

Prediction of Chlorophyll *a* in Kurtboğazı and Çamlıdere Reservoirs

Nilsun DEMİR¹ Handan ÇAMDEVİREN² Sıddık KESKİN²

Geliş Tarihi : 16.11.1998

Abstract : The relationships between chlorophyll *a* and some physical and chemical properties of water were investigated by using multiple linear and nonlinear regression models in Kurtboğazı and Çamlıdere reservoirs. With these two different approaches chlorophyll *a* was aimed to be estimate more accurately.

The determination coefficients were found as 95% and 82% for multiple linear regression models while 85% and 70% for nonlinear regression models for Kurtboğazı and Çamlıdere reservoirs, respectively.

Key Words: Chlorophyll *a*, reservoir, multiple regression, nonlinear model

Kurtboğazı ve Çamlıdere Barajlarında Klorofil *a*' nın Tahmini

Özet : Kurtboğazı ve Çamlıdere barajları için kurulan çoklu doğrusal ve doğrusal olmayan regresyon modellerinden yararlanılarak, suyun bazı fiziksel ve kimyasal parametreleri ile klorofil *a* arasındaki ilişkiler değerlendirilmiştir. Bu iki farklı yaklaşımdaki amaç klorofil *a*' nın güvenilir bir şekilde tahmin edilmesidir.

Belirleme katsayıları Kurtboğazı ve Çamlıdere baraj gölleri için, doğrusal çoklu regresyon modelinde sırasıyla %95 ve %82 olarak bulunurken, doğrusal olmayan regresyon modellerinde %85 ve %70 olarak bulunmuştur.

Anahtar Kelimeler : Klorofil *a*, baraj, çoklu regresyon, doğrusal olmayan model

Introduction

The strong relationships between physical, chemical parameters and organic matter in water environment were used for the estimation of biomass and nutrients in last decades. Models improved in these studies were classified as;

- a- Simple linear and nonlinear regression models,
- b- Multiple linear and nonlinear regression models,
- c- Path analysis.

Most of these studies incorporated the use of simple linear and nonlinear regression models. Chlorophyll *a*, total phosphorus, Secchi depth were selected as dependent variable (Dillon and Rigler, 1974; Seip et al., 1992; Mazumder, 1994a; Mazumder, 1994b; Zakova et al., 1993; Komarkova and Hejzlar, 1996). There are a few studies in which multiple linear regression, nonlinear regression models and path analysis were used (Brezonik, 1978; Hoyer and Jones, 1983; Vezina and Pace, 1994).

Multiple regression model was preferred to simple regression model in this study, because multiple regression model describes the variation better while maintaining all linear and nonlinear direct effects.

Some model studies were performed for water sources of Turkey (Curi ve Tanyeri, 1974; Gökkurt, 1989; Pulatsü et al., 1997). Limnological properties of Çamlıdere and Kurtboğazı reservoirs were investigated by Bakan (1997). This will be the first model for a reservoir in Turkey.

The aim of this study is to improve models which describe variation on the chlorophyll *a* and to determine complex relationships between parameters in Kurtboğazı and Çamlıdere reservoirs.

Material and Method

Çamlıdere reservoir is situated 60 km southwest of Ankara. The reservoir has a surface area of 32 km². In the reservoir, three stations were sampled. Station 1, located approximately 100 m distance from the dam, station 2 and station 3 located in the same distance east and west of station 1 (Fig. 1).

¹ Universite of Ankara, Faculty of Agriculture Dep. of Fisheries and Aquaculture-Ankara

² Universite of Ankara, Faculty of Agriculture Dep. of Animal Science-Ankara

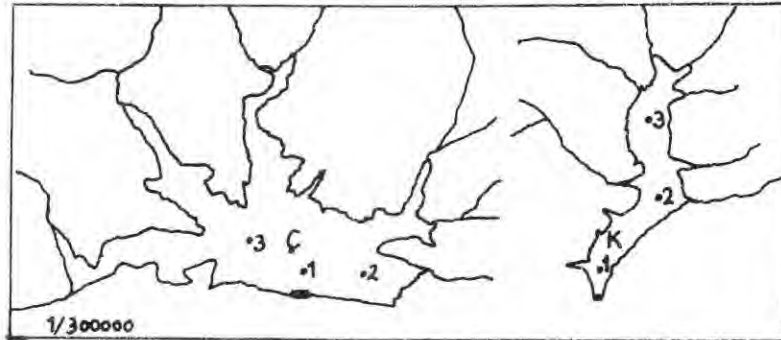


Figure 1. Maps of study reservoirs, Ç; Çamlidere, K; Kurtboğazi (• : sampling stations)

Kurtboğazi reservoir is situated 56 km west of Ankara in central Anatolia. The surface area of the reservoir is 5.5 km². In the reservoir, three stations were sampled. Station 1 located approximately 100 m distance from the dam, station 2 located in middle part of the reservoir and station 3 located in the northern part of the reservoir (Fig. 1).

Kurtboğazi and Çamlidere reservoirs were sampled monthly from June 1995 to May 1996. Water temperature (T), electrical conductivity (EC), Secchi depth (SD), pH and dissolved oxygen (DO) were measured *in situ*. In addition, organic matter (OM), alkalinity (Alk), total hardness (H), calcium (Ca) and magnesium (Mg) hardness, nitrite-nitrogen (NO₂-N), nitrate-nitrogen (NO₃-N), ammonia-nitrogen (NH₃-N), orthophosphate (ORTO) and total phosphorus (TP) were determined according to APHA (1975).

Phytoplankton (Phyto) and zooplankton (Zoo) samples were counted using an inverted microscope according to Lund et al. (1958) and Wetzel and Likens (1991). Chlorophyll a was determined according to Strickland and Parsons (1972).

Multiple linear regression equations were performed for each reservoir according to Draper and Smith (1980). Chlorophyll a is an important indicator of water quality. Because of this it was selected as dependent variable. 24 observations from each reservoir were used for models. The stepwise variable elimination method was used for selection of independent variables. The possibility of autocorrelation was analysed with Durbin-Watson test. Cook D_i (i=1,...,24) and Mahalanobis Distance tests (MD_i, i=1,...,24) were also used to find out whether the outlier and influenced observations existed. VIF statistics were used for controlling highly correlated independent variables selected for models (multicollinearity).

Nonlinear regression equations were performed for each reservoir (Draper and Smith, 1980). The relationships between independent variables and chlorophyll a were plotted prior to constructing nonlinear models. Then, Quasi and Simplex estimation method was used for obtaining the coefficients of nonlinear equations and the suitable coefficients were selected as a result of iterations. The coefficients were controlled by loss function and included to the model when loss function was minimum iteration step.

Statistical analyses were carried out with Minitab (ver. 10.5) and Statistica for windows (ver. 5.0).

Results and Discussion

Multiple linear regression models

The data from Kurtboğazi reservoir were analysed by stepwise variable selection method with four variables selected for multiple regression analysis (Table 1).

In(Phyto), EC, H and T were selected between the seventeen independent variables. Then, the multiple regression equation was developed to predict chlorophyll a (Equ. 1¹)

After the hypothesis control, all the coefficients given in the regression equation were found significant (p < 0.01). The standard error of the equation and determination coefficient were 1.28 and 95% respectively.

Durbin-Watson test (D=1.31) showed that there was no autocorrelation. Descriptive statistics of the residuals were analysed (Table 2). The minimum, maximum, mean and standard deviation of the residuals were found low and they showed the reliability of the model.

Table 1. The results of stepwise variable selection method in Kurtboğazi reservoir

Step	Multiple R	R ²	F (Equ.)	P	Variable
1	0.898	0.81	87.9	0.001	ln(Phyto)
2	0.947	0.90	88.1	0.001	ln(Phyto), EC
3	0.967	0.94	92.7	0.001	ln(Phyto), EC, H
4	0.975	0.95	89.7	0.001	ln(Phyto), EC, H, T

$$\text{Chl.}a = -164.7^{**} + 17.7^{**}(\ln(\text{Phyto.})) + 0.34^{**}(\text{EC}) - 0.38^{**}(\text{H}) + 0.14^{*}(\text{T})$$

(13.98) (1.05) (0.05) (0.11) (0.06) (Equ. 1¹)

Multiple Linear
Regression Model (Kurtboğazi)

* p < 0.05 ; **p < 0.01

Table 2. Descriptive statistics of residuals and predicted in Kurtboğazi reservoir

	Min.	Max.	Mean	Std. Error
Predicted	0.75	18.32	6.39	1.08
Residual	-1.08	2.27	0.00	0.24
Z Predicted	-1.09	2.31	0.00	0.21
Z Residual	-1.47	1.78	0.00	0.19

Durbin- Watson Stat. = 1.31

The highest values for Cook D_i and Mahalanobis distance were found as 0.79 and 9.17 respectively. These showed that there were no outlier and influenced observations. Also, multicollinearity was not found (Variance influence factor = VIF < 10) between independent variables (Table 3). Because of these reasons, linear multiple regression equation was found suitable for the estimation of chlorophyll *a* in Kurtboğazi reservoir according to Draper and Smith (1980).

The data from Çamlidere reservoir were analysed with Stepwise variable selection method with four variables selected for multiple regression analysis (Table 4).

ln(Zoo), H, NH₃-N and OM were selected between the total 17 independent variables. Then, the multiple regression equation was developed to predict chlorophyll *a* (Equ. 2¹).

After the hypothesis control, all the coefficients given in the regression equation were found significant (p < 0.01). The standard error and determination coefficient of the equation were 0.64 and 82% respectively.

Durbin-Watson test (D=1.97) showed that there was no autocorrelation. The highest values for Cook D_i and Mahalanobis distance were found as 0.41 and 9.40

respectively. These showed that there were no outlier and influenced observations (Table 5).

The variance influence factor was calculated for each variable showed that multicollinearity among independent variables were not found (Table 6). For these reasons linear multiple regression equation was found suitable for the estimation of chlorophyll *a* in Çamlidere reservoir.

The multiple regression equations showed that total hardness was a significant independent variable for both reservoirs. But the reservoirs were differentiated by the other variables. While ln(Phyto), EC and T were important in Kurtboğazi, ln(Zoo), NH₃-N and OM were important in Çamlidere reservoir. These two reservoirs were different from the point of trophic level and water quality. Kurtboğazi reservoir was classified as eutrophic while Çamlidere reservoir as mesotrophic according to Secchi depth (USEPA, 1974).

Table 3. VIF statistic for variables

Variable	VIF
ln(Phyto)	1.24
EC	1.58
H	1.03
T	1.57

¹ The standard error of the regression coefficients were given in the paranthesis

Table 4. The result of stepwise variable selection method in Çamlidere reservoir

Step	Multiple R	R ²	F (Equ.)	p	Variable
1	0.826	0.68	22.6	0.001	H
2	0.698	0.48	20.9	0.001	H, ln(Zoo)
3	0.874	0.76	21.6	0.001	H, ln(Zoo), NH ₃
4	0.906	0.82	21.7	0.001	H, ln(Zoo), NH ₃ , OM

$$\text{Chi. } a = -1.8^{**} + 0.62^{**}(\text{H}) + 0.79^*(\ln(\text{Zoo})) - 46.36^{**}(\text{NH}_3) + 0.17^*(\text{OM})$$

(0.56) (0.09) (0.29) (15.62) (0.07) (Equ. 21)

Multiple Linear
Regression Model (Çamlidere)

* p < 0.05 ; ** p < 0.01

Table 5. Descriptive statistics of residuals and predicted in Çamlidere reservoir

	Min.	Max.	Mean	Std. Error
Predicted	1.76	6.64	3.24	1.19
Residual	-1.26	1.06	-0.02	0.57
Z Predicted	-1.19	2.74	0.006	0.96
Z Residual	-1.97	1.67	-0.03	0.89

Durbin – Watson Stat. = 1.97

Table 6. VIF statistic for variables

Variable	VIF
H	1.43
ln(Zoo)	3.22
NH ₃	3.07
OM	1.56

water residence time, limited light transparency, the discrepancies between primary production and nutrients result in the reservoirs having different structures than natural lakes and phosphorus is not transferred to algal mass because of high turbidity and flow rate (Lind et al., 1993).

Multiple nonlinear regression models

We examined nonlinear relationships between independent variables and dependent variable to determine the relations in the system more accurately and to explain the variations on chlorophyll a. We selected independent variables by plotting them against chlorophyll a. Then, nonlinear equations were constructed for both reservoirs (Equ. 3 and 4).

Phyto, Zoo, TP and SD variables were selected for Kurtboğazi while Phyto, H and SD were selected for Çamlidere's models. We found nonlinear relationships between SD and chlorophyll a concentration for both reservoirs. Brezonik (1978) indicated linear and hyperbolic relationships between SD and chlorophyll a. Hoyer and Jones (1983) found relationships between chlorophyll and total phosphorus in reservoirs and developed a multivariable model regressing chlorophyll a on total phosphorus. They also showed how the zooplankton and chlorophyll a concentration were directly related, inversely

The multiple regression equations showed that total hardness was a significant independent variable for both reservoirs. But the reservoirs were differentiated by the other variables. While ln(Phyto), EC and T were important in Kurtboğazi, ln(Zoo), NH₃-N and OM were important in Çamlidere reservoir. These two reservoirs were different from the point of trophic level and water quality. Kurtboğazi reservoir was classified as eutrophic while Çamlidere reservoir as mesotrophic according to Secchi depth (USEPA, 1974).

We predicted chlorophyll a with multiple regression model. Riley and Prepas (1985) showed that chlorophyll a was predicted from total phosphorus (TP). Smith (1986) used multiple regression models and showed that total phosphorus and total nitrogen were good predictors of chlorophyll a. In our study, we didn't find a linear relationship between TP and chlorophyll a. In reservoirs, TP is high because of floods and fertilization from the surrounding catchment area. However, the shortage of

¹ The standard error of the regression coefficients were given in the parenthesis

related or unrelated over time in Missouri reservoirs. In Kurtboğazi's nonlinear model the effect of TP on chlorophyll *a* together with SD were shown. This relationship was not found in multiple linear model. The chlorophyll *a* is an index of algal biomass and we found relationships between chlorophyll *a* and Phyto for both reservoirs.

The determination coefficients and standard error of the residuals were 85% and 0.30, and 70% and 0.17 for equation 3 and 4, respectively. The determination coefficients were high and standard error of residuals were low in nonlinear estimations. These results indicated the appropriateness of the nonlinear models.

Nonlinear regression model (Kurtboğazi)

Nonlinear regression model (Kurtboğazi)

$$\text{Chl } a = a + b(\ln(\text{Phyto})) + (\ln(\text{Zoo}))^c + d(\text{TP}) + \text{SD}^e \quad (\text{Equ. 3})$$

$$\text{Chl } a = a + b(\ln(\text{Phyto})) + \text{H}^c + \text{SD}^d \quad (\text{Equ. 4})$$

Table 7. The coefficients in the equation 3 and 4 (\pm standard error)

	a	b	c	d	e
Kurtboğazi	-52.62 ^{**} ± 13.58	9.10 ^{**} ± 2.47	1.46 ± 0.61	0.04 ± 0.02	-9.21 ^{**} ± 0.99
Çamlidere	-28.12 ^{**} ± 4.90	4.72 ^{**} ± 0.89	0.59 ^{**} ± 0.04	0.08 ± 0.34	

- $p < 0.05$; ** $p < 0.01$

References

- APHA. 1975. Standard Methods for the Examination of Water and Wastewater. 14th ed. John D. Lucas Co., 1193 p., USA.
- Bakan, A.N. 1997. Ankara'ya Su Sağlayan Kurtboğazi ve Çamlidere Baraj Gölleri ile İvedik Su Arıtım Tesisinde Plankton Kompozisyonunun Karşılaştırmalı Olarak İncelenmesi. A.Ü. Fen Bilimleri Ens., Doktora Tezi, 112 s., Ankara.
- Brezonik, P.L. 1978. Effect of organic color and turbidity on Secchi disk transparency. J. Fish. Res. Board Can. 35: 1410 – 1416.
- Curi, K.V. and S. Tanyeri, 1974. Nehirlerdeki Özümlenebilirlik Kapasitesi Üzerine Genel Analitik Model Ve Porsuk Nehrine Tatbiki (TÜBİTAK) Proje no: MAG-329, 103 p., İstanbul.
- Dillon, P.J. and F.H. Rigler, 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. J. Fish. Res. Board Can. 31 : 1771-1778 .
- Draper, N.R. and H. Smith, 1980. Applied Regression Analysis. Univ. of Wisconsin, 710 p., USA.
- Gökkurt, S. 1989. Water Quality Model for Karasu River. M.E.T.U. Master Thesis, 105 p., Ankara
- Hoyer, M.V. and J.R. Jones, 1983. Factors affecting the relation between phosphorus and chlorophyll *a* in midwestern reservoirs. Can. J. Fish. Aquat. Sci. 40 : 192-199.
- Komarkova, J. and J. Hejzlar, 1996. Summer maxima of phytoplankton in the Rimov reservoir in relation to hydrologic parameters and phosphorus loading . Arch. Hydrobiol. 136 : 217-236.
- Lind, O.T., T.T. Terrell and B.G. Kimmel, 1993. Problems in reservoir trophic-state classification and implications for reservoir management. In : M. Straskaba, J.G. Tundisi, A. Duncan (eds), Comparative Reservoir Limnology and Water Quality Management, Kluwer Ac. Publ. p. 57-67. The Netherlands.
- Lund, J.W.G., C. Kipling and E.D. Le Cren, 1958. The inverted microscope method of estimating algal numbers and statistical basis of estimations by counting. Hydrobiologia, 11 : 143-170.
- Mazumder, A. 1994 a. Phosphorus-chlorophyll relationships under contrasting herbivory and thermal stratification; prediction and patterns. Can. J. Fish. Aquat. Sci. 51 : 390-400,
- Mazumder, A. 1994 b. Phosphorus-chlorophyll relationships under contrasting zooplankton community Structure potential mechanisms. Can. J. Fish. Aquat. Sci. 51 : 401-407.
- Pulatsü, S., H. Çamdeviren and E. Başpınar, 1997. Mogan gölünde (Ankara) klorofil-a konsantrasyonunun tahmininde çoklu regresyon ve path analizi kullanımı. Tarım Bilimleri Dergisi, 3 : 65-68.
- Riley, E.T. and E.E. Prepas, 1985. Comparison of the phosphorus-chlorophyll relationships in mixed and stratifical lakes. Can J. Fish. Aquat. Sci. 42 : 831-835.
- Seip, K.L., H. Sas and S. Vermij, 1992. Changes in Secchi disk depth with eutrophication. Arch Hydrobiol. 124 : 149-165.
- Smith, V. H. 1986. Light and nutrient effects on the relative biomass of blue-green algae in lake phytoplankton. Can. J. Fish. Aquat. Sci. 42 : 148-153.
- Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Handbook of Seawater Analysis. 2nd Ed. Bull. Fish Res. Board Can. No: 167, 311 p., Canada.
- USEPA, 1974. An Approach to a Relative Trophic Index System for Classifying Lakes and Reservoirs. US Environmental Protection Agency, 22 p., USA.
- Vzina, A. F. and M. L. Pace, 1994. An inverse model analysis of planktonic food webs in experimental lakes. Can. J. Fish. Aquat. Sci. 51:2034-2044.
- Lwetzal, R. G. and G. E. Likens, 1991. Limnological Analysis, 2nd ed. Springer Verlag, 324 p., New York.
- Zakova, Z., D. Berankova, E. Kockova, P. Kriz and H. Mlejnkova, 1993. Investigation of the development of biological and chemical conditions in the Vir reservoir 30 years after impoundment. Wat. Sci. Tech, 28: 65-74.