - | - | - |
| | $5^{th}$ | 0.052+0.437*reflec_8 | 0.55 | - | - | - | - | - | - |
| $SiO_2$ | $1^{st}$ | 2.082+225.371*reflec_8 | 0.47 | -10.776 | **0.264** | **0.136** | 1.288 | 1.474 | 0.758 |
| | $2^{nd}$ | 6.542+233.258*reflec_5-155.372*reflec_6 | 0.796 | 10.719 | **0.038** | **-0.072** | **0.925** | **1.054** | **1.000** |
| | $3^{rd}$ | 11.769+102.322*reflec_4-85.277*reflec_9 | **0.847** | 17.603 | **0.049** | **-0.096** | **0.879** | **1.081** | **0.970** |
| | $4^{th}$ | 9.295-180.949*reflec_1 | 0.45 | - | - | - | - | - | - |
| TDS | $1^{st}$ | 164.488-395.906*reflec_6 | 0.808 | -2.867 | **0.008** | **0.031** | **1.034** | **1.009** | **1.000** |
| | $2^{nd}$ | 164.505-150.108*reflec_6 | 0.446 | 5.687 | **0.006** | **-0.052** | **0.948** | **1.007** | **1.000** |
| | $3^{rd}$ | 154.985+2038.49*reflec_2-1701.5*reflec_4 | **0.923** | 4.901 | **0.013** | **-0.048** | **0.958** | **1.013** | **1.000** |
| | $5^{th}$ | 134.257+176.93*reflec_6 | 0.814 | - | - | - | - | - | - |

Total phosphorus (TP) was validated during end of flood season, the results show that retrieval model of second mission is suitable for estimating TP as all statistical performance measures comply with criteria of good model. Also, Silica ($SiO_2$) validation results show that model of third mission, which conducted in 2007, is suitable to estimate silica during the end of flood.

All statistical performance measures calculated for TDS comply with limits for good model, although model of third mission has the highest R-squared value, but it will be excluded as the other models show a relation with reflec_6 as a common band. So that, the suitable retrieval model for estimating TDS is first mission model.

## 6 CONCLUSIONS AND RECOMMENDATIONS

The Pearson correlation between measured parameters indicates a very good correlation between optical water quality parameters and other non-optical parameters which enables us to estimate different parameters using remote sensing techniques. Different regression models for each water quality parameter depending on the season of measurement. Retrieval models were validated for the end of flood season, as it has more repetitive measurements, to select the best model to estimate each WQP. The analysis and validation results, using statistical performance measures, show that bands (5 and 6) can be used as common predictors for both optical and non-optical water quality parameters. It is recommended to use of the regression models in studying the time series variation of WQPs in different seasons. It is also recommended to use other remote sensing images rather than MERIS to estimate WQPs for Lake Nasser as MERIS is no longer available.

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