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Chlorophyll (a) and turbidity relationships with environmental variables in the Mansour Eddahbi lake reservoir (Ouarzazate, Morocco)

S. Bacroume[1,2*], S. Garras[1], S. E. Barcha[2], I. Chemaou El Fehri[1], A. Bellaouchou[2], M. Fekhaoui[1]

[1]*Group of Pollution, Ecotoxicological and Health Risk, Scientific Institute, Rabat, Morocco.*
[2]*Laboratory of Materials and Nanotechnology and the Environment, Department of chemistry, Faculty of Sciences, Mohammed V University, Rabat, Morocco.*

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[*]Corresponding Author. E-mail: bacroume27@gmail.com; Tel: (+212623504240)

Abstract
The evolution of several physico-chemical parameters in the Mansour Eddahbi lake reservoir has been analyzed via a number of linear regression models, through the analyzed equations of chlorophyll (a), turbidity and the total phosphorus. Based on the established models, this study indicates that the environmental variables (turbidity, dissolved oxygen, Kjeldahl, nitrogen, total phosphorus, chlorophyll (a), temperature and pH) are the key factors of the reservoir's phytoplankton growth. Besides, the approach based on the comparison of the chlorophyll (a) parameters with the other physico-chemical parameters could be useful as a mean of the reservoirs water quality evaluation and a new method of eutrophication analysis.

Keywords: chlorophyll; eutrophication; linear regression; Mansour Eddahbi; phytoplankton.

Introduction

The eutrophication of lacustrine environments is one of the most threatening environmental problems [1-2], Indeed it tends the entire evolution process of an aquatic ecosystem is evolving towards a state of trophic imbalance. According to the hydrological climatic conditions, the Lake undergoes major changes which settle in the surface and in-depth waters [3].and affect at the same time the physicochemical properties of the water and its watery communities [4]. In Morocco, the semi-arid climate, the development of the urban centers, the demographic pressure and the limitation of the underground water resources, make the country resorts more and more to surface waters from the lakes tanks to satisfy its population needs of drinking water [5]. Though, the eutrophication of lakes due to various discharges at the watershed level, domestic and industrial [6] wastewater can make the purification of water very complicated. On this subject many studies have been carried out analyzing the possible hazard of pollution concerning the various limnic mediums (river, natural lakes…) [7-9]. However despite these studies there is only few computer or mathematical models explaining the eutrophication phenomenon affecting the water quality [10-11]. The objective of our study is to develop a mathematical model capable of predicting the eutrophication of the dam Mansour Eddahbi, thanks to the analysis and the follow-up of several physical and chemical parameters during the (2000-2008) period.

2. Materials and methods

2.1. Study site

The Mansour Eddahbi Lake is situated on the river Draa at the confluence of Draa valley and Ouarzazate. The dam is located 25 km south-east of the city of Ouarzazate at an altitude of 1160 m and a latitude of 30 ° 56 ° N and longitude 6 ° 54 ° W.

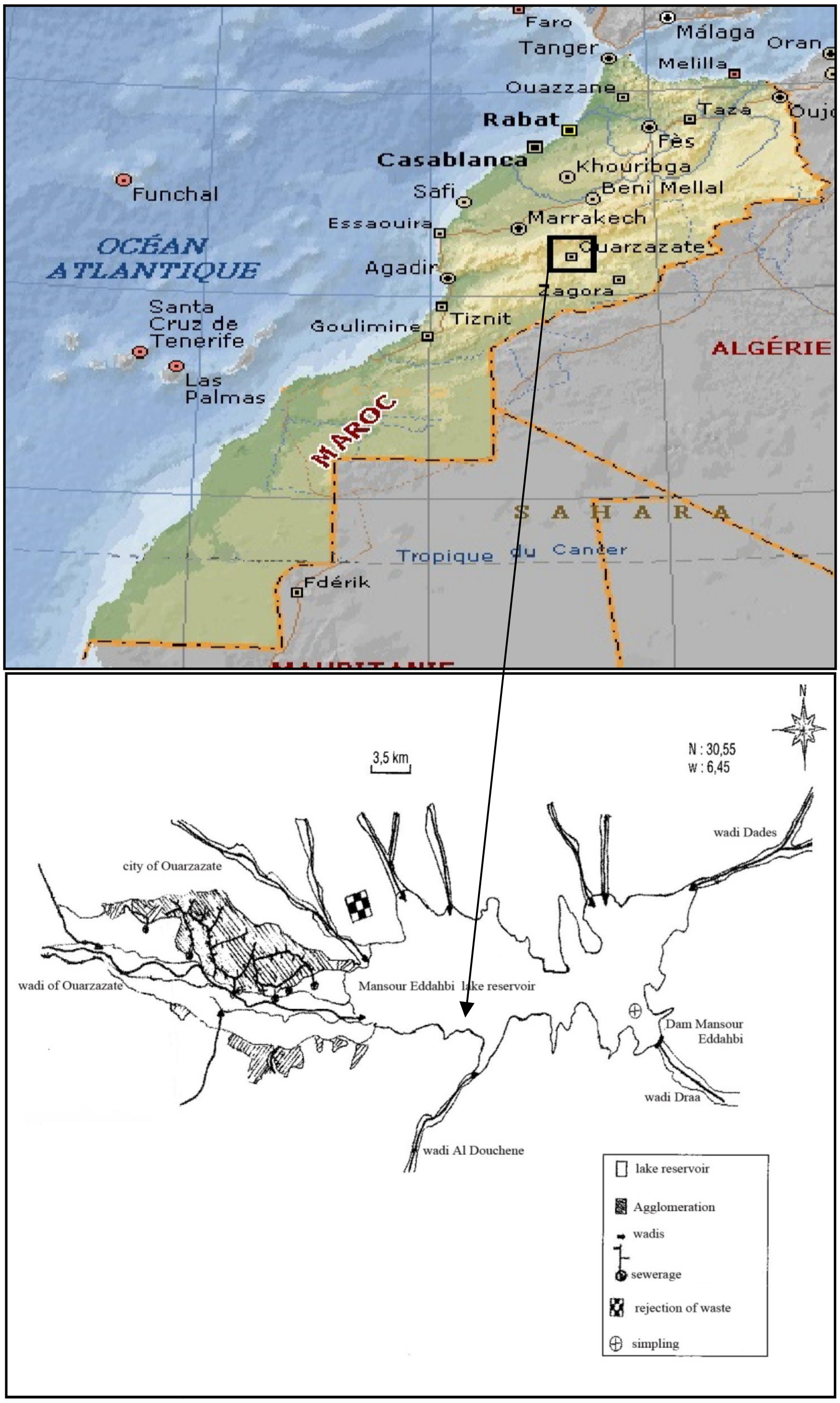

Figure 1: Geographical location of the reservoir lake Mansour Eddahbi [9].

2.2. Database and statistical analysis

The statistical analysis is based on a 3026 values database representing the daily evolution physical and chemical parameters at the reservoir Mansour Eddahbi form the 07/05/2000 to 16/10/2008. These, measurements have been done in the context of a report produced by the National Electricity Office and Drinking Water. The regression modeling was performed by the software SPSS 13, the method of analysis is based on the choice of minimizing all the variables that can explain the variation of the predicted parameter.

The environmental parameters analyzed include: water temperature (Temp) in °C, pH, conductivity (Cond) in µS /cm, the turbidity (Turb) in NTU, dissolved oxygen (DO) in mg O_2 /l, kjeldahl nitrogen (KN) in mg /l, total phosphorus (TP) in mg /l and chlorophyll (a) (Chl a) in mg / m^3.

3. Results and discussion

The bi-diversified (bi-variable) correlations of Spearman (Table 1) established between Log_{10} of the turbidity and the chlorophyll (a) with the quality parameters (total phosphorus, kjeldahl nitrogen, and dissolved oxygen), and the seasonality of the water (Temperature, pH and conductivity) show the existence of significant correlations between these parameters:

Table 1: bivariate correlations chlorophyll (a) and turbidity with different physicochemical parameter

		Log_{10}Chla	Log_{10}Turb	Log_{10}Temp	Log_{10}pH	Log_{10} Cond	Log_{10} DO	Log_{10} KN	Log_{10} TP
Log_{10} Chl a	Corr Coef	1	-0.989*	-0.978*	-0.990*	-0.981*	-0.988*	0.988*	0.983*
	Sig(2-tailed)	.	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	3026	3026	3026	3026	3026	3026	3026	3026
Log_{10} Turb	Corr Coef	-0.989*	1	0.987*	0.990*	0.993*	0.992*	-0.996*	-0.991*
	Sig(2-tailed)	0.000	.	0.000	0.000	0.000	0.000	0.000	0.000
	N	3026	3026	3026	3026	3026	3026	3026	3026

*Correlation is significant at the 0.01 level (2-tailed); Corr Coef: Correlation Coefficient; N: number of samples.

Therefore, the highlighted linear regression shows the possibility of predicting changes in chlorophyll (a) and turbidity.

3.1. Predicted chlorophyll (a) equations

The biomass of phytoplankton in terms of the concentration of chlorophyll a is one of the most widely accepted methods in the study of biological production as it indicates total plant material available in the water at primary level of the food chain [12-13]. Hence the growing and declining condition of algal bloom can be described by the spatial and temporal variation of chlorophyll (a).
Based on the correlations of chlorophyll (a) and the various physical and chemical parameters, several equations have been established to estimate the evolution of chlorophyll (a) (phytoplankton) in the Mansour Eddahbi lake reservoir.

Equation 1:

$$Log_{10}Chl\ (a) = 9.185 + 0.933 Log_{10}Temp - 10.665\ Log_{10}pH - 0.116 Log_{10}Turb - 0.084\ Log_{10}TP \quad \textbf{(1)}$$

(R^2=0.825; n=3026; P<0.001)

The variance of the chlorophyll (a) (dependent variable) which was expressed by the independent variables is 82.5%. Table (2) analysis of variance (ANOVA) indicates that this strong relation isn't due to random sampling and the model is significant (p <0.001).

Table 2: ANOVA of model (1)

Model (1)	Sum of squares	Df	Mean square	F	Sig
Regression	5.675	4	1.419	3546.347	0.000
residual	1.207	3018	0.000		
Total	6.882	3022			

The phosphorus is an essential nutrient to plant growth, however [14-15], above a certain concentration and when conditions are favorable, it can cause excessive growth algae and higher aquatic plants. This increase may be followed by an accumulation of plant biomass and detritus which generally lead to a degradation of the water quality [16].

Various studies showed that the Chl (a) is well correlated with the TP, with the consideration that it is the limiting factor of algal growth [17-19]. Although, the equation (1) indicates the importance of other elements such as the phosphorus. Another impressive parameter is the pH in the equation (1) and the negative relationships pH-Chl (a) that is due to the effect of the first one as a good tracer of the photosynthetic activity of the phytoplankton, in the middle aquatic environment. The phytoplankton could influence the value of the pH, in the fresh water system [20]. The pH changes are function of the photosynthetic activity that removes CO_2 from the environment and the acid-base balance of the carbonate species reactions [21]. However, as shown in equation (*) Redfield [22] consumption of protons will also help increase the pH during photosynthesis:

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O + 18\ H^+ \text{ (+trace elements + Light Energy)} \quad (*)$$
$$\downarrow$$
$$\{C_{106}H_{263}O_{110}N_{10}P_1\} + 138\ O_2$$

Globally, in aerobic conditions, the release of phosphorus by the sediment is stimulated by the pH increase by the following reacting following mechanism:

$$FePO_4 + H_2O + 2OH^- \longrightarrow Fe\,(OH)_3 + HPO_4^{2-}$$

However, in anaerobic medium the ferric iron attached to the phosphorus is reduced by the following reaction:

$$FePO_4 + H_2O + e^- \longrightarrow Fe^{2+} + OH^- + HPO_4^{2-}$$

So the release of phosphorus by the sediment is controlled by the pH and the redox potential [23-24], this can explain the interaction between pH -Chl (a).

Moreover the water temperature is a major driver in the algal growth. It is positively correlated with phytoplankton in most seasons [1]. It is a key regulatory factor for phytoplankton community composition and algae-bloom [12-25]. Alternatively, the turbidity has a negative effect on algal photosynthesis. It influences the degree of light penetration in the water column; also the turbidity adsorbs phosphates (nutrient) by silt [25].This may explain the interaction of the turbidity and chlorophyll (a).

Equation 2:

$$Log_{10} Chl\ (a) = 0.627 + 0.156\ Log_{10} KN \qquad \textbf{(2)}$$
$$(R^2=0.734;\ n=3026;\ P<0.001)$$

In the equation (2) 73.4% of the variance of chlorophyll (a) haves been expressed by kjeldahl nitrogen (KN), the result of table (3) indicates that the model is significant ($p < 0.001$).

Table 3: ANOVA of model (2)

Model (2)	Sum of squares	df	Mean square	F	Sig
Regression	5.242	1	5.242	8342.609	0.000
residual	1.900	3024	0.001		
Total	7.143	3025			

The nitrogen and the phosphorus are the nutrients essential for algal growth; they can reach freshwaters through different pathways. They are in different forms: N_2, NH_4^+, NO_3^-, NO_2- and N-organic.

Biological nitrogen fixation is the process used by many organizations to extract atmospheric nitrogen. The nitrogen is then reduced before being assimilated

$$N_2 \longrightarrow (NH_3) \longrightarrow \text{cells}$$

So the overall reaction of the reduction of N_2 to NH_3 was as follows

$$N_2 + 6e^- + 6H^+ \longrightarrow 2NH_3$$

The assimilation of nitrogen corresponds to the transformation of mineral nitrogen combined organic nitrogen of living matter (amino acids, proteins)

$$\text{Nitrogenous matter} \longrightarrow NH_3 \longrightarrow R\text{-}CH(NH_2)\text{-}COOH \longrightarrow \text{cellular proteins}$$

However, the insertion of KN(kjeldahl nitrogen) in equation (1) does not provide any new response element, knowing that KN allows predicting Chl (a) equation (2).This can be explained by fact that the nature of the interaction of nitrogen and biomass is indirect, in shallow lakes, phosphorus is the limiting element[1].

Equation 3:

$$Log_{10}Chl\ (a) = 1.57 - 1.099\ Log_{10}DO \qquad \textbf{(3)}$$

(R^2=0.762; n=3026; P<0.001)

The variance of chlorophyll (a) which was expressed dissolved oxygen (DO) is 76.2%, the model is significant (p <0.001) from table (4).

Table 4: ANOVA of model (3)

Model (3)	Sum of squares	Df	Mean square	F	Sig
Regression	5.439	1	5.439	9657.313	0.000
residual	1.703	3024	0.001		
Total	7.143	3025			

The dissolved oxygen (DO) is an important indicator of the ability of a water body to support aquatic life. Low DO concentration (3mg/l) in fresh water aquatic system indicates higher pollution causing negative effects on aquatic ecosystem. This model reflects the influence of algal biomass on the dissolved oxygen rate during photosynthesis and during the decomposition of organic matter. The sign of the correlation DO- Chl (a) (positive or negative) depends on the oxygen production rate and the consumption rate in the decomposition of organic matter. The correlation is positive if the production rate exceeds the consumption rate and vice versa [12-25].

3.2. Predicted turbidity equations

By the same approach followed in the models of Chlorophyll (a), we established the models of the turbidity, the parameter of control of the eutrophication (transparency):

Equation 4:

$$Log_{10}Turb = -11.392 + 0.326 Log_{10}Temp + 7.193\ Log\ pH + 0.964 Log_{10}Cond + 1.988 Log_{10}DO \quad \textbf{(4)}$$

(R^2=0.957; n=3026; P<0.001)

95.7 % of the variance of the turbidity is explained by the independent variables, it is a significant model (p<0.001), based on the result of table (5).

Table 5: ANOVA of model (4)

Model (4)	Sum of squares	Df	Mean squares	F	Sig
Regression	378.68	4	9.467	16938.271	0.000
residual	1.688	3021	0.001		
Total	39.557	3025			

Turbidity is caused by particles suspended or dissolved in the water that scatter light making the water appear cloudy or murky. Particulate matter can include sediment -especially clay and silt, fine organic and inorganic matter, soluble colored organic compounds, algae, and other microscopic organisms. The turbidity reflects the minerals dissolved in the water and this may explain the relation Turb-Cond. The dissolved oxygen used during the decomposition of organic matter leads to inorganic compounds that increase the turbidity; the inorganic compounds are treated again by living aquatic organisms to produce the organic matter.

Equation 5:

$$Log_{10}Turb = 0.287 - 0.427\ log10\ KN \quad \textbf{(5)}$$

(R^2=0.986; n=3026; P<0.001)

The variance of the turbidity was explained by kjeldahl nitrogen (KN) is 98.6%. The result of table (6) indicates that the model is significant (p <0.001).

Table 6: ANOVA of model (5)

Model (5)	Sum of squares	Df	Mean squares	F	Sig
Regression	39.008	1	39.008	215225.15	0.000
residual	0.548	3024	0.000		
Total	39.557	3025			

The correlation turbidity with kjeldahl nitrogen (KN) explained that KN is a nutrient promotes algal blooms.

Equation 6:

$$Log_{10}Turb = 1.561 - 0.188\ log_{10}TP - 2.105\ log_{10}Chl\ (a) \quad \mathbf{(6)}$$

(R^2=0.768; n=3026; P<0.001)

In this equation 76.8 % of the turbidity variance was expressed by the total phosphorus (TP) and chlorophyll (a), the table (7) show that this model is significant (p<0.001).

Table 7: ANOVA of model (6)

Model (5)	Sum of squares	Df	Mean squares	F	Sig
Regression	30.345	2	15.173	4993.15	0.000
residual	9.177	3020	0.003		
Total	39.522	3022			

This model reflects the interaction of the turbidity with organic matter (Chl (a)) and with nutrient (TP) that promotes the production of organic matter.

Conclusion

Eutrophication is a complex phenomenon influenced by environmental factors. It could modify the dynamics of physicochemical variables in the environment and the relationships between them. The regression model developed, highlighted the interactions of the turbidity and the chlorophyll (a) with physicochemical parameters. However, the model (1) as given below;

$$Log_{10}Chl\ (a) = 9.185 + 0.933 Log_{10}Temp - 10.665\ Log_{10}pH - 0.116 Log_{10}Turb - 0.084\ Log_{10}TP$$

Establishes functional relationships between chlorophyll (a) and the main indicators of the trophic state parameters and might be considered as an effective predictive model of the evolution of phytoplankton growth of dams in general, and of the Mansour Eddahbi Lake, in particular. This prediction will carry out the managers to make adequate decisions for safeguarding the quality of the water and the watery ecosystem and its link with the public health

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