EUTROPHICATION ASSESSMENT OF LAKE MANZALA USING GIS TECHNIQUES

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ABSTRACT

A geographical information system (GIS)-based method of Lake Eutrophication assessment was undertaken to study the spatial distribution of eutrophication conditions in lake environments. In the present study, tabular data supported by field checks have been analyzed by GIS functions and operations to assess, monitor and model the environmental conditions of the Manzala Lake. A representation of the spatial distribution was developed using the inverse distance weighted (IDW) interpolation method. The eutrophic state index was calculated to describe the trophic state of the lake environment A GIS overlay technique was applied to synthesize the information into a final map illustrating the spatial distribution of water quality conditions within the study area.

1. INTRODUCTION

There are two systems of lake classification which are based upon processes within lakes, and which are used universally (Chapman [1]). These are the physical or thermal classification and the classification by trophic level. For Manzala Lake, as eutrophication is the principal water quality problem, the classification is based upon the trophic level.

The concept of trophic status as a system of classification was introduced by early limnologists such as Nauman [2], and has been subject to continuous development up until the present time (Vollenweider [3]; Pouriot and Meybeck [4]. The process off eutrophication underlying this scheme is one of the most significant processes affecting lake management and is therefore described in more detail.

Eutrophication is the process by which lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae to levels those are considered to be an interference with desirable water uses such as recreation fish maintenance and water supply. Eutrophication can also result in detrimental effects on the biological stability of lake and reservoir ecosystem, affecting virtually all the biological populations and their interactions in the water body. Consequently, eutrophication of lakes and reservoirs can have significant negative ecological, health social and economic impacts on human use of a primary and finite resource.

The multidimensional nature of the eutrophication phenomenon means that no single variable is representative of the eutrophication status of a given water body. Therefore, more trophic criteria or indices using multivariate approaches. (e.g. Carlson [7]) offers the most suitable and acceptable method for evaluating lake eutrophication. However, the primary disadvantage of such methodology has to do with the spatial discontinuity of their data. They do not provide an explicit view of the trophic status of lake eutrophication nor any clear-cut information related to water quality for lake researchers and managers. Lake eutrophication assessment requires not only a large number of variables, but also a spatial distribution of eutrophication levels based on each of the variables. The spatial assessment, however, of eutrophication levels may become quite complicated, since the function and dynamics of each parameter may lead to different eutrophication tends. There seems to exist, then, a need for appropriate methodologies and tools capable to synthesize spatially the eutrophication trends presented by various parameters. By synthesizing such trends, a final thematic map illustrating the spatial distribution of eutrophication conditions can be created. Fortunately, this can be easily performed through use of a geographic information system (GIS).

Geographic Information Systems (GIS) is a powerful tool that is being used to analyze satellite images, aerial photographs and hard copy maps to derive information and create solutions for a specific problem by using definite criteria. The GIS system is very powerful for analysis and creation of models that incorporates the relations between the different features on the surface and its effect on the environment. GIS can be used to perform a number of fundamental spatial analysis operations. Its major advantage is that it allows the user to identify the spatial relationships between various map features. More precisely, overlay techniques allow to synthesize of different map layers, based on a database where the information is stored as a whole. Comparisons, as well as further analyses, among and between both variables and layers can be easily performed (GIS [5]).

This research objective is to integrate GIS techniques into the lake eutrophication assessment process and then to study the resulting spatial distributions of lake eutrophication conditions.

But why is it important to assess the lake water quality? This question can best be answered by looking at Lake Manzala as a natural resource and at its socio-economic aspects. Manzala Lake is the largest of the northern Nile Delta coastal lakes. It is an important and valuable natural resource area for fish catch, wildlife, hydrologic and biologic regime and table salt production. It produces about 50 percent of the fish catch of the northern lakes and fresh water fisheries.

Manzala Lake, the area of study, is characterized by special sensitive environments. Human activities including discharge of sewage and industrial waste and the impact of canal and road networks have a serious impact on the water quality of the Lake. The lake has been gradually transformed from a largely marine or estuarine environment to eutrophic fresh water system.

Many researches had been conducted to assess lake Manzala water quality .among these are Fouad [6], Faouzi [7], Montasir [8], El-Wakel & Wahby [9], Bardash [10]; Fryer & Iles [11], Bishai & Youssef [12], Shaheen & Youssef [13] and Balarin & Hatton [14].

MacLaren [15] presented the most comprehensive assessment of the lake and admits in his results that nutrients from the major drains have created eutrophic conditions in those parts of the lake closest to the drains outlets. These conditions have changed the aquatic biota leading to a less diverse but highly productive system, which supports a high yield of Tilapia fishery especially in the El Genki area. The lake is still an important habitat for many species, including number of aquatic birds. Increase of nutrients load in the southern sector of the lake could exceed the environmental assimilation capacity and tolerance limits of major commercial fish species. The northern sector and parts of the western sector, which are relatively unaffected by wastes and nutrient loading, provide a reservoir for “natural” fish and other aquatic species. Preservation of these areas for that purpose would allow for greater flexibility in fisheries and Lake Management.

El-Shobashi [16] has carried a comprehensive water quality to assess the pollution situation in Lake Manzala for water, sediment and fish. It concludes that the lake Manzala became a sink pond after these recent modifications and changes binside its environment, thus the fish which is dwelling the lake have become nearly polluted now, this may lead to many side effects to the consumers and population.

All the previous studies admit that the major problem of the lake is the increase in nutrients loading into the lake especially from the input drains that accelerate the eutrophication process occurring within the lake. But almost no research tries to quantify and qualify the eutrophication processes occurring in the lake.

2- MATERIALS AND METHODS

2.1 Study Area and Data Collection

Lake Manzalah the largest natural lake in Egypt, is located between 31 00-31 30 N and 31 45-32 22E longitude. It extends to 64.5 km in the maximum length and 49 km in the maximum width and 239 km in total length of the shore line. The lake is bordered by Mediterranean sea to the north and the North-East, Suez Canal to the East, Dakahlia and Sharkia Provinces to the South and Damietta Branch of the Nile to the West, (see Figure 1). There are narrow outlets at El-Bighdadi, El-Gamil and El-Qaboti at the northern side of the lake. The lake is connected with the Damietta Branch of the Nile through El Inaniya Canal. Therefore, the southwestern corner of the lake receives the majority of its freshwater input from the Sirw and Fariskur pumping stations, and the Inaniya Canal.

Lake Manzala is a highly dynamic aquatic system that has undergone considerable physical, chemical and biological changes during the past century. This was as a result of different aspects of human impacts of which closing and/or opening of straits, establishment of Aswan High Dam, silting of the lake, continuous drying processes for cultivation purpose and human settlement and pollution with different kinds of water discharge into the lake. Six main agricultural drains use to flow into Lake Manzala and affect its water quality. Drainage water contributes about 98% of the total annual inflow to Lake Manzala. There are seven drains carrying the fresh and drainage water to the lake.

The following are these drains with their relative contribution of the total flow in water as shown in Figure (1):

Hadous Drain: It is the largest drain in the eastern Delta, serving some 790000 feddans of agricultural lands. It contributes about 49% of the total inflow.

Bahr El Baqar Drain: It serves an agricultural area of some 536000 feddans, and also receives about 300 million m3/y of sewage from Cairo. It contributes about 25% of the total inflow

Sirw Drain: It serves 68700 feddans and it contributes about 13% of the total inflow

Ramsis Drain: It is about 24 km long and discharges a relatively small amount of water to Lake Manzala. It contributes about 4% of the total inflow.

Fariskur Drain: It serves about 20000 feddans. It contributes about 4% of the total inflow.

Matariya Drain: It serves 50000 of land under agricultural reclamation. It contributes about 2 % of the total inflow.

Measurement and sampling of lake's water for analytical purposes were performed monthly from July until October 2003. The water samples have been collected from 10 stations along the lake. The geographic positions of these samples were determined using GPS as well as being collected every sample together with depth and water quality information as illustrated in Figure (1).

Figure (1) Geographical Location and distribution of sampling sites along Manzala Lake

2.2 The Trophic State Index

In this study, the Carlson trophic State Index (TSI) is used to provide a single quantitative index for the purpose of classifying and ranking lakes, most often from the standpoint of assessing the trophic state of the lake. In recent years the Carlson [17] Index appears to have attained general acceptance in the limnological community as a reasonable approach to this problem. This is a measure of the trophic status of a body of water using several measures of water quality including: transparency or turbidity (using Secchi disk depth (SD) recordings, chlorophyll-a (CHLA) concentrations (algal biomass), and total phosphorus (TP) levels (usually the nutrient in shortest supply for algal growth).

TSI ranges along a scale from 0-100 that is based upon relationships between secchi depth and surface water concentrations of algal chlorophyll, and total phosphorus. Its major assumptions is that suspended particulate material in the water controls secchi depth and that algal biomass is the major source of particulates; values below 40 generally considered to represent oligotrophic condition, and values above 60 representing eutrophic condition. The values between 40 and 50 represent mesotrophic condition, the values between 50 and 60 represent moderately eutrophic and the values above 70 represent hypereutrophic. The classification scheme of TSI Carlson Index is illustrated in Table (1).

A set of equations were then derived to describe these relationships with higher values corresponding to increased fertility, that is, more eutrophic. An increase in TSI of 10 units corresponds to a halving of secchi depth and a doubling of phosphorus concentration.

$$TSI\ (TP) = 10(6 - Ln\ (48/TP)/\ln 2),\ \ (TP\ in\ ug/L) \quad (1)$$

$$TSI\ (CHLA) = 10(6-(2.04-0.68\ Ln\ (CHLA))/\ln 2),\ (CHLA\ in\ ug/L) \quad (2)$$

$$TSI\ (SD) = 60 - 14.41 * Ln\ (SD),\ (SD\ in\ meters) \quad (3)$$

$$Average\ TSI = [TSI(TP) + TSI(CHLA) + TSI(SD)]/3 \quad (4)$$

Table 1 Classification Scheme of the Trophic State Index (TSI[18]).

TSI (Carlson [18])	**TROPHIC STATUS INDEX & WATER QUALITY**
< 30	Oligotrophic; clear water; high DO throughout the year in the entire hypolimnion
30-40	Oligotrophic; clear water; possible periods of limited hypolimnetic anoxia (DO =0)
40-50	Moderately clear water; increasing chance of hypolimnetic anoxia in summer; fully supportive of all swimmable/aesthetic uses
50-60	Mildly eutrophic; decreased transparency; anoxic hypolimnion; macrophyte problems; warm-water fisheries only; supportive of all swimmable/aesthetic uses but "threatened"
60-70	Blue-green algae dominance; scums possible; extensive macrophyte problems
70-80	Heavy algal blooms possible throughout summer; dense macrophyte beds; hypereutrophic
> 80	Algal scums; summer fish kills; few macrophytes due to algal shading; rough fish dominance

2.3 The General Trophic State of lakes

Another classification of the trophic state of lakes by using the range of water quality variables described in Table (2). For lakes, three designations have been used:

1. Oligotrophic – clear, low productivity lakes.
2. Mesotrophic – intermediate productivity lakes.
3. Eutrophic – High productivity lakes relative to a basic natural level.

Table 2 Trophic State of Lakes [21]

Water quality Variable	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Reference**
TP (ug/L)	<10	10-20	>20	[19]
Chlorophyll(ug/L)	<4	4-10	>10	[20]
Secchi Depth	>4	2-4	<2	[19]
Oxygen (% Saturatiom)	>80	10-8-	<10	[19]

2.4 Nitrogen to Phosphorus (N/P) RATIO

As the principal nutrients entering the Manzala Lake are phosphorus and nitrogen, a balance of these is necessary for the development of the undesirable growths associated with eutrophication. Therefore, the N/P ratio has been calculated from the lake data for nitrogen as nitrate and phosphorus as phosphate and represented using GIS as a limiting factor responsible for controlling eutrophication. The relative importance of nitrogen and phosphorus to phytoplankton productivity was calculated by the atomic ratio of the inorganic forms of the two elements Mc Pherson et al. (1982).

It is well known that the growth and proliferation of aquatic plants is a result of the utilization and assimilation o organic materials through the photosynthesis. Thus the plant biomass increases by the uptake of available phosphorus and nitrogen from the water. It was found that the nutrient that will control the maximum amount of plant biomass is the nutrient that "run off" or reaches a minimum before other nutrient. Therefore under a certain condition, nitrogen may reach a minimum value before phosphorus and as a result control the maximum amount of plant biomass and vice versa.

This Situation depends on the relative amount of nitrogen and phosphorus required by aquatic plants and their availability in water body. Accordingly, a mass ratio of available forms o nitrogen and phosphorus (N/P) were used to calculate the limiting nutrient in water. In this respect different ratios were suggested by many authors (Chiaudini and Vighi, 1974; Forsberg and Ryding, 1980; Smith and Shapiro, 1980). The most conservative ratio suggests that when N/P ratrio is between 5 and 10, either nutrient could be limiting and if less than 5, nitrogen is the limiting for plant growth.

The N/P ratio in a waterbody can be useful as a diagnostic tool for assessing the types o algae exist under different nutrient conditions (Smith, 1983) related nutrient ratios to the concept of resource competition as a major factor affecting phytoplankton community structure. He reported that low total N:total P ratios appear to favor green algal dominance in natural lakes in the temperate zone.

2.5 Calculation of Eutrophication levels and Generation of Thematic Maps

The data were represented by The software integrated land and water information systems (ILWIS) developed and marketed by international institute for Aerospace Survey and earth Sciences (ITC, 1995) .It is a Geographic information System (GIS) with Image processing capabilities. The ILWIS software allows you to input, manage, analyze and output geographical data. From the data you can generate information on the spatial and temporal patterns on the earth surface. You therefore can answer such questions as what features, where and when.

ILWIS in this research is used as a tool for construction a GIS the study area Also GIS has been used for displaying the TSI(CHLA), TSI(SD) AND TSI(TP) on a geographically registered map and in colour to correspond with varying levels using the inverse distance interpolation method (IDW). By categorizing the interpolated values, a clear illustration of the different trophic levels was developed on three thematic maps. Finally, it is used for the calculation of the overall trophic state index the N/P ratio by using the overlaying technique to illustrate the spatial distribution of eutrophication conditions within the study area.

To estimate unknown values, we use weighted linear combinations where the weights account for the distance to the nearby samples by using the inverse distance method. This method relies on the idea that that data are more likely to be useful if they are measured near the point of interpolation. Thus more weight is given to the closest samples and less to those who are farthest away. The value of intermediate point is thus calculated from the summation of the product of the observation values v_i and weights, divided by the summation of weights. The inversely distance algorithm used is by making the weights inversely proportional to any power of the distance.

$v_1 = \frac{\sum_{i=1}^{p} \frac{1}{d_i^n} v_i}{\sum_{i=1}^{p} \frac{1}{d_i^n}}$ where v are the sample values, d are the distances from the p samples.

As we decrease n, the weights given to the samples become more similar .For progressively larger values of n the closest sample would receive a progressively larger percentage of the total weight as shown in Figure (2).

The (IDW) interpolation method has been widely used on many types of data because of its simplicity in principle, speed in calculation, easiness in programming, and credibility in interpolating surfaces (Lam, 1983).

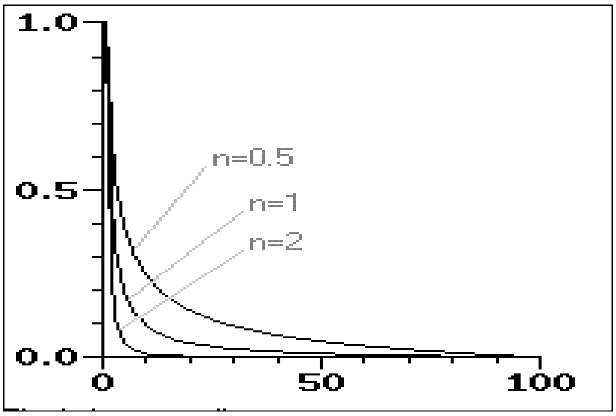

Figure 2 The weight at different n values for different distances

2.6 The Overlay of the thematic maps

The overlay technique, widely used in GIS applications, was applied to synthesize the three thematic maps and develop the final eutrophication map. The following steps describe the procedure used to generate the final thematic map as shown in Figure (3).

1. Development of TSI of each indicator scale from 0 to 100
2. Analysis the three thematic maps on a cell by cell basis
3. Overlaying the three maps to generate the final eutrophic state map
4. Classifying the final map using the Carlson classification scheme of lakes.

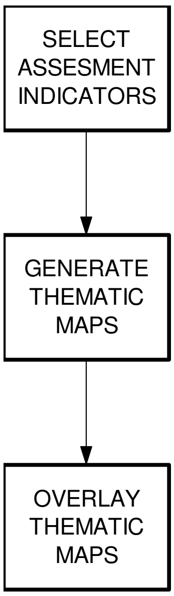

Figure 3 Diagram for the GIS-Based Method for lake eutrophication Assessment

3- RESULTS AND DISCUSSIONS

The thematic maps TSI(CHLA), TSI(SD) and TSI(TP), developed using (IDW) interpolation method were calculated and presented spatially in Figures (4, 5 and 6). The final TSI map developed as a result of the overlay technique is given in Figure (7).

Figure (4) shows the spatial distribution of TSI (CHLA). From it, the middle part of the lake is characterized mainly as hypereutrophic, while the eutrophicc field, TSI (CHLA) is distributed in the eastern part of the lake. The eutrophication levels near the discharge of drains are representative of eutrophic to extremely hypereutrophic. Figure (5) illustrates the spatial distribution of TSI (SD). From it, the middle part of the lake is characterized mainly as severely eutrophic, while the western part of the lake is upper mesotrophic to moderately eutrophic. The eutrophication levels at the eastern part s mesotrophic. Figure (6) illustrates the spatial distribution of TSI (TP). From it, the middle part of the lake is characterized mainly as upper-mesotrophic, while the northwestern and the eastern parts are characterized to be moderately mesotrophic. The eutrophication levels in the remaining parts of the lake are mesotrophic.

Finally, the overall distribution is illustrated in Figure (7). Eutrophic conditions (TSI 60-70) cover most of the study area especially in the eastern part where it receives the discharge o Bahr El Baqar drain that accounts for 60% of the nutrient loadings into lake Manzala (Mclaren, 1984) and also at the western part of the lake that receives the discharge from the faraskour and Hadous drains that contribute about 30% o the nutrient loading into the lake. The middle part of the lake is characterized as moderately eutrophic. A very limited area of the lake is classified as mesotrophic.

The N/P ratio was calculated from the data for nitrogen as nitrate and phosphorus as phosphate collected at ten sites along the lake and presented spatially in Figure (8). From the map, it is shown that N/P ratio is less than 5 in most of the parts of the lake which means that nitrogen is the limiting nutrient that controlled the plant biomass. While in the extreme eastern part of the lake, N/P ratio is more than 5 in most of the parts of the lake which means that phosphorus is the limiting nutrient that controlled the plant biomass.

Figure (9) shows the general eutrophication status of the lake taking into consideration the water quality indicators in Table (2) that includes the total phosphorus (TP), the chlorophyll-A, the Secchi depth (SD) and the percentage of saturation of dissolved oxygen in the lake. Meanwhile, the general picture is saturated or over saturated at most locations of the lake, with a tendency towards a relative decrease in oxygen content at the western and southwestern sides of the lake. High saturation with DO could be principally, accompanied with the high rate of DO production through photosynthesis process due to the presence of heavy quantities of submerged plants.

The relative decrease in DO content at the western and southwestern sides could reflect the dominant effect of drainage effluents on these locations.

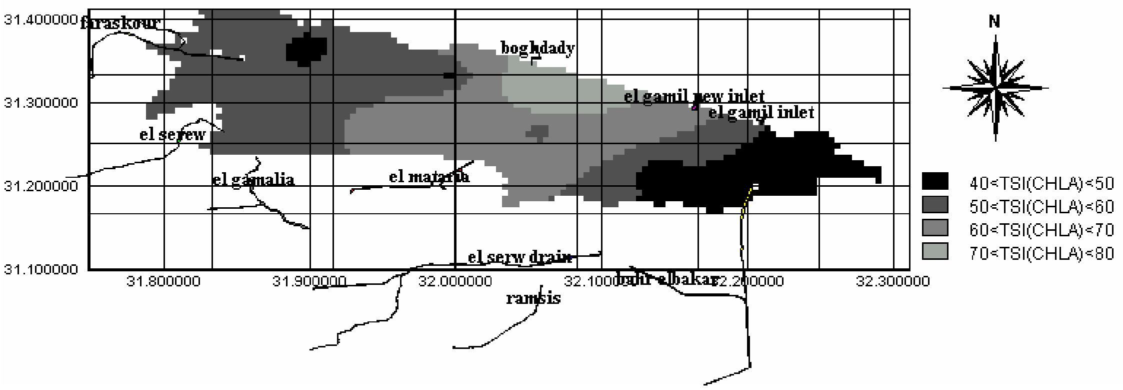

Figure 4 Spatial Distribution of the lake trophic state index based on CHLA

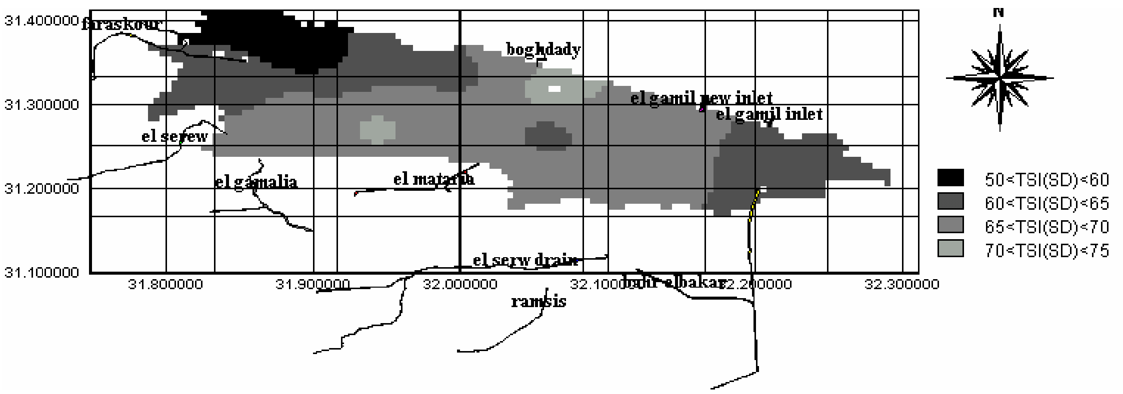

Figure 5 Spatial Distribution of the lake trophic state index based on SD

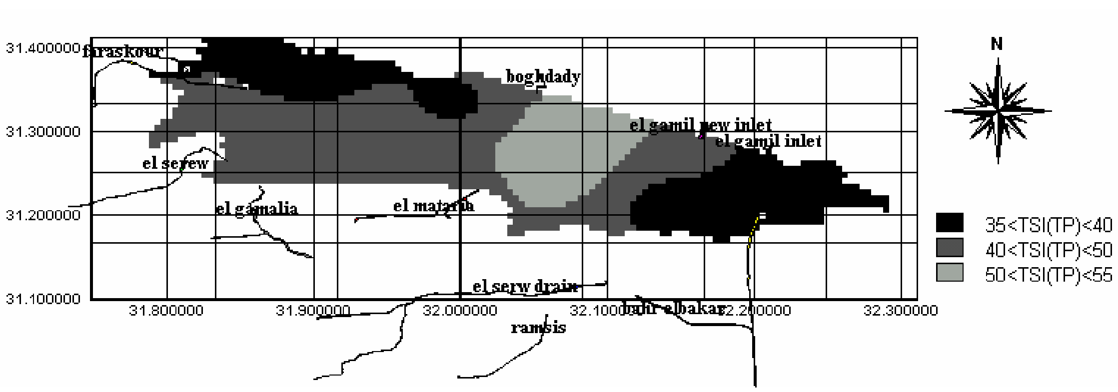

Figure 6 Spatial Distribution of the lake trophic state index based on TP

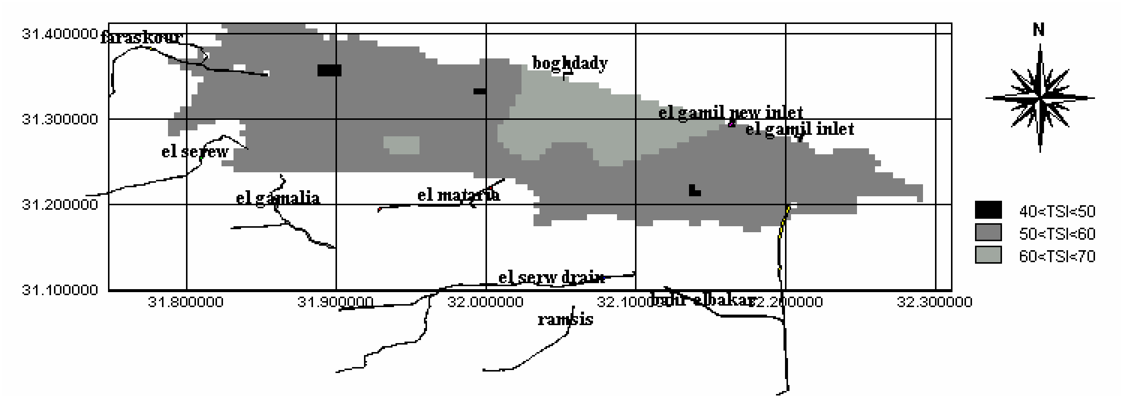

Figure 7 Spatial Distribution of the lake trophic state index

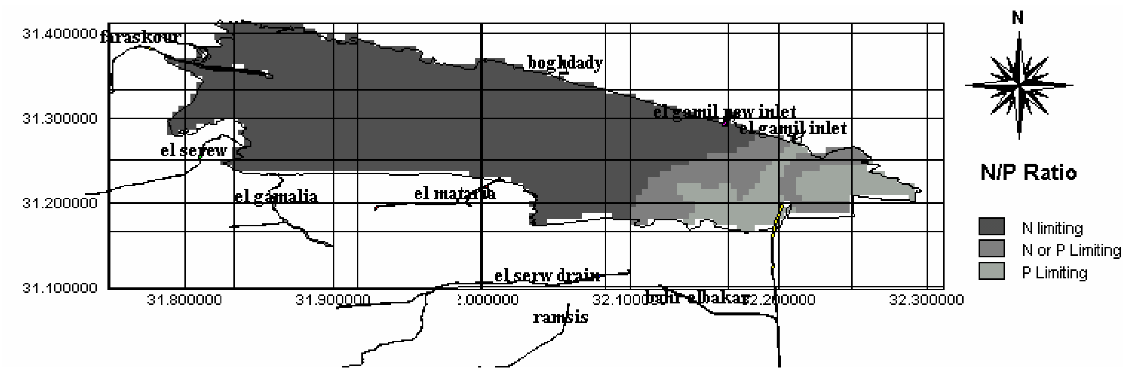

Figure 8 Spatial Distribution of the N/P Ratio of Manzala Lake

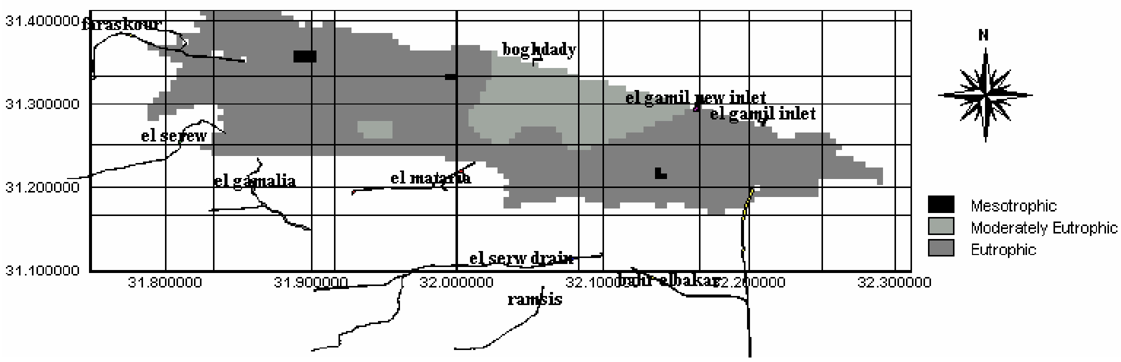

Figure 9 General Trophic State of Manzala Lake

4. CONCLUSIONS

Since that Nutrients from the major drains have created eutrophic conditions in those parts of the lake closest to the drains outlets. The water classification of Lake Manzala is based upon the calculation of the trophic state index (TSI) and the N/P ratio. A geographical information system (GIS) based method is derived of lake eutrophication assessment in order to study the spatial distribution of eutrophication condition in lake environments by using the IDW interpolation techniques and the GIS techniques within the Ilwis software package.

The spatial distribution of Lake Manzala eutrophication levels is closely correlated with the actual conditions of the lake. Results from the study indicate that the boundaries associated with different trophic levels (mesotrophic, moderately eutrophic and eutrophic) could be clearly defined in a final eutrophication map. Therefore, the integration of TSI calculations into GIS is important in creating a complete picture o the trophic state of the lake. The GIS manages the spatial and attribute data, in addition to manipulate and display the results of TSI calculations. The proposed method will help a lot to make a good water quality management plan of the lake to ensure its sustainability.

5. RECOMMENDATIONS

Eutrophication can be controlled by reducing the nutrient input into the lake, increasing the nutrient output from the lake, immobilizing the nutrients within the lake, or by controlling the excessive growth of algae.

Limiting nutrient input often requires implementing zoning regulations and enforcing legislation that mandates protection of watersheds. Nutrient input can also be controlled by cultivating buffer strips of grasses and shrubs, and by preserving natural wetlands that serve to filter pollutants and provide flood control.

Increasing nutrient output from a body of water to control eutrophication can be accomplished by aeration, dredging, dilution, flushing and by dropping water levels. Immobilization of nutrients within a lake can be done by the addition of aluminum or iron salts or calcium nitrate into the water. These chemicals bind to the phosphorus to form insoluble compounds that precipitate down into the lake sediment.

Biomanipulation is a new lake restoration technique that shows some promise. This technique adjusts the fish species composition of the lake in order to encourage the growth of zooplankton. These tiny animals reduce the algae population by eating them. Destruction of the existing fish population and restocking with a type of fish like the large mouth bass that does not feed on zooplankton may be required.

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