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Water quality index (WQI) assessment of Plastiras Lake in Thessaly (central Greece) one year after tropical storm Daniel

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Abstract

The aim of the study was to evaluate the Water Quality Index (WQI) of Plastiras Lake in Thessaly and the possible impact of flooding on lake ecosystem one year after Daniel storm phenomenon. Water quality was determined by comparing the physical and chemical characteristics of the water sample with water quality guidelines or standards. Physic – chemical parameters were monthly monitored during the study. The tested parameters were pH, dissolved oxygen (DO), total dissolved solids (TDS), total hardness (TH), nitrogen nitrate (N-NO3), nitrite (N-NO2) and ammonium (N-NH4), phosphorous orthophosphate (P-PO4), sulfate (SO4), electrical conductivity (EC), temperature (T) and chloride (Cl^-).

Based on the results, water quality index ranged from 53,3 to 88,04 indicating lake water of good class assessing the water quality for aquatic life.

Keywords: Water Quality Index; Aggregation Function; Daniel Storm; Surface Water Quality; Surface Water Classification

1. Introduction

Quality of water sources is an important issue for water resource management. Water quality refers to the different physical, chemical and biological characteristics of water. The increasing level of pollution due to industrialization, population growth and agricultural activities with their consequences on water resources necessitate the development of WQI (Water Quality Index) that quantify and assess the quality of a given water body.

Water quality index provides a unitless single numerical value that expresses overall water quality at a certain location and time providing a detailed overview of quality of water. The first modern WQI was developed by Horton to assess the pollution by selecting ten water quality parameters to form an index with values between 0 (poor quality) and 100 (water of perfect quality).

Systematic observations of different water quality parameters are necessary not only to evaluate its quality but also for assessment of the health of ecosystems along with the usage of these sources in various domestic, industrial and agriculture spaces.

Four common steps are being followed in most of the approaches for calculation of WQI which include

- Selection of variables

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- Transformation of the variables
- Formation of sub-indices by giving weightage to each variable
- Computing an index score using aggregation of subindices [1-3]

The main aim of all the techniques used for determination of WQI were to reduce the complex monitoring data into a single value helpful in determining the quality of water and to fulfill the objectives of water quality.

The Plastiras Lake, an artificial lake in Central Greece, was constructed in 1959 and contains today 400 million cubic meters of water. Plastiras reservoir serves multiple and conflicting purposes, which are hydroelectric power generation, water supply, irrigation and recreation.

Europe has been under the influence of a weather phenomenon known as an Omega block throughout the early September 2023, 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 emerged in the Ionian Sea in Greece, partially attributed to this atmospheric setup 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 [4-6].

Therefore, the aim of this study was to provide a detailed overview of quality of water of Plastiras Lake one year after Daniel storm phenomenon and the possible impact of the flooding on lake ecosystem.

2. Materials and methods

Sampling was always carried out on a monthly basis for twelve months from November 2023 to October 2024. The water samples were collected at 1-2 m depths from the surface using Niskin bottle. The samples were kept in polyethylene bottles of 1000 ml 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.

2.1. Water Quality Index Calculations

The water quality index was determined using the World Health Organization's recommended water quality standards for water (WHO 2017). The water quality index was computed based on the weighted arithmetic method introduced by Horton (1965) and developed by Brown et al., 1972.

Calculation of water quality index (WQI) was carried out by using the expression given in equation (1).

$$WQI = \Sigma\, q_n \times W_n \,/\, \Sigma\, W_n \quad (1)$$

where, q_n=quality rating of n^{th} water quality parameter, W_n=unit weight of n^{th} water quality parameter.

The quality rating (q_n) is calculated using the expression given in equation (2).

$$q_n = [(V_n - V_{id}) \,/\, (S_n - V_{id})] \times 100 \quad (2)$$

where, V_n=estimated value of n^{th} water quality parameter at a given sample location, V_{id} = ideal value for n^{th} parameter in pure water, (V_{id} for pH = 7 and 0 for all other parameters), S_n=standard permissible value of n^{th} water quality parameter. The unit weight (W_n) is calculated using the expression given in equation (3).

$$W_n = k \,/\, S_n \quad (3)$$

where, S_n=standard permissible value of n^{th} water quality parameter, k=constant of proportionality and it is calculated by using the expression given in equation (4).

$$k = [\, 1/\, (\Sigma\, 1/S_{n=1,\, 2.n})] \qquad (4)$$

Based on the above WQI values, the quality of surface water is classified as excellent, good, poor, very poor and unsuitable, as mentioned in Table 1 [7-11].

Table 1 Water quality classification based on WQI values

Water quality index (WQI)	Rating of quality	Grading
0-50	Excellent	A
50-100	Good	B
100 - 200	Poor	C
200-300	Very poor	D
300-	Unsuitable	E

3. Methods of analysis

All calculations were done according to APHA [12]. Orthophosphate was measured spectrophotometrically with vanado molybdophosphoric acid method (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 [13]. 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. Chloride was measured with argentometric method. Silver nitrate reacts with chloride to form turbid silver chloride in proportion to the amount of chloride in the sample. Sulphate measured using barium chloride method. Sulfate ion is precipitated in an acid medium with barium chloride to form a barium sulfate suspension in proportion to the amount of sulfate present. Conductivity (EC), total dissolved solids (TDS) measurements were made using a Milwaukee digital laboratory versatile bench meter (model MW180 max) according to the official method by APHA (Standard Methods of Water Analysis). Conductivity and TDS calibration performed using two standard solutions of 84 and 1413 μs/cm. pH measurements were made using a digital laboratory pH meter (model WTW pH 525) which was calibrated using certified pH= 4.0 and pH= 7.0 buffer solutions, according to the official method. The total hardness of the water sample was determined using the EDTA (Ethylenediaminetetraacetic acid) method, which involves a titration with EDTA to complex with calcium and magnesium ions [4,12].

4. Results and discussion

For the purpose of calculation of WQI for the study area, twelve water quality parameters have been selected. They are TDS, pH, TH, N-NO3, Cl, SO4, DO, T, EC, P-PO4, N-NO2, N-NH4. The standard values of water quality parameters and their corresponding ideal values and weight factors are given in Table 2 while descriptive statistics are presented in Table 3.

Table 2 Standard values of water quality parameters and their corresponding ideal and weight factor values

No	Parameters	Unit	Ideal Value	Sn	Weight factor
1	Total dissolved solids	mg/lt	0	500	0.001
2	pH	unit	7	8.5	0.11
3	Total hardness	ppm	0	300	0.0033
4	N-Nitrate	ppm	0	45	0.1
5	Chloride	ppm	0	250	0.004
6	Sulphate	ppm	0	200	0.005
7	Dissolved oxygen	ppm	14.6	6	0.16
8	Temperature	^{o}C	24	25	0.04
9	Conductivity	μs/cm	0	300	0.0033
10	P-Phosphate	ppm	0	0.3	0.1

11	N-Nitrite	ppm	0	3	0.33
12	N-Ammonium	ppm	0	0.5	0.1

Table 3 Descriptive statistics of water parameters

	Mean	Standard error of mean	Standard deviation	Variance	Range	Min	Max
P-PO_4	0.256	0.043	0.098	0.009	0.21	0.13	0.34
N-NO_3	0.067	0.012	0.0282	0.0007	0.064	0.026	0.09
N-NO_2	0.0268	0.0050	0.0113	0.0001	0.029	0.016	0.045
N-NH_4	0.273	0.0934	0.2089	0.04364	0.43	0.08	0.51
SO_4	8.83	1.187	2.654	7.046	5.66	6	11.66
Cl	7.44	2.23	4.987	24.877	10.47	3.73	14.2
pH	7.79	0.061	0.138	0.019	0.345	7.68	8.025
T	17.16	3.062	6.847	46.890	18.5	9	27.5
D.O	8.274	0.403	0.902	0.814	2.25	7.05	9.3
E.C	940.96	107.128	239.546	57382.58	592.5	749.5	1342
TH	119.366	3.521	7.873	61.997	20	110	130

Seasonal variation of value parameters is demonstrated in Table 4. D.O. concentration ranged from 7.05 ppm in Summer 24 to 9.3 ppm in Autumn 23 with a mean value of 8.27 ppm. The mean observed values of D.O have never reached critical values complies with WHO standards indicating good water quality conditions suitable for human consumption and for most aquatic biota. PO4 - P concentration ranged from 0.13 to 0.34 with an average value of 0.256 ppm. The higher values were observed in Summer 24 while the lowest value was observed in Winter 2023.

Nitrate, an essential nutrient for aquatic plant, is the most highly oxidized form of nitrogen compounds and due to aerobic decomposition of organic matter is present in surface waters. According to WHO (2004), concentrations of observed nitrates are within acceptable range of 50 ppm and seasonal fluctuations can be caused by plant growth and decay. NO3 - N concentration fluctuated from 0.05 to 0.09 with an average value of 0.067 ppm. The higher values were observed in Winter 2023 and in Autumn 2024 (0.09 ppm) while the lowest value was observed in Autumn 2023 (0.02 ppm). A higher value of nitrate and phosphate is responsible for eutrophication, anoxia, and algal blooms in surface water bodies. NO2 - N concentration ranged from 0.016 to 0.045 with an average value of 0.0268 ppm. The higher values were observed in Summer 2024 while the lowest value was observed in Winter 2023. Concentrations of measured nitrite were within the allowable limit of 0.1 ppm for surface water.

EC parameter and concentration of TDS were observed in higher values in Autumn 24 with an average value of 940.96 ppm for EC while the lowest values were observed in Summer 24 and in Autumn 23. High observed values of conductivity due to its measure of cations, is an indirect measure of total dissolved salts, may arise through natural weathering of sedimentary rocks due to flooding or may have anthropogenic source. TH values ranged from 110 to 130 ppm with an average value of 119.3 ppm. Lake's hardness can be affected by the type of minerals in the soil and TH values in this survey are within allowable limits. NH4 - N concentration ranged from 0.08 to 0.51 with an average value of 0.273 ppm. The higher values were observed in Spring 2024 while the lowest values were observed in Autumn 2023. Sulphate concentration ranged from 6 ppm (Autumn 2023) to 11.6 (Winter 2023) with an average value of 8.83 ppm. According to WHO (2004) allowable limits of 500 ppm in aquatic ecosystems have no relation with observed mean value of 10 ppm in this study. Finally, pH value was measured in a mean value of 7.79 The pH of the aquatic systems is an important indicator of the water quality. Results obtained varied between 7.68 and 8.02 are within allowable limits for surface water. Chloride enters surface water with the weathering of sedimentary rocks or agricultural run-off. The low levels of chloride in the present study ranged from 3.73 to 14.2 ppm with a mean value of 7.44 ppm.

Correlation analysis of water parameters is presented in Table 5. 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.

Strong positive correlation was noticed between pH, EC and TDS, between N-NO3 and S-SO4. Also, good positive correlation has T with N-NO2 and N-NH3 and P-PO4 with N-NO2, Strong but negative correlation was observed between T and D.O, TH with Cl, TDS with P-PO4, N-NH3 and Cl and between P-PO4 and N-NO2. Also, notable negative correlation was observed between DO, N-NO2 and N-NH3 [14-20].

Table 4 Seasonal variation of value parameters from Autumn 23 to Autumn 24

ΠΑΡΑΜΕΤΡΟΣ	Unit	Autumn 23	Winter 23	Spring 24	Summer 24	Autumn 24
pH	unit	7.68	7.77	7.82	7.7	8.025
Temperature	^oC	14	9	16.33	27.5	19
Dissolved oxygen	ppm	9.3	8.86	8.46	7.05	7.7
EC	μs/cm	773	958.66	881.66	749.5	1342
Total Hardness	ppm	110	130	124.33	117.5	115
Total dissolved solids	ppm	387	481.66	443.33	370.5	668
Total phosphate	ppm	0.32	0.13	0.32	0.34	0.17
Nitrate	ppm	0.05	0.09	0.026	0.08	0.09
Nitrite	ppm	0.03	0.016	0.023	0.045	0.02
Ammonium	ppm	0.08	0.14	0.51	0.49	0.145
Sulfate	ppm	6	11.66	6	10.5	10
Chloride	ppm	14.2	3.73	4	3.9	11.4

Table 5 Correlation analysis of parameters

	pH	T	DO	EC	TH	TDS	P-PO4	N-NO3	N-NO2	N-NH3	S-SO4	Cl-
pH	1											
T	-0.003	1										
DO	-0.29	-0.885	1									
EC	0.96	-0.122	-0.195	1								
TH	0.025	-0.410	0.082	0.009	1							
TDS	0.965	-0.145	-0.174	0.999	0.024	1						
P-PO4	-0.56	0.551	-0.140	-0.716	-0.454	-0.724	1					
N-NO3	0.282	0.099	-0.398	0.458	0.085	0.447	-0.675	1				
N-NO2	-0.55	0.823	-0.538	-0.615	-0.468	-0.635	0.768	-0.051	1			
N-NH3	-0.16	0.612	-0.562	-0.384	0.262	-0.389	0.595	-0.407	0.497	1		
S-SO4	0.201	0.104	-0.462	0.331	0.411	0.323	-0.651	0.925	-0.053	-0.129	1	
Cl-	0.173	-0.128	0.343	0.265	-.,831	0.262	0.021	-0.025	-0.072	-0.696	-0.4	1

Table 6 Seasonal and total mean water quality index

	Autumn 23	Winter 23	Spring 24	Summer 24	Autumn 24
WQI	71.098	88.046	73.201	58.301	53.316
WQI TOTAL	68.793				

Water quality index presented in Table 6, ranged from 53.31 to 88.04 with an average value of 68.79. The higher value was observed in Winter 2023 while the lowest value was observed in Autumn 2024. High value of WQI appeared because of DO, pH, temperature and phosphate values. In addition, the seasonal values of WQI indicate that in winter season surface water is more affected than the other seasons as a result of variation in physicochemical characteristics of surface water. Based on the above WQI values, the quality of surface lake water is classified as good grading B water, assessing its quality for aquatic life.

5. Conclusion

WQI models are based on analysis of sizable datasets of water quality in order to calculate quickly and easily the water quality index, a number that represents the status of water body. Application of water quality index has been useful in assessing the overall quality of Plastiras Lake water in Thessaly and the possible impact of the flooding on lake ecosystem one year after Daniel storm phenomenon. Climate change and human actions may also have a major impact on water quality leading to changes in water chemistry.

Compliance with ethical standards

Disclosure of conflict of interest

The author has no conflicts of interest to declare.

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