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Total Phosphorus Behavior Modelling in the Smir Lake Reservoir (Tetouan, Morocco)

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Abstract
In Morocco, as elsewhere in the world, the phenomenon of eutrophication threatens to destroy the fragile balance of most water resources, especially water reservoirs and dams. To contribute to the knowledge of the key factors involved in the sound understanding and proper management of this phenomenon, we undertook the task of exploiting a basic physicochemical Smir dam data, collected from 2001 through 2008, with a view to developing mathematical approaches and numerical models susceptible of providing information on the current status as well as expected future developments relative to the changes that are likely to trigger this process. To this end, we have analyzed the behaviour of several parameters; namely, phosphorus, a major element that characterizes the eutrophication of inland waters. The results obtained indicate the possibility of predicting the behaviour of the total phosphorus in function of several environmental variables and the corresponding trophic state.

Keywords: Eutrophication, Modelling, Phosphorus, Smir lake reservoir.

Introduction
Morocco boasts a wealth of renewable water resources estimated in annual average at 20 billion m^3, including 16 billion m^3 of surface water and 4 billion m^3 of subterranean water. This quantity equals a ratio of about 691 m^3 per inhabitant per year [1].
Water availability depends upon weather conditions, which are relatively unfavourable. Morocco's hydraulic infrastructure is currently made up of 130 large dams, including the Smir reservoir, which is located in the northern part of the country.
Protecting dams has been an issue of growing concern for years, even though one cannot always be successful and the protection and precautions necessary thereto are not always guaranteed.
Eutrophication is one of the serious ecological problems concerning fresh water worldwide [2-3]. It has for long been an issue for people in charge of water management as well as for researchers working in aquatic areas. It is generally defined as the enrichment of water in nutrients, primarily phosphorus and nitrogen, which are favourable to the growth of vegetation (both algae and macrophytes). Eutrophication is most often associated with anthropogenic effects resulting from the presence of agricultural land, waste discharged by sewage treatment plants or domestic effluents [4]. It causes the degradation of aquatic habitat and a decline of biodiversity. Such deterioration is, of course, not shorn of detrimental effects on human health as the quality of water worsens, which renders the treatment of storage facilities to produce drinking water complex and costly [5- 6].
If the special and temporal follow-up of the evolution of the physico-chemical parameters are well-known [7-8], the modelling of eutrophication remains, nevertheless, a new approach to predict the trophic status of a dam. And in order to develop a new understanding of the eutrophication process, it is important to study the link between the evolution of environmental variables (temperature, pH, PT, turbidity, dissolved oxygen (DO)…) and the dynamic of phytoplankton [9-10]. This phytoplankton dynamic, in terms of biomass, is represented by the concentration of chlorophyll (a) (Chl a), which is one of the most widely accepted methods in the study of the biological production of aquatic phytoplankton [11].

In order to explore the link between environmental variables and algae biomass, the multi-varied statistical analysis is the most commonly used in assessing the quality of surface water and characterizing eutrophication [12]. By means of this statistical approach, strong relationships between phosphorus, chlorophyll (a) and water transparency have been observed and reported for the fresh water systems worldwide [13-17]. This achievement has enabled researchers to establish, through linear regression, mathematical models that predict the existence of chlorophyll (a).
Besides, the majority of these models are only used for the concentration of chlorophyll (a), total phosphorus and transparency, although light and temperature constitute, together with nutrients, the major variables that control photosynthesis in aquatic areas. Other researchers followed the same approach to establish their model of chlorophyll (a) prediction, with the insertion of other environmental variables (DO, T, SiO4, KN, pH…) [8,18]. Nevertheless, and through the same approach, we try to establish a model through linear regression that predicts total phosphorus in the Smir Lake, basing our work on the strong correlations that exist in relation with other environmental parameters.

2. Materials and methods

2.1. Study Site

The site of the dam at Oued Smir is located 22 km away from the city of Tetouan (Figure 1). It was used to store water in 1991, and is used exclusively to provide drinking water for the city as well as an important number of summertime vacation centers (M'diq, Martil, Restinga, Cabo Negro and Fnideq).
The average annual input of the site is on the order of 31 million m^3. It is made of altered and healthy schist in depth covered with alluvia. It is located in a catchment area covered with medium-size vegetation that allows, due to erosion caused by rains, to move large quantities of suspended matter and nutrient substances to the dam [19; 20]. The principal morphometrical characteristics of this reservoir lake can be summed up in Table 1

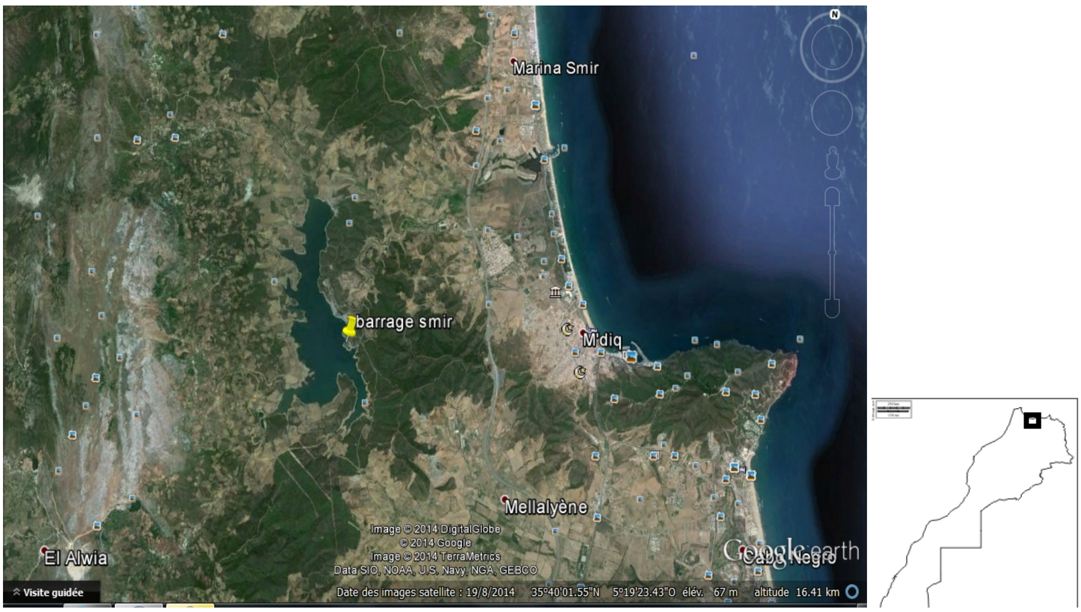

Figure 1*:* Geographic location of the Smir lake reservoir(google earth 2014)

Table 1*:* Main morphometric characteristics of the Smir lake reservoir

Normal level of restraint	43,50 NGM
Overall capacity of the reservoir	43 Mm^3
Annual average intakes	31 Mm^3
Surface of the retaining	4,7 Km^2
Average depth of restraint	15 m

2.2. Statistical Analysis

The data were analyzed from a database (BBD) obtained within the framework of an agreement between the National Electricity Office and Drinking Water - Water Branch (Branch Onee-Water) and BD consulting , with the values of several physical and chemical parameters measured at the reservoir lake Smir. The data sample consists of 2778 observations, made over a period lating from 09/01/2001 to 19/08/2008 using SPSS20 software. The missing values were estimated by different correlations for each parameter; and regression models were established between different physico-chemical parameters of the dam. The analysis method is based on theselection of the minimum set of variables that can explain the variation of the predicted parameter. The parameters tested include: water temperature (T) in centigrade scale, pH, conductivity (Cond) in S/cm, turbidity (Turb) in NTU, dissolved oxygen (DO) in mg/l; Kjeldahl nitrogen (KN) in mg/l, total phosphorus (TP) in mg/l and chlorophyll (a) (Chl a) in mg/m^3.

With

T: water temperature measured in Celsius (°C) degree.

pH: potential for hydrogen, an index that allows for the measurement of hydrogen ion in a solution. It is an indicator of acidity.

Conductivity: a measurement of the concentration in water of inorganic salt, and the aptitude of the latter to serve as a conduit for electricity. In natural waters, it is low but rises with pollution; Conductivity allows for the overall appreciation of the ensemble of products in water solutions. Here it is expressed in micro-siemens per centimetre.

Turbidity: a manifestation of water whose transparency is limited by the presence of solid matters in suspension. The appropriate measurement unit is Nephelometric Turbidity Unit (NTU).

Dissolved Oxygen (DO): the quantity of oxygen (O_2) available in water, and vital for aquatic life, as well as for the oxidation of organic matter; the result of analysis is expressed in mg/l. (milligram per litre).

The Kjeldhal nitrogen (KN): it is the sum of organic nitrogen+ammoniac contained in water. The result of analysis is expressed in mg/l. (milligram per litre).

Total phosphorous (TP): a vital element for the development of all living organisms, TP = P organic + P mineral expressed in mg/l. (milligram per litre).

Chlorophyll (a): a pigment present in all plant cells, a parameter which is indicative of algae density, expressed in mg/m3 (milligram per cubic metre).

A simple linear model is formalised according to the linear regression which follows:

$$Y = aXi + b + \varepsilon$$

where :

- Y is the variable to be explained (dependent),
- X is the variable to be explained (independent),
- a and b are the regression parameters,
- ε is a residue due to the effect of the variables that have not been taken into consideration in the model.

This general equation may be simplified by eliminating the non-significant terms with a view to obtaining a more reduced equation. With i = 1,2….2778 observations

3. Results and discussion

The analysis of multiple linear regressions is a general technique used to analyze linear relationships between a single dependent variable and several other independent variables. However, this analysis is closely linked to that of correlation; the stronger correlation is between two variables, the better it becomes for us to predict or explain the value of the dependent variable.

With regard to total phosphorus, this approach shows strong correlations with turbidity (0.866) and dissolved oxygen (0.659), and medium correlations with temperature (0.58) and pH (0.459) (table 2). This helps come up with a model of linear regression between phosphorus and these four variables.

Therefore, we have ignored the correlation between total phosphorus and the other remaining parameters: conductivity (0.165), kjeldahl nitrogen (0.299) and chlorophyll (a) (0.081), as they present weak correlations.

Table 2: Bivariate correlation of Log_{10} of total phosphorous concentration with different physico-chemical parameters

		Log_{10} TP	Log_{10} Turb	Log_{10} T	Log_{10} pH	Log_{10} DO	Log_{10} Cond	Log_{10} KN	Log_{10} Chla
Log_{10} PT	Pearson Correlation	1	0.866**	-0.58**	0.459**	0.659**	-0.165**	-0.299**	0.081**
	Sig. (bilateral)		0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	2780	2779	2780	2780	2780	2780	2780	2780

** The correlation is significant at 0.01 degree (bilateral), N: Number of observations.

3.1. MODEL 1

For the purpose of our modeling process of total phosphorus, we will analyze the linear relationships between total phosphorus during the study period of time stretching from 09/01/2001 to 19/08/2008, using instructions provided by the SPSS20 software, by the four chosen variables.

Fisher Hypothesis Test: « ANOVA Test »

We can study the relationship between total phosphorus and other variables by means of a hypothesis that allows us to test the nullity of the slope of the regression line. To do so, we will resort to the analysis of variance on the SPSS -Test ANOVA software (table 3).

Table 3: Analysis of Model Variance

Model	Sum-of-Squares	ddl	Mean of Squares	D	Sig
Regression	51,053	4	12, 763	2655,597	0,000
Residue	13,332	2774	0,005		
Total	64,385	2778			

When the "means of squares" correspond to the value of the sum of squares divided by their respective freedom degree, the level of significance (sig) is by far below 5%. Consequently, the line slope is different from 0, and the variable explains significantly the model.

Adjustment Quality: R^2 Determination Coefficient

When we develop a statistical model, we aim to explain as far as possible the variability of parameters; that is, the model variance. Thus, the more we explain this variance, the better the quality of parameter representation by the model will be.

To assess the quality of variability or variability promotion of total phosphorus, we resort to the determination coefficient R-Two (or R^2). (table 4)

Table 4: Coefficient of R-Two Determination

Model	R	R-Two	Estimate Standard Error	Statistical Changes				
				R-Two Variation	F Variation	ddl1	ddl2	Sig.
1	0.890	0.793	0.069326	0.793	2655.597	4	2774	0.000

As a result, 79,3% of the total phosphorus variance (dependent variable) has been shown by the independent variables: pH, turbidity, dissolved oxygen and temperature, which are seasonality variables. This strong relation is not random, and the model is significant ($p<0,001$) (table 3) and (table 4).

Confidence Intervals of the Model

On the other hand, the decomposition of variability and the importance of each parameter in the regression model (1) (table 5) gives us an idea on the weight of each variable in equation (1).

According to the table above, we notice that the significance level of all explanatory variables is lower than 5%, and that the equation of the linear line is given by the same table. Therefore, we have got the following regression equation:

$$Log_{10}(TP) = -12.593 + 0.726\ log_{10}(Turb) + 8.604\ log_{10}(pH) + 2.147\ Log_{10}(DO) + 1.078\ Log_{10}(T) + \varepsilon$$

(1) With R^2= 0,793, p=0,000 and N=2780

In another respect, decomposition of variability and the importance of each parameter in the regression model (1) (table 5) give us an idea on the weight of each variable in equation (1).

Table 5: Coefficients of each Parameter of Model (1)

Model 1	Non-Standardised Coefficients		Standardised Coefficients	t	Sig
	A	Standard Erreur	B		
Constant	-12,593	0,836		-15,061	0,000
$\log_{10}$ Turb	0, 726	0, 015	0, 810	47,264	0,000
$\log_{10}$ pH	8,604	1,037	0, 096	8,294	0,000
$\log_{10}$ DO	2,147	0, 143	0, 188	15,055	0,000
$\log_{10}$ T	1,078	0, 135	0, 135	7,988	0,000

*B: Coefficients of each Parameter

3.2. MODEL 2

We again use the same approach while we eliminate in this case the pH variable.

- *Fisher Hypothesis Test: «ANOVA Test»*

Table 6: Analysis of Model (2) Variance

Model		Sum of Squares	ddl	Mean of Squares	D	Sig.
2	Total Regression	50,722	3	16,907	3433,974	0,000
	Residue	13,663	2775	0,005		
		64,385	2778			

The level of significance (sig) is much lower than 5%; consequently, the line slope is different from 0, and the variable explains significantly the model.

- *Quality Adjustment : Coefficient of R^2 Determination*

Table 7: Coefficient of R-Two Determination

Model	R	R-two	Adjusted R-Two	standard Estimate Error
2	0,888	0,788	0,788	0,070168204462223

Thus, 78.8% of the total phosphorus variance (dependent variable) is expressed by the independent variables: turbidity, dissolved oxygen and temperature. This strong relationship is not random, and the model is significant ($p<0,001$), (table 6) and (table 7).

- *Confidence Intervals of the Model*

In addition, decomposition of the variability and the importance of each parameter in the regression model (2) (table 8) gives an idea on the weight of each variable in equation (2).

Table 8: Coefficients of Each Parameter of the Mu model (2)

Model 2		Non-standardized Coefficients		Standardized Coefficients	t	Sig.
		A	Standard Error	Beta		
2	(Constant)	-5,886	0,215		-27,340	0,000
	Log_{10}Turb	0,794	0,013	0,885	60,397	0,000
	Log_{10}DO	2,547	0,136	0,223	18,743	0,000
	Log_{10} T	1,723	0,112	0,215	15,433	0,000

The data presented by the table above shows that the level of significance of all explanatory variables is lower than 5% and the linear line equation is shown by the same table. As a result, we get the following regression equation:

$$Log_{10}(PT) = -5.886+0.794log_{10}(Turb) + 2.547\ Log_{10}(DO) +1.723\ Log_{10}(T) + \varepsilon$$

(2) With R^2= 0,788, p=0,000 and N=2780

3.3. MODELE 3

We will then eliminate the turbidity variable, and consider whether the omitted module is significant.

- *Fisher Hypothesis Test: « Test ANOVA »*

Table 9: Analysis of Model Variance (3)

Model		Sum of Squares	ddl	Mean of Squares	D	Sig.
	Regression	31,373	2	15,686	1307,404	0,000
3	Residue	33,319	2777	0,012		
	Total	64,691	2779			

The level of significance (sig) is much lower than 5%. Accordingly, the line slope is different from 0, and the variable explains significantly the model.

- *Adjustment Quality: Coefficient of R² Determination*

Table10: Coefficient of R-Two Determination

Model	R	R-two	Adjusted R-Two	Standard Error Estimate
3	0,696	0,485	0,485	0,109535560275912

Thus, 48.5% of the total phosphorus variance (dependent variable) has been shown by the two independent variables: dissolved oxygen and temperature, and the model is significant (p<0,001) (table 9) and (table 10).

- *Confidence Interval of the Model*

In addition, the decomposition of the variability and the importance of each parameter in the regression model (3) (table 11) gives us an idea on the weight of each variable in equation (3).

Table 11: Coefficients of Each Parameter of the Model (3)

Model 3		Non-Standardisés Coefficients		Standardisés Coefficients	t	Sig.
		A	Standard Error	Beta		
	(Constant)	-2,901	0,326		-8,891	0,000
3	Log_{10} DO	5,515	0,197	0,484	28,013	0,000
	Log_{10} T	-2,264	0,137	-0,285	-16,494	0,000

According to the table above, we notice that the level of significance in all the explanatory variables goes below 5%, and that the equation of the linear line is shown by the same table.
Thus, we get the following regression equation:

$$Log_{10}(TP)= -2.901+5.515\ Log_{10}(DO)-2.264\ Log_{10}(T) + \varepsilon$$

(3) With R^2= 0,485, p=0,000 and N=2780
According to the Fisher Hypothesis Test, we can conclude that the models present a level of significance that is much lower than 5%.

According to the coefficient of R^2 determination: R^2= 0,793 for Model (1), R^2= 0,788 for Model (2) and R^2= 0,485 for model (3). Therefore, it is Model (1) that presents the strongest R^2 coefficient, followed by Model 2.
According to the confidence interval of Models (1), (2) and (3), Model (1) gives importance to the pH variable, while Model (3) gives importance to the dissolved oxygen variable. Concerning temperature, we can say that

there is no big change between Model (1) and Model (2), while there is a slight increase of its weight in Model (3).
In conclusion, Model (1) is more reliable and responds to the three tests already carried out.
Phosphorus is often a limiting element of vegetal production and plays a significant role in the process of eutrophication of a reservoir [16,21-24].
The original source of this element is strictly geological. It is much absorbed onto the clay particles of the water column, which reduces its availability for algae and macrophytes. However, intakes of nutrient salts, especially phosphorus coming from wastewater disposal in watercourses, explain the high productivity of algae.

- Phosphorus-pH Relation

Alkalinity or the acidity of aqueous spaces depends primarily on the existing quantity of CO_2 as well as on the importance of photosynthetic intensity [25]. Absorption of dioxide by plants is, in fact, proportional to the increase of the phytoplankton photosynthesis and can increase the value of pH in fresh water [26], and consequently, the decrease of fixation capacity of phosphorus to iron and aluminum hydroxides and the ions orthophosphates related to iron [27].
Mobilization of phosphorus can be affected by several factors such as temperature, dissolved oxygen, and pH, and the nature of sediments [28-29-30]. In anoxic conditions, release of chemically related phosphorus is due to the reduction of oxides [31], mineralization of organic matter [25-32] and acidification of sediments [33].

- **Total Phosphorus-Turbidity Relation**

This relation can be linked to heavy rainfall which causes more intense water flow on the ground, and results in a bigger quantity of suspended matter, especially phosphorus, iron, manganese, for the study site abounds in iron manganese [20]; and in the watercourses, the higher the quantity of suspended matter is, the higher turbidity might be. It can also be due to the death of phytoplankton algae which release phosphate groups from organic molecules, releasing a larger and more important quantity of phosphorus in water.

- **Total Phosphorus-Dissolved Oxygen Relation**

Organic matter (phytoplankton) is thus taken care of by micro-organisms that are decomposers such as heterotrophic bacteria. The latter, by their enzymatic interaction, mineralize particle and dissolved organic phosphorus. This mineralization consumes dissolved oxygen, whose low concentration can affect the conditions of oxide reduction at the level of sediments and favours sustained release of phosphorus [27].

- **Relation Total Phosphorus-Temperature**

Water temperature remains an essential component in the process of algae growth. It correlates positively with phytoplankton in most seasons [3]. It represents a regulating factor for the abundance of phytoplankton and the composition of algae community [2]. Apparition of algae can only be observed at a temperature of 20°C [25]. Finally, temperature is among the components that control the sustained release of sediment phosphorus.

Conclusion

In this study, the mathematical model obtained:

$$\boxed{\mathrm{Log10(PT)} = -12.593 + 0.726\ \log10(\mathrm{Turb}) + 8.604\ \log10(\mathrm{pH}) + 2.147\ \mathrm{Log10}\ (\mathrm{DO}) + 1.078\ \mathrm{Log10}\ (\mathrm{T}) + \varepsilon}$$

reveals that there exists a significant link between phosphorus, which is a dominant component of eutrophication, and the other physico-chemical parameters such as pH, turbidity, dissolved oxygen and temperature.
This model helps us to observe the evolution of phosphorus and limit the parameters that intervene in the eutrophication process of the Smir Dam.
By using the model thus constructed, we can better understand where the risks of eutrophication exist today within the different sites of the dam. Finally, the model enables us to predict and examine what will happen in the future in the area of eutrophication.
In future studies, it would be highly commendable to explore whether this simple phosphorus model can be applicable to other dams of the country.

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