# Managing the Risk of Cyanobacteria through Water Quality Characteristics Analysis: a Case Study of two Warm Mediterranean Reservoirs

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**Abstract**

This study correlated the trophic condition of two Mediterranean water bodies with different typology with their water quality characteristics. The two studied cases included Polemidia Dam, a reservoir enriched with tertiary treated wastewater in Cyprus and Lake Karla, a re-established reservoir in Greece. The aim was to identify the key environmental variables driving cyanobacteria blooming and their cyanotoxicity and therefore to address effective management tools for each case. Monitoring data collected from both sites were analyzed using mathematical models (linear regression models) and statistical tools (Principal Component Analysis) in order to first correlate the water quality characteristics with the eutrophic state of the dam and to find which component mostly explains the variation in our dataset. As expected, temperature is not a limiting factor for bloom formation for both waterbodies. Among the variables tested, phosphorus (P) was found to be the key element for the growth of cyano-HABs in Lake Karla, while a significant reduction in the TP concentration of the recycled water used to enrich Polemidia reservoir following year 2010 altered the trends of cyano-HABs formation and their characteristics. It is anticipated that the outcomes of this study will assist in identifying the most challenging issues related to cyano-HABs in warm reservoirs in the near future conditions.

**Keywords:** eutrophication, cyanobacteria, PCA, multiple linear regression, cyanotoxins

## 1. Introduction

Eutrophication is one of the most frequent problem that surface waters experience which can lead to the formation of cyanobacteria harmful algal blooms (Cyano-HABs) that directly affect water quality by producing undesirable color, taste, odor and by releasing harmful cyanotoxins into the water (Paerl, &Paul, 2012). Worldwide increase on cyano-HABs formation calls for taking both action and preventative measures to ensure the wellness of individuals coming in contact with the cyanobacterial contaminated water either through recreational activities, inadequately treated potable water, and contaminated with cyanotoxins food. Freshwater resources are constantly under pressure from climate change, urbanization, pollution, overexploitation, and increasing competition between various user groups. At European and EU Member State level, freshwater policy derives mainly from the Water Framework Directive - WFD (2000/60/EC) and calls for "good ecological status/potential" for all surface waters.

Herein, two case studies concerning Mediterranean reservoirs located in Greece and Cyprus which frequently exhibit persistent cyano-HABs are discussed. Specifically, this study focused on the newly recreated artificial Lake Karla in Greece, which is a very shallow and heavily modified waterbody, exposed to point and diffuse pollution sources due to intensive agricultural and livestock activities. Polemidia reservoir in Cyprus is one of the oldest artificial dams in Cyprus and it is solely used for crop irrigation. It is constantly enriched with tertiary treated water from the Sewerage Board of Limassol Amathus (SBLA) while until recently (2016) untreated urban and industrial wastewater was leaking into the dam from a nearby landfill of Vati, leading to enhanced eutrophication. The water quality characteristics of these surface waterbodies were linked to the formation of toxic cyanobacterial blooms.

## 2. Methods

Annual data provided by the national waterbodies authorities as well as by regular monitoring were collected and analyzed for both cases; Polemidia Dam (CY) and Lake Karla (GR). To examine which environmental variables contribute the most to the trophic condition of the reservoirs, principal component analysis (PCA) was applied because it can assess the effect of multiple variables at the same time. In addition, through multiple linear regression analysis, we were able to correlate characteristics of the blooms with nutrients (N, P) and water temperature. Multiple linear regression (MLR) analysis was performed in MATLAB® and it was used to explain the relationship between one continuous dependent variable (TP, $PO_4^{2-}$, TN, $NH_4^+$, $NO_2^-$, $NO_3^-$, $T_{water}$) and two or more response variables (Cyanobacteria biovolume, $mm^3/L$; Chlorophyll-a $mg/m^3$; COD, mg/L; Phytoplankton Biovolume, $mm^3/L$;).

## 3. Results and Discussion

The collected data were firstly organized in a way to be able to be analyzed in MATLAB®. The construction of coherent tables enabled the better understanding in revealing trends, as well as, the calculation of different ratios, such as TN:TP and DIN:TP. The dataset was split into two parts (2007-2010 and 2011-2017) as the limited nutrient based on Redfield ratio (TN:TP=16) changed from N limited to P limited, respectively. However, during years 2010, 2014, and 2015 annual average chlorophyll-a concentration was higher than 150 ppb which indicated the presence of high-density phytoplankton. It was therefore decided to use a different ratio to Redfield's TN:TP, the dissolved inorganic nitrogen concentration to total phosphorus (DIN:TP) ratio. If this ratio is DIN:TP>22 then the dam is P-limited but if DIN:TP<22 then the dam is N-limited. Indeed, this ratio reversed the results obtained by the Redfield ratio and better described the eutrophic state of the dam (Ptacnik et al., 2010).

Following this outcome, MLR analysis was reapplied for each one of the two sampling periods. Figure 1 shows an example of the data attained from cyanobacteria biovolume [$mm^3/L$] per sampling event (blue points) where the red line indicates the predicted model calculated by the input parameters for each year (2007-2015). The trends between predictive and actual data formulated better correlations following data splitting. In addition, the predictive equations were simpler for the first period compared to the second probably because during the first period the eutrophic state of the dam was N-limited while during the second it interchanged between N-limited and P-limited.

In addition, the PCA analysis performed on the data obtained from Lake Karla showed that the first axis (PC1 component) explains the 40,37 % of the total variance, highlighting the positive correlation between the concentrations of microcystins and ammonia ($NH_3$) while the second axis (PC2 component) explains the 25.3% of the variation showing the positive correlation with Temperature, TP and Nitrates.

## 4. Conclusions

To conclude, phosphorus is the nutrient that is a limiting factor for phytoplankton growth in Polemidia Dam due to fluctuations in its concentration and its drastic abatement after year 2010. The Redfield ratio (TN: TP) which is 16: 1 was not able to explain why cyanobacteria were occurring in the dam while it was giving nitrogen as the limiting factor. Therefore, the DIN:TP ratio was used as it gives a better correlation of nutrients with the concentrations of the studied parameters. Furthermore, the DIN: TP ratio considers only the forms of nitrogen present in the water column, thus better representing the availability of the elements in the Polemidia reservoir water.

There is evidence that there is not a generalizable response to anthropogenic pressures/stressors for cyanobacteria blooming, i.e. that the "one-size fits- all" approach is not appropriate across all lakes (Taranu et al., 2012) thus a "lake-type approach" should be taken for finding the most suitable management tools.

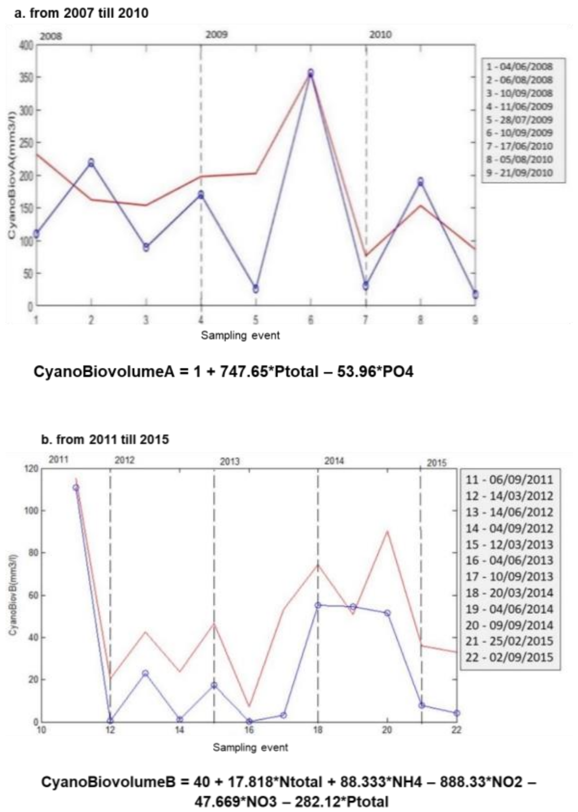


**Figure 1.** Cyanobacteria biovolume [$mm^3/L$] trends in Polemidia Dam during the period 2007 – 2015 splitted into two time frames. (a) Data from 2007 – 2010 and (b) Data from 2011 – 2015 (blue line indicates the actual data given by the WDD for each sampling event, red line indicates the mathematical model)


**References**

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