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# Case study: Nutrients distribution and assessment of the current trophic status of Plastiras lake in Thessaly (central Greece) after tropical storm Daniel

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## Abstract

Based on the interactions of three water quality variables, chlorophyll-a (Chl-a), secchi depth (SD – water transparency) and total phosphorus (TP), this study was aimed to assess the trophic state of Plastiras Lake through the modified method of Carlson's trophic state index (CTSI). Eutrophication is one of the most serious problems for water quality and CTSI is an important index for monitoring water quality status and eutrophication assessment. The classification scale for Trophic State Index (TSI) fluctuates from 0 to 100 and the results of this study showed that the mean TSI for Chl-a was 42.95, for SD was 45.50 and for TP was 75.15. The overall CTSI finally was 54.53. These show that Plastiras Lake is presently classified as mesotrophic to eutrophic which reflects the current levels of nutrients in the lake.

**Keywords:** Nutrient concentration; Carlson's Trophic State Index; Eutrophication; Daniel storm

## 1. Introduction

The Plastiras Lake (location lat,long: 39.630108779137345, 22.443925813830585) is an artificial lake in Central Greece constructed in 1959 with the completion of the dam at the southern end of the Tavropos or Megdovas river.The reservoir has a surface area of 25 $km^2$. It contains 400 million cubic meters of water, has a maximum length of 12 kilometers and a width of 4 kilometers. The depth of the lake varies, as it is determined by the original landscape of the area. Its maximum depth varies from 52 to 60 m and the average depth at maximum water level is 14 m. The maximum water level is +792 m, the average altitude of the basin is +800 m and the highest peak is at +2.150 m. Nowadays, Plastiras reservoir serves multiple and conflicting purposes, which are hydroelectric power generation, water supply, irrigation and recreation. Throughout the early September 2023, Europe has been under the influence of a weather phenomenon known as an Omega block, characterized by the presence of a high-pressure system positioned between two low-pressure systems appearing high persistence over a week in the area. Storm Daniel (named by the Hellenic National Meteorological Service) emerged in the Ionian Sea, partially attributed to this atmospheric setup. The southern warm and moist air combined with cold upper air established favorable instability conditions coinciding with an unprecedented deluge of rainfall that surpassed all previous recorded measurements over the region of Thessaly. Plastiras Lake had a significant contribution to the reduction of the impact of the Daniel-induced floods receiving more than 50 million $m^3$ of water and its level rose 2.6 m protecting the wider area [1,3].

Therefore, the aim of this study was to evaluate the trophic status of Plastiras Lake and the possible impact of the flooding on lake ecosystem after Daniel storm phenomenon.

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## 2. Materials and methods

Sampling was always carried out during the morning period on a monthly basis for 8 months from November 2023 to June 2024. The water samples (three replicates were used in every chemical analysis) were collected at 1-2 m depths from the surface using Niskin bottle. The samples were kept in 500 ml polyethylene bottles and placed on ice. In the laboratory the samples were kept frozen in the dark (-18 ºC) until they were analyzed.

All the chemicals and solvents used were purchased from Sigma-Aldrich at the analytical grade or highest level of purity available and used as received. For the preparation of solutions, double distilled water was used.

- Water transparency (m) in the sampling station was measured using a Secchi disc depth (SDD) and the value was taken at the depth where the standard black and white colour of disc disappeared.
- Orthophosphate was measured with vanadomolybdophosphoric acid method. Orthophosphate reacts in acid conditions with ammonium vanadomolybdate to form vanadomolybdophosphoric acid. This yellow color is proportional to the concentration of orthophosphate and is measured spectrophotometrically (Jasco model V-630 UV/VIS spectrophotometer) and colorimetrically (model LaMotte SMART3).
- Nitrate -nitrogen was measured with cadmium reduction method. Powdered cadmium is used to reduce nitrate to nitrite. The nitrite - nitrogen that is originally present plus reduced nitrate is determined by diazotization of sulfanilamide and nitrite followed by coupling with N-(1 naphthyl)- ethylenediamine dihydrochloride to form a highly colored azo dye which is measured spectrophotometrically (Jasco model V-630 UV/VIS Spectrophotometer) and colorimetrically (model LaMotte SMART3).
- Ammonia- nitrogen was measured with nesslerization method. Ammonia forms a colored complex with Nessler's Reagent in proportion to the amount of ammonia present in the sample. Water samples for chlorophyll-a (chl-a) determination were filtered through Whatman GF/C glass fiber filters and pigment extraction was performed using 90% acetone. Pigment concentration was measured by spectrophotometry (Jasco model V-630 UV/VIS spectrophotometer) and all calculations were done according to APHA [4].

The three trophic state indicators ($TSI_{SD}$, $TSI_{CHL-a}$, $TSI_{TP}$) were computed mathematically based on the respective equations for the three parameters (Secchi depth, chlorophyll-a and total phosphorus), and the overall Carlson Trophic State Index (CTSI) was calculated by averaging the TSI values obtained from the three trophic state indicators [5-11].

$$CTSI = [TSI_{(TP)} + TSI_{(Chl-a)} + TSI_{(SD)}] / 3$$

Where:

$TSI_{(TP)} = 14.42 * Ln(TP) + 4.15$ (μg $L^{-1}$ )

$TSI_{(Chl-a)} = 9.81* Ln(Chl-a) + 30.6$ (μg $L^{-1}$ )

$TSI_{(SD)} = 60 – 14.41* Ln(SD)$ (m)

## 3. Results

Monthly variation of concentration of nutrients and chlorophyll -a is demonstrated in Table 1. $NO_3$ - N concentration ranged from 0.02 to 0.18 with with an average value of 0.065 ppm. The higher values were observed in June 2024 and in February 2024 (0.18 ppm) while the lowest value was observed in December 2023 (0.02 ppm). $NO_2$ - N concentration ranged from 0.01 to 0.03 with with an average value of 0.0225 ppm. The higher values were observed in November 2023, in May 2024 and in June 2024 (0.03 ppm) while the lowest value was observed in February 2024 (0.01 ppm). $NH_4$ - N concentration ranged from 0.08 to 0.52 with with an average value of 0.2712 ppm. The higher values were observed in March 2024, in April 2024, in May 2024 (0.5-0.52 ppm) while the lowest values were observed in November 2023 and in December 2023 (0.08 ppm). $PO_4$ - P concentration ranged from 0.03 to 0.32 with with an average value of 0.21 ppm. The higher values were observed in January 2024, in April 2024 and in May 2024 (0.32 ppm) while the lowest value was observed in December 2023 and in June 2024 (0.03 ppm). Chlorophyll-a concentration ranged from 1.09 to 15.08 with with an average value of 5.0212 ppm. The higher value was observed in March 2024 (15.08 ppm) while the lowest value was observed in December 2023 (1.09 ppm).

Correlation analysis of nitrogen -nitrate, nitrite and ammonia, orthophosphate and chlorophyll -a is presented in Table 2. The correlation test is a statistical technique used to test the presence or absence of a relationship, and the direction of the relationship, between two or more variables. The extent of the relationship between these variables is expressed as a correlation coefficient, with a value between -1, 0, and +1. A strong relationship is expressed by -1 and +1, whereas if each of the variables has no relationship at all, then the correlation coefficient is 0. N-$NH_4$ has a strong positive correlation with P-$PO_4$ and Chl-a and N-$NO_2$ has a significant positive correlation with P-$PO_4$. N-$NO_3$ has a strong and negative correlation with P-$PO_4$ and significant negative correlation with N-$NH_4$ and N-$NO_2$.

Total concentration of nitrogen and ratio of TIN/P-PO4 from November 2023 to June 2024 are presented in Table 3. TIN concentration ranged from 0.12 to 0.58 with with an average value of 0.37 ppm. The higher values were observed in March 2024, April 2024 and May 2024 (0.58 ppm) while the lowest value was observed in December 2023 (0.12 ppm). Ratio of TIN/P-PO4 ranged from 0.49 to 10.42 with with an average value of 3.64 ppm. The higher values were observed in February 2024 (10.42) and in June 2024 (8.58) while the lowest value was observed in November 2023 (0.49).

Trophic state indicators from November 2023 to June 2024 are presented in Table 4.

TSI -C index ranged from 32.78 to 57.21 with with an average value of 42.98. The higher value was observed in March 2024 (57.21) while the lowest value was observed in January 2024 (32.78). TSI-S index varied from 41.94 to 46.79 with with an average value of 45.50. The higher value was observed in March 2024 (46.79) while the lowest values were observed in May 2024 and in June 2024 (41.94). TSI-P index ranged from 54.39 to 87.60 with with an average value of 75.15. The higher values were observed in November 2023, in January 2024 and in March - June 2024 (87.60) while the lowest value were observed in December 2023, in February 2024 and in June 2024 (54.39). Average TSI index varied from 43.66 to 63.87 with with an average value of 54.53. The higher values were observed in March 2024 (63.87), April 2024 (60.82) and May 2024 (57.36) while the lowest value was observed in December 2023 (43.66).

Correlation analysis of Trophic state indicators and TSI average is presented in Table 5. Average TSI has a strong positive correlation with TSI -C index and TSI -P index while TSI-P index has a significant negative correlation with TSI-S index. Finally, average value of TSI index from November 2023 to June 2024 is presented in figure 1.

**Table 1** Monthly variation of concentration of nutrients and chl-a from November 2023 to June 2024

| | ***N - NO3 (ppm)*** | ***N-NO2 (ppm)*** | ***N-NH4 (ppm)*** | ***P-PO4 (ppm)*** | ***Chl -a (μg/lt)*** |
|---|---|---|---|---|---|
| November 2023 | 0.05 | 0.03 | 0.08 | 0.3 | 2.12 |
| December 2023 | 0.02 | 0.02 | 0.08 | 0.03 | 1.09 |
| January 2024 | 0.07 | 0.02 | 0.19 | 0.32 | 1.25 |
| February 2024 | 0.18 | 0.01 | 0.15 | 0.032 | 3.32 |
| March 2024 | 0.02 | 0.02 | 0.52 | 0.3 | 15.08 |
| April 2024 | 0.03 | 0.02 | 0.5 | 0.32 | 6.65 |
| May 2024 | 0.03 | 0.03 | 0.52 | 0.32 | 3.38 |
| June 2024 | 0.12 | 0.03 | 0.13 | 0.03 | 7.28 |

**Table 2** Correlation analysis of nitrogen -nitrate, nitrite and ammonia, orthophosphate and chlorophyll -a

| | **N - NO3** | **N-NO2** | **N-NH4** | **P-PO4** | **Chl -a** |
|---|---|---|---|---|---|
| N - NO3 (ppm) | 1 | -0.3877 | -0.47162 | -0.60193 | -0.17189 |
| N-NO2 (ppm) | | 1 | 0.037191 | 0.29277 | -0.0252 |
| N-NH4 (ppm) | | | 1 | 0.614826 | 0.595766 |
| P-PO4 (ppm) | | | | 1 | 0.19944 |
| Chl -a (μg/lt) | | | | | 1 |

**Table 3** Total concentration of nitrogen and ratio of TIN/P-PO4 from November 2023 to June 2024

| | **November 2023** | **December 2023** | **January 2024** | **February 2024** | **March 2024** | **April 2024** | **May 2024** | **June 2024** |
|---|---|---|---|---|---|---|---|---|
| TIN (ppm) | 0.16 | 0.12 | 0.28 | 0.34 | 0.56 | 0.55 | 0.58 | 0.28 |
| TIN/P-PO4 | 0.49 | 3.67 | 0.85 | 10.42 | 1.71 | 1.68 | 1.77 | 8.58 |

**Table 4** Trophic state indicators from November 2023 to June 2024

| **TSI -C** | **TSI - S** | **TSI - P** | **AVERAGE TSI** | |
|---|---|---|---|---|
| 37.97 | 44.16 | 87.60 | 56.58 | November 2023 |
| 31.44 | 45.16 | 54.39 | 43.66 | December 2023 |
| 32.78 | 44.16 | 87.60 | 54.85 | January 2024 |
| 42.37 | 54.15 | 54.39 | 50.30 | February 2024 |
| 57.21 | 46.79 | 87.60 | 63.87 | March 2024 |
| 49.18 | 45.68 | 87.60 | 60.82 | April 2024 |
| 42.54 | 41.94 | 87.60 | 57.36 | May 2024 |
| 50.07 | 41.94 | 54.39 | 48.80 | June 2024 |

**Table 5** Correlation analysis of Trophic state indicators and TSI average

| | **TSI -C** | **TSI - S** | **TSI - P** | **AVERAGE TSI** |
|---|---|---|---|---|
| TSI -C | 1 | | | |
| TSI - S | 0,061302833 | 1 | | |
| TSI - P | 0,15373093 | -0,338144114 | 1 | |
| AVERAGE TSI | 0,591917987 | -0,069679194 | 0,866794 | 1 |

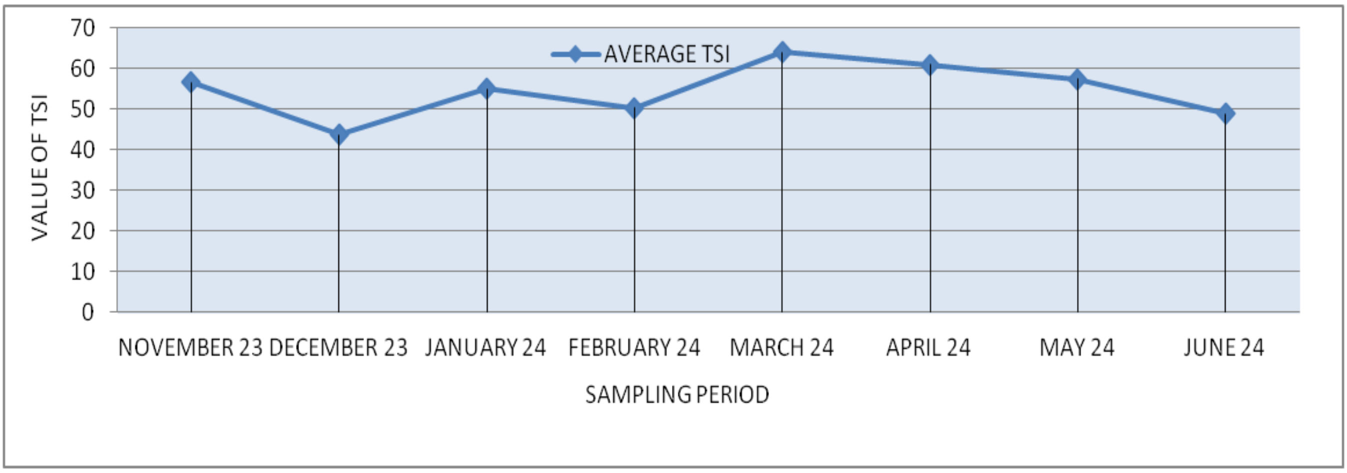


**Figure 1** Average value of TSI from November 2023 to June 2024

## 4. Discussion

Carlson's trophic state index (CTSI) was developed based on the relationship among secchi disc depth, phosphorous and chlorophyll-a. This index is a monitoring tool to assess the trophic status (oligotrophic, mesotrophic, eutrophic, and hypereutrophic) of an aquatic ecosystem which indeed serves as baseline for measuring biological integrity and interface between human and water environment. Eutrophication of water ecosystems occurs when there's an accumulation of nutrients. Natural and anthropogenic causes contribute to this natural process and can eventually deteriorate the water quality. Reservoir water quality is a significant concern across the world as it faces multiple problems linked to anthropogenic activities such as excessive input of nutrients and pollutants from agricultural and industrial runoff. Also, water quality patterns are regulated by hydrology, local and regional climatic conditions land use and geological landscape [12 - 17].

Chlorophyll-a (chl-a), total phosphorous (TP), total inorganic nitrogen (TN) and TN:TP ratio have been recommended as valuable markers for eutrophication control in aquatic systems. Total phosphorous is considered as the most important element for determining the biological productivity in aquatic ecosystem. It acts as valuable nutrient for plant growth and fundamental element in the metabolic reactions of plants and animals. It is also considered as an important factor affecting the trophic status of lakes.

The term inorganic nitrogen includes all the major inorganic nitrogen components ($NH_3$, $NH_4^+$, $NO_2^-$, $NO_3^-$) present in water. Both the dissolved forms of inorganic nitrogen and those adsorbed onto suspended inorganic and organic material are included, since they are all available for uptake by algae and higher plants. Unionised ammonia, the most toxic form of nitrogen, gets oxidized by Nitrosomonas into nitrite. In a further step, nitrite, which still represents a toxic ion for fishes, is transformed into nitrate by Nitrobacter. Nitrate, a less toxic form, can be incorporated by plants and algae boosting their growth. Inorganic nitrogen is seldom present in high concentrations in unimpacted surface waters. This is because inorganic nitrogen is rapidly taken up by aquatic plants and converted into proteins and other organic forms of nitrogen in plant cells.

In freshwater systems, TP strongly regulates algal chlorophyll while in contrast, TN has a strong influence on CHL-a in marine systems. CHL-a is the most trustworthy indication of algal biomass, whereas secchi depth (SD) is the most accurate indicator of water clarity in lentic systems. The TN:TP ratios are widely used indicators to determine nutrient limitations status of algae in aquatic habitats. If the TN:TP ratio is less than 6, aquatic habitats are termed N-limited; if the ratio is larger than 16, aquatic ecosystems are deemed P-limited and if the ratio is between 6 and 16, co-limitation occurs [18 - 27].

In the present study the TN:TP ratios showed that nitrogen was periodically in deficit (TN:TP < 6). Only in February 2024 and in June 2024 co-limitation of TN and TP occurred. The positive correlation between chlorophyll-a and phosphates mainly indicates that the higher the concentration of phosphorous in water, more is the primary productivity resulting in higher chlorophyll-a concentration. The concentration of chlorophyll-a varied across different seasons, with higher levels observed during spring and summer (March 2024 to June 2024), and lower levels in autumn and winter. Low concentration of chlorophyll-a in winters could be explained by low primary productivity, which is further related to low temperature, less nutrient concentration and less photosynthetically active radiations. Higher concentration of chlorophyll-a during spring season may be due to phytoplankton activity and lower water levels in lake ecosystem. This fluctuation exhibited a strong correlation with water quality that could be attributed to the important nutrient concentrations in spring/summer compared to autumn. This study also revealed that the phytoplankton community and distribution were mainly influenced by nutrients. Correlation analysis of Trophic state indicators revealed that average CTSI has a strong positive correlation with TSI-C index and TSI -P index indicating that the higher the values of TSI -C and TSI-P indexes the more the value of average TSI increases. Based on the average values obtained throughout the sampling period, the CTSI value was 54.53 using the standard classification, our findings indicate that the water body in the studied lake is mesotrophic to eutrophic.

## 5. Conclusion

Climate change may also have a major impact on water quality leading to changes in water chemistry. We investigated the relationship between water transparency, nutrients and chl-a to determine potential limiting factors. Carlson's Trophic State Index (CTSI) indicates a mesotrophic to eutrophic status of Plastiras Lake. The outcomes of this study may provide helpful information to improve in future the management of the lake.

## Compliance with ethical standards


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### *Disclosure of conflict of interest*

The authors have no conflicts of interest to declare.


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