# Water Quality Assessment of Lake Burullus, Egypt, utilizing Statistical and GIS Modeling as Environmental Hydrology Applications

**Ahmed Mohsen**
Tanta University
**Bakenaz Zeidan**
Tanta University
**Mohamed Elshemy** ( m.elshemy@f-eng.tanta.edu.eg )
Tanta University

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## Abstract

GIS is a very powerful tool for analyzing huge amount of data and connecting them with the geography, moreover recently there is great advancement in the field. The main objective of this study is to assess the water quality (WQ) and trophic status (TS) conditions of Lake Burullus, Egypt, using statistical modeling (PCA/FA & CA), WQ index (L-WQI) and trophic status index (Carlson TSI & TRIX) approaches, in addition to using GIS tools for building models able to automatically calculate the various indices and producing color coded maps for the lake. The results indicated that PCA/FA grouped the twenty-four WQ parameters into nine principal components explaining 72.6% of the total variance, domestic and agriculture pollution were dominant. CA divided the twelve sampling stations into most and least polluted groups. The lake WQ was classified as a “Very Poor”, according to L-WQI. Moreover, the results of the Carlson TSI and TRIX indices were coincided and classified the eutrophication levels in the lake as “Hyper-Eutrophic” and “Elevated Trophic”, respectively. Based on the results of this study, Lake Burullus needs urgent plans for recovering its WQ. Pre-treatment for its drains effluents and implementing of a periodical WQ monitoring program are highly recommended.


## 1. Introduction

Water quality (WQ) assessment of water bodies has become one of the crucial processes in environmental hydrology applications. Most of the water bodies around the world are suffering from a several water quality problems, due to the harmfully impacts of population growth and the anthropogenic activities. Lake Burullus is one of the contaminated water bodies, due to discharging of large quantities of drained water from eight agriculture drains into the lake, in addition to the reclamation activities for agriculture and aquaculture. WQ assessment methods can be divided into four main approaches; statistical analysis of WQ data, WQ Index (WQI), Trophic Status Index (TSI) and Biological analysis (M. Elshemy, 2010). There are a numerous of studies, which used one or more of the previous approaches, in order to assess the WQ conditions of studied water resources (Bhat, Meraj, Yaseen, & Pandit, 2014; Bora & Goswami, 2016; Burns, McIntosh, & Scholes, 2005; Chen, Niu, & Zhang, 2013; Devi Prasad, 2012; M. M. Elshemy, 2010; Gu et al., 2016; Jiang-Qi, Qing-Jing, Pan, Cheng-Xia, & Mu, 2013; Kazi et al., 2009; Khan, Tobin, Paterson, Khan, & Warren, 2005; Li et al., 2007; Lumb, Halliwell, & Sharma, 2006; Ozbay & Yerel, 2009; Ray, Bari, & Shuvro, 2011; Salah, Turki, & Al-Othman, 2012; Shrestha & Kazama, 2007; Taner, Üstün, & Erdinçler, 2011; Tokatlıa, Köse, Emiroğlu, & Çiçek, 2014; Vargas-González et al., 2014; Varnosfaderany, Mirghaffary, Ebrahimi, & Soffianian, 2009; Vijayakumar, Gurugnanam, Nirmaladevi, & Panchamin, 2015; Wills & Irvine, 1996; Xing, Guo, Sun, & Huang, 2005; Zhao, Xia, Yang, & Wang, 2012).

Statistical assessment approach aims to better understand and interpret WQ data matrices, which result from in-situ measurements. Statistical assessment can interpret the data by summarizing it using descriptive statistics to find the relationship between the various WQ parameters or detect similarities among samples and/or variables. Statistical approach includes many methods, such as Correlation Analysis, Principal Component Analysis (PCA), Factor Analysis (FA), the Cluster Analysis (CA) and Discriminate Analysis (DA) (Alkarkhi, Ahmad, Ismail, mat Easa, & Omar, 2009). The multivariate statistical techniques are promising techniques for WQ assessment. Application of such techniques for analyzing environmental data has increased tremendously in recent years (Alkarkhi et al., 2009). These techniques are useful tools for interpreting a complicated WQ data matrix (Mazlum, ÖZER, & MAZLUM, 1999). These techniques can be used to identify the sources of pollution affecting the water bodies and produce a rapid solutions for such environmental problems (Reghunath, Murthy, & Raghavan, 2002). Zhao et al. (2012) assessed the WQ conditions of Baiyangdian Lake (China), using PCA and CA techniques. The spatiotemporal variation of WQ of Euphrates River (Iraq) was assessed using CA technique  (Salah et al., 2012).

WQI is a useful tool, as it can represent the overall WQ conditions in a single term (Tyagi, Sharma, Singh, & Dobhal, 2013). WQI approach was first invented by Horton (1965), by selecting nine of the most regularly used WQ parameters (Temperature change, BOD, DO, coliforms…etc.) to produce his index. In 1970 Brown et al. produced a new WQI (National sanitation foundation WQI, or NSF-WQI), similar to Horton WQI, based on the weights of nine WQ parameters. Many other indices were produced after the NSF-WQI, such as: the Oregon WQI (OWQI) (Dunnette, 1979), the Bascarón Adapted WQI (WQIBA) (Martínez de Bascaran, 1979), the Canadian Council of WQI (CCME WQI) (Saffran, Cash, Hallard, Neary, & Wright, 2001) and the Lagoon WQI (L-WQI) (Taner et al., 2011). The Lagoon WQI (L-WQI) was developed by Taner et al. (2011). This index is specialized for WQ assessment of lagoons, due to their particular ecological, morphological and hydrodynamic characteristics. This index was used to assess the water quality condition of the Kücükcekmece Lagoon in Turkey, and to validate the index and the results showed a high correlation between this parameter and the observed WQ trends in the lagoon. The WQ status of Lake Manzala was assessed using the L-WQI and the NSF-WQI (M. Elshemy, 2016). The author recommended also using the L-WQI rather than the NSF-WQI in lagoons, due to its accurate assessment.

The trophic state is defined as the total weight of biomass in a given water body at the time of measurement (Carlson, 1977). TSI is one of the indirect WQ assessment approaches, which can characterize the health of lakes by using the nutrient concentration, or other parameters which are affected by the nutrient concentration, such as the chlorophyll-a or Secchi depth transparency. The relationship between nutrient concentrations and algal biomass, is the basis for many commonly used eutrophication models (Brown, Hoyer, Bachmann, & Canfield Jr, 2000). TSI approach can be used to compare the lakes according to their level of biological activity on a scale from 0 to 100 (Carlson, 1977). There are many TSI indices that developed in the literature, such as the National Eutrophication Survey index (EPA, 1974), the Loading Plots index (R. A. Vollenweider, 1976), Carlson TSI  (Carlson, 1977), the Trophic State Classification Probabilities index and the OECD Fixed Boundary System index (R. Vollenweider & Kerekes, 1982), the U.S. Environmental Protection Agency index (EPA, 1988), and the TRIX index (R. Vollenweider, Giovanardi, Montanari, & Rinaldi, 1998). In 2011 Jarosiewicz et al. examined the trophic state of eight selected lakes in the north of Poland, using the Carlson TSI (Jarosiewicz, Ficek, & Zapadka, 2011) . In 2012 Prasad assessed the trophic status of two lakes in Mandya district in India, using Carlson TSI (Devi Prasad, 2012). Salas et al. (2008) evaluated the eutrophication condition of Mar Menor coastal lagoon (southeast Spain) and the Mondego estuary (northwest Portugal), using TRIX index (Salas, Teixeira, Marcos, Marques, & Pérez-Ruzafa, 2008).

Geographic Information System (GIS) is a powerful tool that is frequently being used in assessment studies. Interpolation technique aims to predict a surface value at any un-sampled point using the surrounding sampling stations. GIS applications include many interpolation techniques, such as the Inverse Distance Weighted (IDW) technique, the Spline technique and the Kriging technique. On the other hand, model builder tool in the GIS systems is a visual programming language for building geo-processing workflows. The geo-processing models automate and document spatial analysis and data management processes. Model builder tool is a very helpful and powerful tool, whereas it can save time and efforts, which may be lost in the routine processes.

Recently WQ and Trophic Status of Lake Burullus was discussed in several studies as summarized in Table1 (A Elsayed, A Okbah, M El-Syed, A Eissa, & E Goher, 2019; AbdEl-Hamid, Hegazy, Ibrahim, & Khalid, 2017; Alprol et al., 2021; El-Alfy, Darwish, Basiony, & Elnaggar, 2021; Hasan, 2021; Masoud, El-Horiny, Khairy, & El-Sheekh, 2021). As can be seen, Carlson TSI was frequently used to evaluate the lake TS, which was classified as a ”hyper-eutrophic”, except for the lake regions close to the lake outlet. TRIX was only used in two studies, and the TS was ranked as “high – trophic“ level. For WQ, WQI approach was not frequently applied for the lake, except for limited studies, where AWQI (Tiwari & Manzoor, 1988) was applied to evaluate the lake WQ. GIS technique was used for mapping some of the studies’ results.

This study aims to assess the WQ and TS of Lake Burullus for about 4 years (from February 2010 to August 2013), annually and seasonally. Based on the previous literature, Lagoon WQI (L-WQI) will be used for the first time to assess the WQ conditions of the lake. L-WQI is designed particularly for lagoons WQ evaluating and was not previously used for this lake. Moreover, Carlson TSI and TRIX will be used to investigate the lake TS. Statistical assessment approaches (PCA/FA and CA) will be applied to identify the main pollution sources which affect the lake WQ conditions. Referring to all WQ GIS studies for the Egyptian lakes, GIS modelling will be utilized, for the first time, to facilitate the calculation process of WQI and TSIs indices and automate their process starting from WQ &TS data entering to maps exporting. This GIS modeling will facilitate the calculation and export processes of WQI and TSIs indices.

## 2. Materials And Methods

WQ conditions of Lake Burullus was assessed during the period from August 2010 to August 2013, using the statistical, WQI and TSI approaches. Statistical approach includes PCA/FA and CA, which were applied to classify the WQ parameters (WQPs), according to their similarities and dissimilarities, and to define the sources of pollution. All calculations of PCA/FA and CA had done by SPSS V20 software (IBM SPSS). The L-WQI was used to evaluate the lake water quality during the study period, moreover, Carlson and TRIX TSIs were also used to evaluate the lake WQ during the study period indirectly through assessing the trophic conditions of the lake. ARCGIS 10.1 software (ESRI) was used to develop WQI and TSI models. Fig.1 shows the general schema of the methodology for WQ assessment of Lake Burullus.

### 2.1 STUDY AREA

Lake Burullus is one of the most important Egyptian lagoons, it is the second largest lagoon after Lake Manzala. Lake Burullus is located at the shores of the Mediterranean Sea, between the two branches of the Nile River, between longitudes 30°31$E \text{ and } 31^\circ05$E and latitudes 31°25$N \text{ and } 31^\circ35$N, Fig.2. the approximated length and width of the lake are 53 km and 13 km, respectively (Frihy & Dewidar, 1993). The area of the lake was declined by about 50% between 1972 and 2015, as it was estimated with 434.6 $Km^2$ in 1972 and 222.0 $Km^2$ in 2015 (Mohsen, Elshemy, & Zeidan, 2018). The average depth of the lake is about 1.0 m; thus, it is considered as a shallow lake. The main link between the lake and the Mediterranean Sea is the so called “Boughaz El-Burullus”, which is considered as the source of life for the lake, as it participates in renewing the ecosystem of the lake. The lake was added to RAMSER sites in 1998 and is considered as a protected area. The pollution main sources in the lake are the eight drains at the southern part of the lake, which are discharging a substantial amount of untreated wastewater on a daily bases, in addition to reclamation activities for aquaculture and agriculture. Okbah and Hussein (2006) reported that the lake receives around 175 M $m^3$ of wastewater per month for the agriculture drains throughout the year. The lake receives also freshwater form Rosetta branch through “Brimbal” canal, however it has very slight impact in enhancing the WQ conditions in the lake, due to low discharges. Besides the WQ problems of the lake it is also suffering from the removal of large quantities of sand from the dunes at the north part of the lake, and the illegal fishing practices including fry catching near the Boughaz. Therefore, the lake needs an urgent management program, in order to prevent the continuous infringements and to protect the lake.

## 2.2 COLLECTED DATA

Water samples were collected from 12 sampling stations by the Egyptian Environmental Affairs Agency (EEAA) and the National Institute of Oceanography and Fisheries (NIOF) (EEAA), every 3 months between February 2010 and August 2013, as a part of the regular monitoring program of the Egyptian costal lakes. The samples were analyzed, and 24 water quality parameters were measured. Fig.2 and Table2 show the sampling locations and the descriptive statistics of the 24 parameters respectively, furthermore TableS1 shows the name and the coordinates of the 12 stations, in addition to the sampling frequency.

## 2.3 STATISTICAL ASSESSMENT

PCA/FA is one of the multivariate statistical approaches, which are used to interpret the large and complex data obtained during the monitoring of WQ for the various water bodies. PCA/FA can reduce the dimensionality of the original data by converting the correlated variable into new uncorrelated factors or components, without losing much information. The principal components are ordered so that the first few components explain the most of variations in the original variables (Mazlum et al., 1999).

The large data matrix of the WQ parameters for Lake Burullus, which is resulting from the field measurement of twenty-four parameters at twelve sampling stations for thirteen campaigns cover the period from February 2010 to August 2013, were interpreted by PCA/FA. The principal components were computed and rotated by varimax technique using SPSS V20 software (IBM SPSS).

CA is used to classify the monitoring stations of WQ according to their similarities and dissimilarities, which leads to reduce the number of stations and development of the sampling strategies. CA aims to collect the similar sampling stations into one group; this similarity can be measured by the distances (metrics) between the sampling locations.

The considered twelve sampling stations of the study area, from February 2010 to August 2013, were classified into groups using the HCA approach. The Euclidean distance and ward`s agglomerative algorithms were used to obtain the dendrograms. All the statistical calculations of the cluster analysis were calculated by SPSS V20 software (IBM SPSS).

## 2.4 WQI APPROACH

L-WQI was used in this study to assess the WQ conditions of Lake Burullus. The main purpose of this index is to evaluate the state of the aquatic biota of the lagoons such as eutrophication and decreases in oxygen levels which resulting from the organic pollution, by the anthropogenic activities. The index can be calculated based on the following parameters; Dissolved Oxygen (DO saturation as ratio), Temperature (T C°), salinity (ppt), Total Nitrogen to Total Phosphorus ratio (TN:TP), Orthophosphate (O-$PO_4$ mg/L), nitrate ($NO_3$ mg/L), chlorophyll-a (Chl-a µg/L), Chemical Oxygen Demand (COD mg/L), pH, turbidity (NTU) and electrical conductivity (EC mS/cm). Taner et al. (2011) Produced a new normalization curve for every L-WQI parameter, based on the international standards and previously developed indices. The index can be calculated as a weighted summation of the variables sub-indices, as shown in (Taner et al., 2011). The WQ of the lake can be classified into four categories: Excellent, Good, Critical and Very Poor, according to the L-WQI value as shown in TableS2.

## 2.5 TSI APPROACH

The trophic status of a water body is defined as the total weight of biomass in it at the sampling time. Carlson TSI can be calculated by any one of three specific parameters (chlorophyll-a, Secchi depth and total phosphorus), as changes in nutrient levels in lakes cause changes in algal biomass which, in turn, cause changes in lake clarity (Elshemy, 2010). Carlson TSI can be calculated using three equations, or the average of them as recommended by Pavluk et al. (2008).

In this study, Carlson TSI was calculated using two parameters Chl-a and TP. The eutrophication conditions of the water bodies can be classified as “Oligotrophic”, “Mesotrophic”, “Eutrophic” or “Hypereutrophic”, according to the Carlson TSI value, as shown in TableS2.

TRIX index is a linear combination of four state variables representing the primary productivity (chlorophyll-a, oxygen saturation rate, dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations). This index can be calculated as shown in (R. Vollenweider et al., 1998).

The eutrophication and water quality conditions of the water bodies can be classified into four groups, according to the TRIX index, where The TRIX index was scaled from 0 to 10 (TableS2.).

### 2.6 GIS MODELING

“Model Builder” tool in ARCGIS 10.1 software (ESRI) was used to build a model for the three previous indices (L-WQI, Carlson TSI and TRIX), using Python programming language. Such models can be used to calculate the indices values for the various stations in the water body, in addition to using the IDW interpolation method to produce maps for the indices. The developed models were applied to assess the WQ and eutrophication status of Lake Burullus for the study period (February 2010 – August 2013) annually and seasonally. Fig.S1 shows the flow chart of the Carlson TSI model as can be seen in ARCGIS 10.1, as an example for the modelling process. It can be noticed that the main used tool is the “calculate filed” tool, which is depending on the python language and IDW tool, which used to interpolate the data and produce color coded maps.

# 3. Results And Discussion

### 3.1 STATISTICAL ASSESSMENT

PCA/FA divided the twenty-four WQ parameters into nine components explains 72.6% of the total variance, based on the correlation matrix. Chatfield et al (1980) reported that components with an eigenvalue of less than 1, should be eliminated. The first nine components have eigenvalues greater than 1. Fig.S2 shows the scree plot of the eigenvalues of the observed components. The factor loading, TableS3, can be classified into three categories (strong, medium and weak), according to their value; > 0.75: strong, between 0.5 and 0.75: medium, between 0.3 and 0.5: weak (Liu, Lin, & Kuo, 2003). The principal components were summarized in the Table3.

PC1 includes the nutrient parameters (N and P), which is considered as an indicator of domestic and/or agriculture pollution in the lake, due to the presence of the agricultural drains in the southern periphery of the lake. The lake outlet “Boughaz Burullus” is considered as the source of the PC2 which has a strong correlation with EC and salinity. PC3 describes the trophic state of the lake which affected by the drained wastewater from the eight drains and it badly affect the dissolved oxygen and pH, whereas this component has a medium correlation with Chl-a, pH and DO. The PC4, PC5, PC7 and PC9 which includes Cu, Cr, Ni and Zn represent the pollution by heavy metal, due to the presence of the point and non-point source pollutions. PC6 which have a medium correlation with $NO_2$, $NO_3$ and COD indicates the depletion of oxygen by the organic and inorganic substances from industrial or agriculture wastes from the drains, while PC8 which includes BOD indicates the depletion of oxygen by biodegradability of organic matters from domestic wastewater from the drains. PCA/FA demonstrated its utility as a perfect tool to classify the large number of WQ.

CA classified the twelve sampling stations entire the lake, according to their similarities and dissimilarities (based on the Euclidean distance), into two main groups. The first one includes S1, S4, S6, S7 and S11, while the second group includes S2, S3, S5, S8, S9, S10 and S12. Fig.S3 shows the dendrogram of the twelve sampling stations which resulting from hierarchical cluster analysis (Ward's method), and Fig.S4 shows the spatial distribution of the two groups.

The first group can be characterized as the most polluted group, where it includes the stations near to the drains' effluents. While the other group can be characterized as the least polluted group, whereas the stations are far from the sources of pollution. The stations S2 and S3 are located near to Boughaz Burullus, the stations S5, S8 and S9 are located in the middle part of the lake and the stations S10 and S12 are located near to Brimbal canal outlet.

The classification of the stations into groups using CA can be used for developing the future sampling planning of the lake. CA is an effective tool in offering a reliable classification of the sampling stations and identifying the sources of pollution.

### 3.2 WQI APPROACH

L-WQI results showed that the lake WQ status for the years of 2010, 2011, 2012 and 2013 is “Very Poor”, as shown in Fig.3, which shows the annual spatial distribution of the index all over the lake for 2010, 2011, 2012 and 2013. It can be noticed that the L-WQI ranges are 10.7 - 22.9, 12.4 - 21.5, 11.1 - 18.6 and 12.2 - 18.6 for the years of 2010, 2011, 2012 and 2013, respectively. According to TableS2, the WQ status of the lake can be classified as a “Very Poor” for the four years. Fig.S5 shows also the seasonal spatial distribution of the index inside the lake, during the study period (2010 – 2013). Fig.4 shows the average annual (a) and seasonal (b) values of the index for the four years. It can be also noticed that all the average values are ranging from 0 to 25, which can be classified as a “Very Poor” WQ.

The WQI results of this study agree with the study of AbdEl-Hamid et al. (2017). However, the WQ study results are completely in contrary to the results of Alprol et al. (2021); as the authors did not consider BOD or fecal coliform variables when applying the used AWQI, which is designed for Indian rivers (Tiwari & Manzoor, 1988). Although the authors reported that the lake receives untreated domestic and sewage water, biological indicators (such as BOD or fecal coliform) were not considered for WQ assessment. Moreover, the TRIX results of the referred study showed the “Bad WQ” conditions of the lake.

### 3.3 TSI APPROACH

Carlson TSI was applied to evaluate the WQ status of Lake Burullus for the period from 2010 to 2013, annually and seasonally, indirectly by evaluating the trophic conditions of the lake, using the developed Carlson TSI model. The results showed that the trophic status of the lake can be classified as “Hyper-Eutrophic” for the period under consideration. Fig.5 shows the spatial annual distribution of the index all over the lake for the considered period. It can be noticed that the minimum values of the index inside the lake were 70.97, 73.91, 78.00 and 73.75 in the years of 2010, 2011, 2012 and 2013, respectively. All these values were greater than 70 which can be classified as “Hyper-Eutrophic” for the four years according to TableS2.

Fig.S6 shows the spatial seasonal distribution of the index inside the lake during the study period (2010 - 2013). It can be also noticed that the minimum values of the index inside the lake were greater than 70; 70.95, 70.95, 71.10 and 71.64 for the seasons of winter, spring, summer and fall, respectively, which can be classified also as “Hyper-Eutrophic”. Fig.4 shows the average annual (a) and seasonal (b) Carlson TSI for the considered period. All the average values of the index, whether for the four years or seasons are greater than 70, which classified as “Hyper-eutrophic”.

TRIX index was also used to evaluate the TS status of Lake Burullus for the period from 2010 to 2013 annually and seasonally, indirectly by evaluating the TS of the lake, using the developed TRIX model. The results showed that the TS of the lake can be classified as “Elevated Trophic” for the period under consideration. Fig.5 shows the annual spatial distribution of the index inside the lake. It can be noticed that the index ranges from 7.84 to 9.66 in 2010, from 7.80 to 9.50 in 2011, from 7.91 to 9.74 in 2012 and from 7.07 to 9.73 in 2013. All values of the index are ranging from 6 to 10 which can be classified as “Elevated Trophic” according to TableS2. Fig.S7 shows the spatial seasonal distribution of the index all over the lake during the study period (2010 – 2013). It can be also noticed that the index ranges from 8.05 to 10 in winter, from 7.28 to 9.37 in spring, from 7.52 to 8.84 in summer and from 7.43 to 9.31 in fall. The trophic state of the index can be classified as “Elevated Trophic” for the four seasons. Fig.4 shows the annual (a) and seasonal (b) averages of the TRIX index for the study period. All the average values of the index, whether for the four years or seasons are ranging from 6 to 10, which are classified as “Elevated Trophic”. The TS study results are consistent with the previous studies’ results (A Elsayed et al., 2019; AbdEl-Hamid et al., 2017; Alprol et al., 2021; El-Alfy et al., 2021; Hasan, 2021; Masoud et al., 2021) which indicated the hyper-eutrophic conditions of the lake.

# 4. Conclusions And Recommendations

Lake Burullus WQ conditions were assessed using three different assessment approaches: 1) Statistical assessment 2) WQI and 3) TSI. GIS technique was used to build a model for the different indices (L-WQI, Carlson TSI and TRIX) to automatically facilitate its calculations and generate color-coded maps for the lake. The following points are summarizing the main findings of this study:

1. PCA/FA reduced and grouped the twenty-four WQPs into nine principal components which explain about 72.6% of the total variance. Each principal component refers to a specific source of pollution.
2. PCA/FA defined and grouped the sources of pollution in Lake Burullus into three main sources; the first group includes the domestic and/or agriculture pollution in the lake due to the effluents of the agricultural drains and the agriculture and aquaculture activities in the southern periphery of the lake. The second group has a strong correlation with EC and salinity, which refers to water exchange with the sea by the lake outlet “Boughaz Burullus”. While, the third group refers to the pollution by heavy metals, due to the presence of the point and non-point sources of pollutions.
3. CA divided the twelve sampling stations into most and least polluted groups. The most polluted group includes the stations which are located near to the drains’ outlets. While the least polluted

group includes the stations which are near to Boughaz Burullus, middle part of the lake and Brimbal canal.

4. The lake WQ status was classified as a “Very Poor” for the study period (2010-2013), according to L-WQI.
5. The results of the Carlson TSI and TRIX indices were coincided, as Carlson TSI classified the eutrophication condition of the lake as a “Hyper-Eutrophic” and TRIX index classified it as an “Elevated Trophic”.

GIS technique is a very helpful and powerful tool for developing WQI models, which can be easily and effectively used for water quality assessment. All used indices to evaluate the WQ and TS conditions of Lake Burullus in this study agreed and confirmed the critical situation of the lake which needs urgent actions to protect the lake. The priority recommendation for enhancing the lake WQ is the pre-treatment of the effluent drains’ discharges which convey industrial, untreated domestic wastewater, in addition to agricultural drainage water. Other recommended actions, such as periodical WQ monitoring program for the lake network should be considered.

# Declarations

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**Authors’ contributions** Ahmed Mohsen developed the considered modeling tools and wrote the initial draft of the manuscript. Mohamed Elshemy obtained the field data from EEAA; moreover, he reviewed the initial draft of the manuscript. The major role of Bakenaz Zeidan was conceptualization, in addition to reviewing the manuscript. All authors read and approved the final manuscript.

**Conflicts of interest/Competing interests** (The authors state that there is no conflict of interest)

**Availability of data and material** (Data are available from the authors with the permission of Tanta University)

**Code availability** (MIKE11 Code (2012) is licensed to the corresponding author by DHI for a single use only)

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# Tables

**Table 1. Recent Lake Burullus previous studies.**

| NO. | Study | WQI | TSI | Findings |
|---|---|---|---|---|
| **1** | (AbdEl-Hamid et al. 2017) | AWQI | Carlson TSI | • Very Bad WQ<br>• Eutrophic to Hyper-eutrophic |
| **2** | (A Elsayed et al. 2019) | - | Carlson TSI | • Hyper-eutrophic |
| **3** | (Alprol et al. 2021) | AWQI | Carlson TSI<br>TRIX | • Good WQ for drinking (WHO standards)<br>• Hyper-eutrophic & High Trophic level |
| **4** | (El-Alfy et al. 2021) | - | Statistical TSI | • Oligo-trophic to Hyper-eutrophic (Mach 2020)<br>• Hyper-eutrophic (June 2020) |
| **5** | (Hasan 2021) | - | Carlson TSI | • Hyper-eutrophic |
| **6** | (Masoud et al. 2021) | - | TRIX | • Very High Trophic level |

**Table 2. Descriptive statistics for the WQ records of Lake Burullus during the study period (February 2010-August 2013).**

| *Parameter* | *Unit* | *Mean* | *Median* | *Mode* | *SD* | *Minimum* | *Maximum* |
|---|---|---|---|---|---|---|---|
| *Temperature* | C° | 23.11 | 24.73 | 26.00 | 4.38 | 14.30 | 29.20 |
| *EC* | mS/cm | 7.55 | 4.20 | 1.21 | 10.26 | 0.83 | 58.08 |
| *Salinity* | g/l | 4.43 | 2.29 | 1.79 | 6.71 | 0.41 | 38.13 |
| *pH* | | 8.46 | 8.42 | 8.77 | 0.42 | 7.48 | 9.71 |
| *DO* | mg/l | 8.43 | 7.94 | 7.86 | 4.06 | 0.92 | 12,15 |
| *BOD* | mg/l | 15.24 | 12.14 | 6.95 | 10.76 | 0.42 | 72.90 |
| *COD* | mg/l | 124.60 | 97.55 | 96.00 | 94.65 | 0.00 | 531.30 |
| *ChL-a* | μg/l | 66.47 | 56.09 | 25.72 | 51.30 | 3.09 | 355.97 |
| *TSS* | mg/l | 104.65 | 78.87 | 43.20 | 97.79 | 18.15 | 675.30 |
| $NH_4$ | mg/l | 0.853 | 0.44 | 0.05 | 1.28 | 0.01 | 2.50 |
| $NO_2$ | μg/l | 74.31 | 14.94 | 3.88 | 116.61 | 0.53 | 655.77 |
| $NO_3$ | mg/l | 0.277 | 0.115 | 0.06 | 0.44 | 0.01 | 3.09 |
| *TN* | mg/l | 4.95 | 4.62 | 2.96 | 2.38 | 0.79 | 12.86 |
| $PO_4$ | μg/l | 176.93 | 98.92 | 18.62 | 214.83 | 0.71 | 1117.12 |
| *TP* | μg/l | 476.97 | 367.31 | 216.25 | 329.35 | 87.20 | 1572.42 |
| $SiO_4$ | mg/l | 3.85 | 2.93 | 1.92 | 3.74 | 0.11 | 28.31 |
| *Fe* | μg/l | 175.62 | 162.32 | 73.77 | 85.10 | 28.74 | 471.05 |
| *Mn* | μg/l | 29.98 | 23.20 | 3.54 | 21.62 | 3.54 | 99.91 |
| *Cu* | μg/l | 20.88 | 16.23 | 3.61 | 17.85 | 0.91 | 106.30 |
| *Zn* | μg/l | 130.84 | 86.84 | 34.50 | 110.23 | 14.42 | 594.26 |
| *Cr* | μg/l | 6.69 | 6.63 | 3.50 | 2.13 | 2.98 | 14.83 |
| *Ni* | μg/l | 7.89 | 7.45 | 4.98 | 3.18 | 0.74 | 22.14 |
| *Cd* | μg/l | 1.91 | 1.455 | 0.24 | 1.57 | 0.1 | 8.51 |
| *Pb* | μg/l | 36.68 | 36.11 | 24.21 | 13.45 | 8.76 | 87.07 |

**Table 3. The Eigenvalues, % of variance and % cumulative of variance of the first nine components after rotation.**

| *Component* | *Eigenvalues* | *% of Variance* | *Cumulative %* | *Strong Correlation* | *Medium Correlation* |
|---|---|---|---|---|---|
| 1 | 3.397 | 14.153 | 14.153 | $NH_4$, $PO_4$ and TP | TN |
| 2 | 2.377 | 9.906 | 24.059 | EC and salinity | TSS |
| 3 | 2.008 | 8.367 | 32.426 | - | pH, DO and Chl-a |
| 4 | 1.816 | 7.568 | 39.994 | Cu and Cr | - |
| 5 | 1.764 | 7.351 | 47.345 | Ni | Pb |
| 6 | 1.751 | 7.297 | 54.641 | - | $NO_2$, $NO_3$ and COD |
| 7 | 1.724 | 7.185 | 61.827 | Zn | Mn and Cd |
| 8 | 1.362 | 5.673 | 67.500 | BOD | - |
| 9 | 1.220 | 5.083 | 72.583 | Si | - |

# Figures

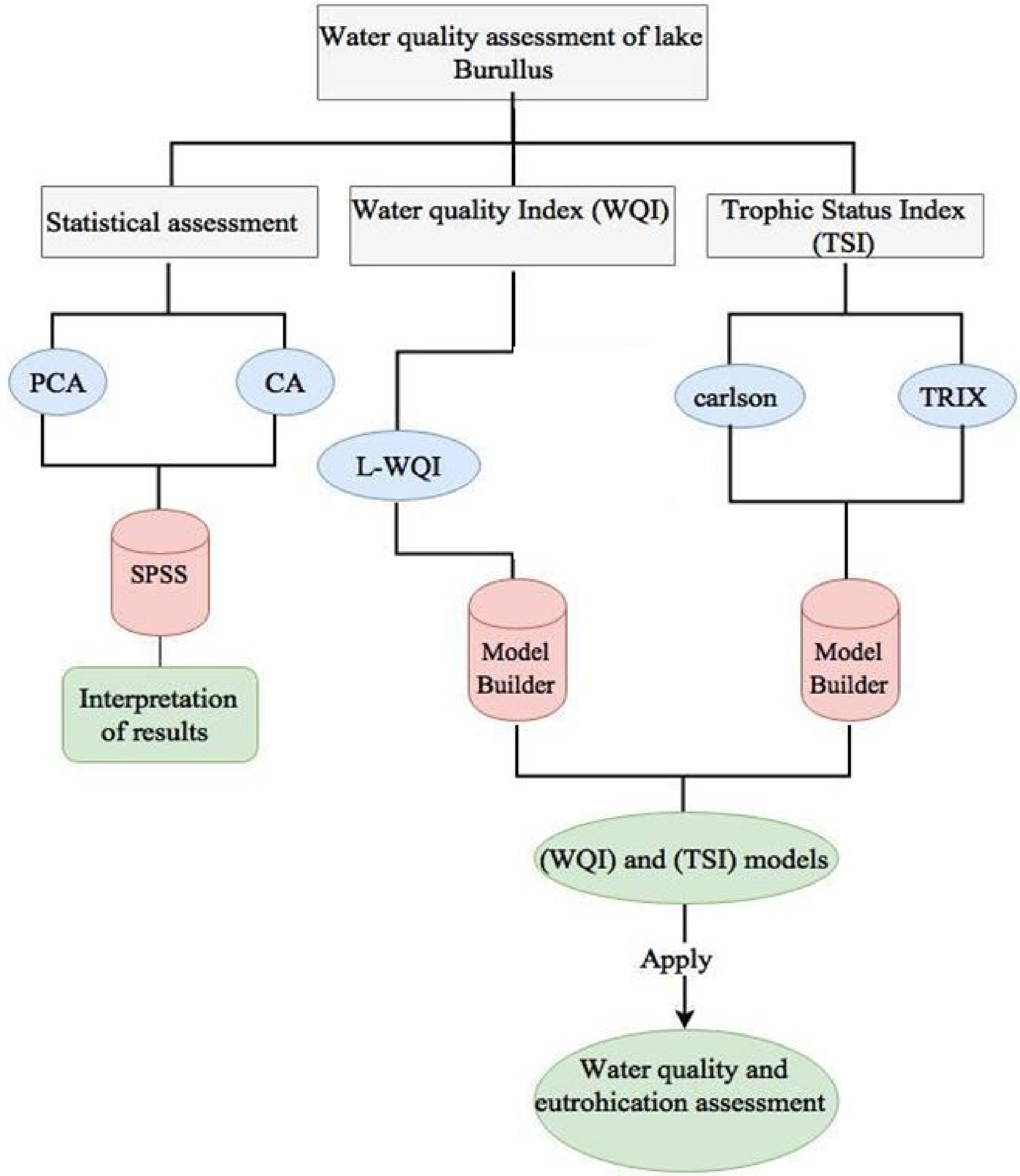
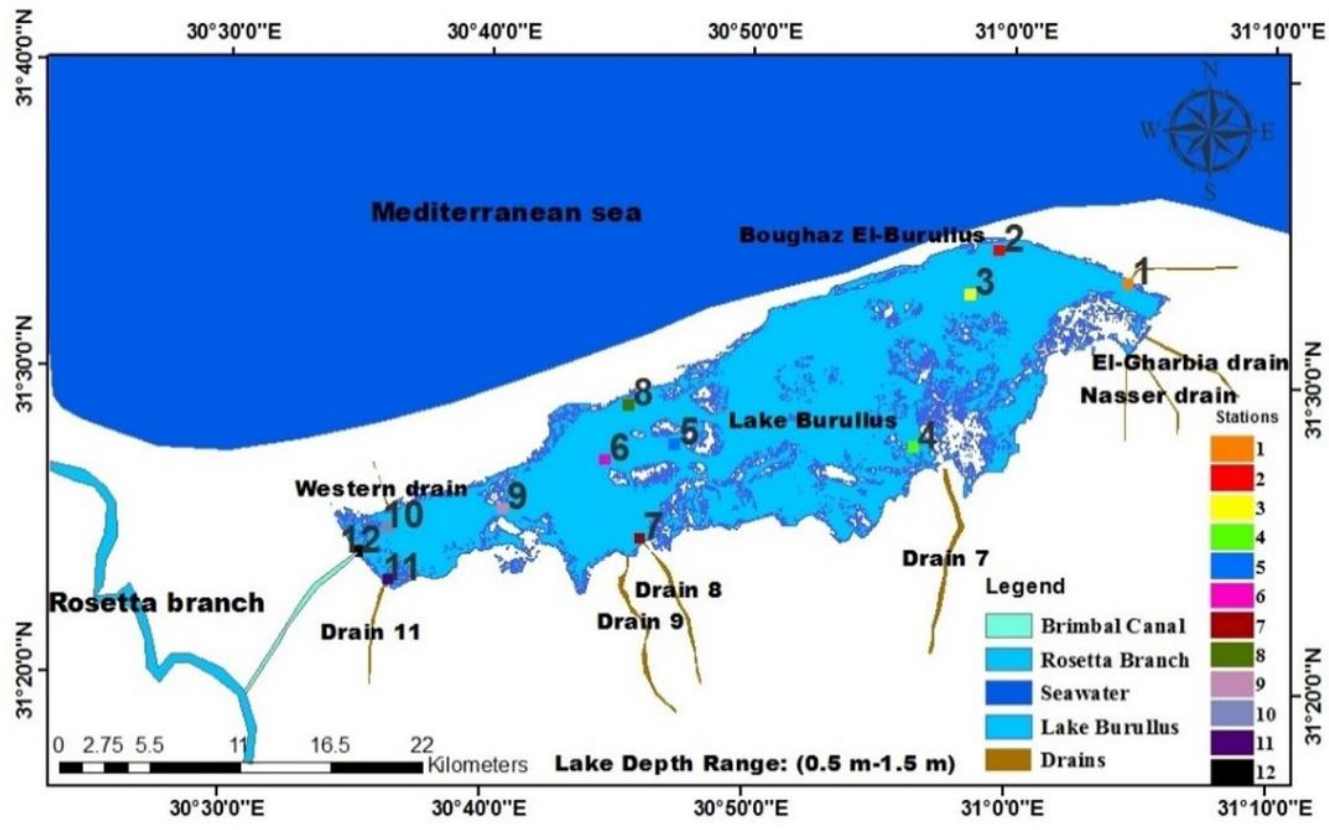


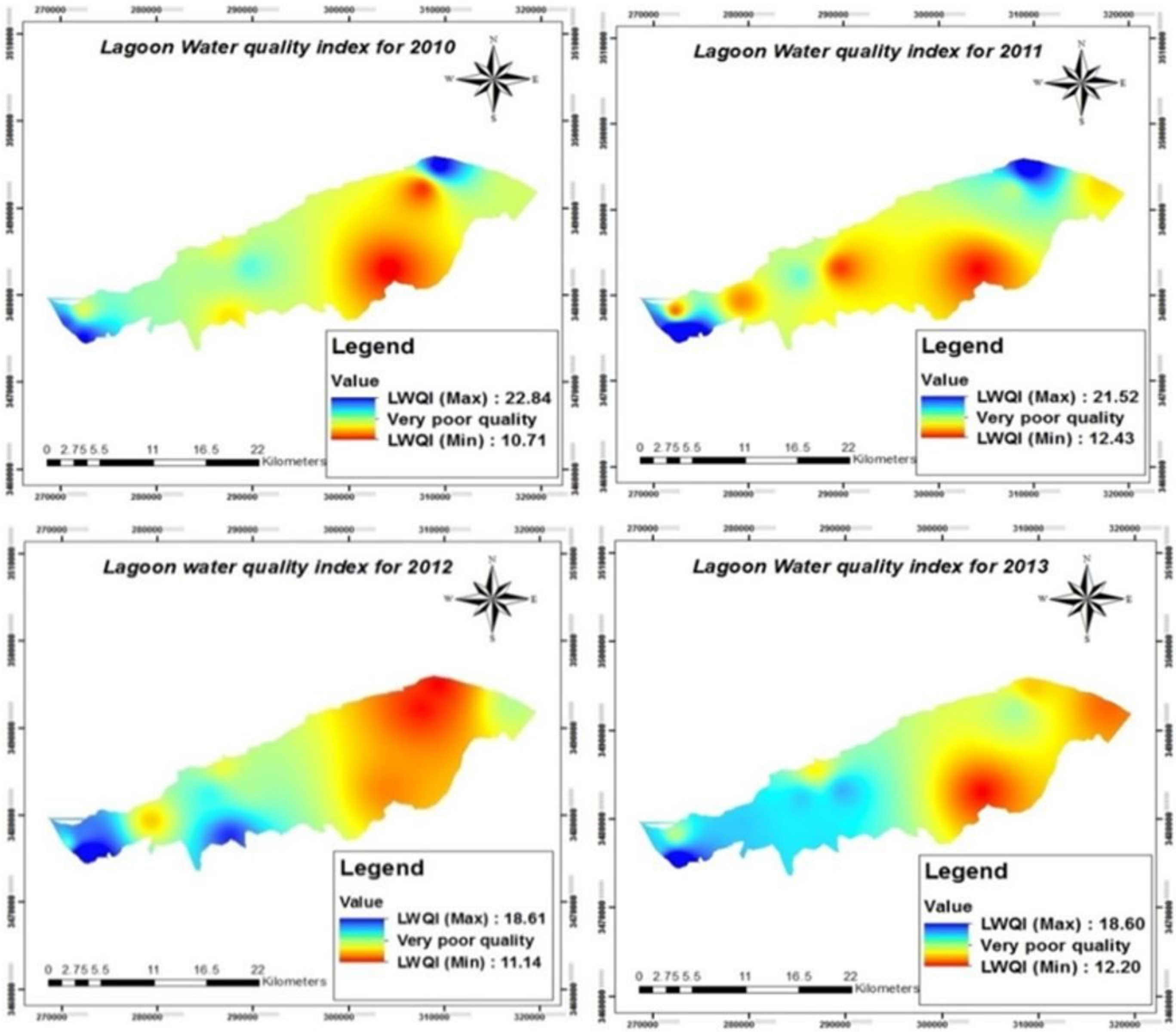

Figure 1

Schema of the methodology for WQ assessment of Lake Burullus.



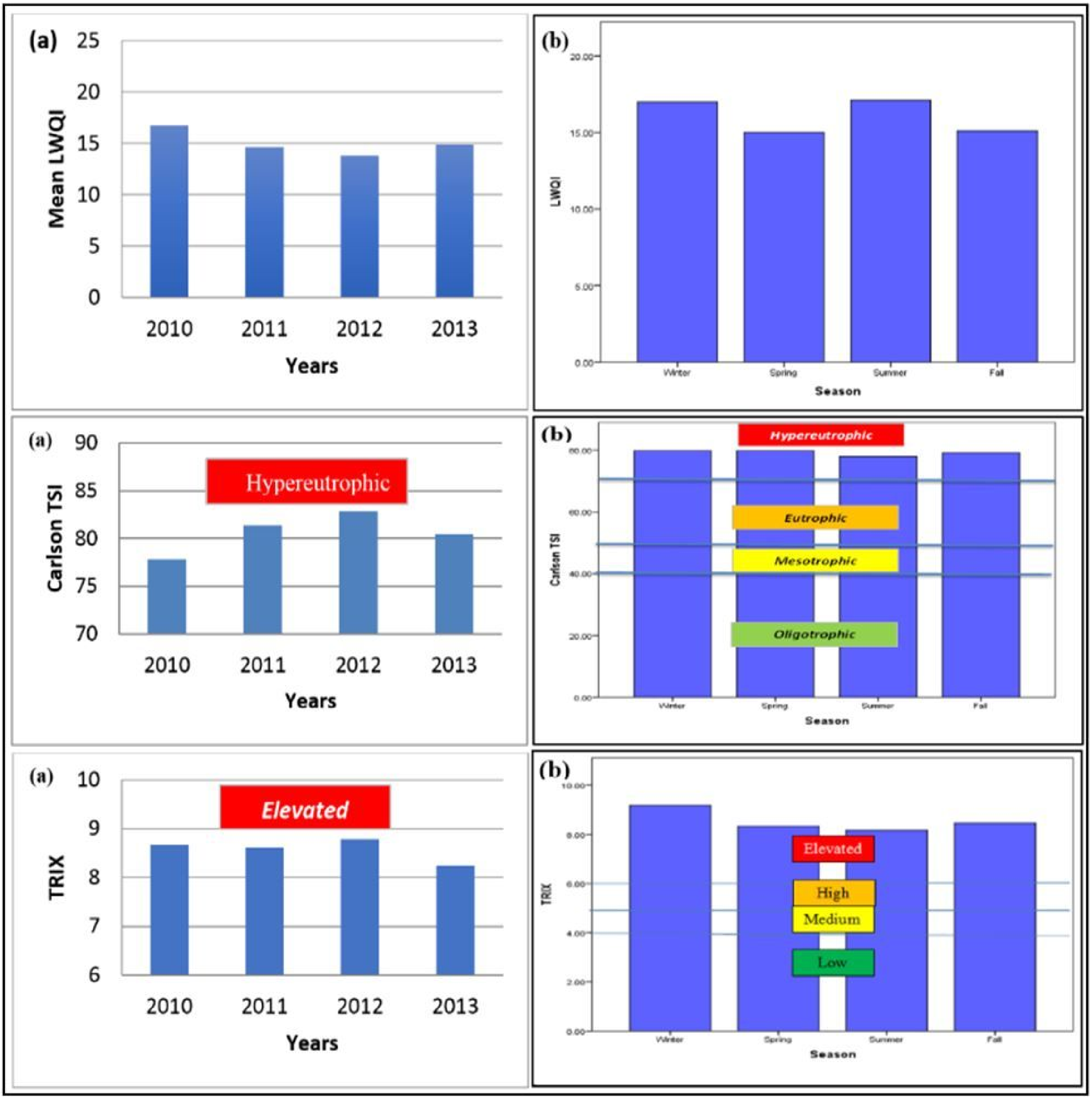

## Figure 2

Layout of Lake Burullus and the spatial distribution of the sampling stations



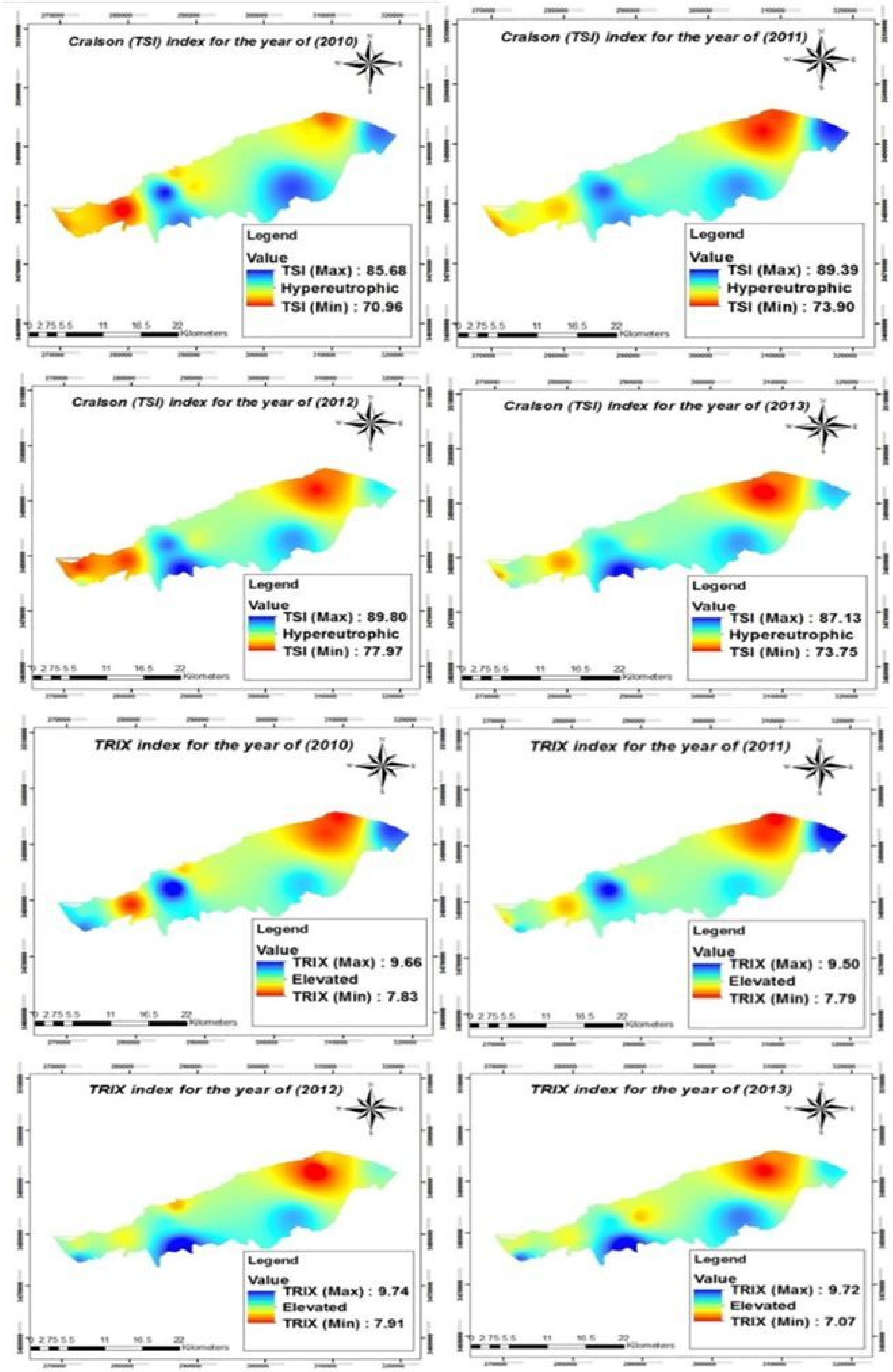

## Figure 3

The spatial annual distribution of L-WQI for Lake Burullus (2010 – 2013)




## Figure 4

Annual (a) and seasonal (b) averages of L-WQI, Carlson TSI & TRIX for Lake Burullus.




### Figure 5

The spatial annual distribution of Carlson TSI and TRIX for Lake Burullus (2010 – 2013)

# Supplementary Files

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- SupplementaryMaterialsWQGIS.docx