Prediction of Chlorophyll a in Kurtboğazı and Çamlıdere Reservoirs

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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 çoku doğrusal ve doğrusal olmayan regresyon modellerinden yararılanlarak, suyun bazı fiziksel ve kimyasal parametreleri ile klorofil a arasındaki ilişkiler değerlendirilmiştir. Bu iki farklı yaklaşımındaki amaç klorofil a’nın güvenilir bir şekilde tahmin edilmesidir. Belirlene katılan Kurtboğazı ve Çamlıdere baraj gölleri için, doğrusal çoku regresyon modelinde sırasıyla %95 ve %82 olarak bulunmuştur, doğrusal olmayan regresyon modellerinde %85 ve %70 olarak bulunmaktadır.

Anahtar Kelimeler: Klorofil a, baraj, çoku 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 the last decades. Models improved in these studies were classified as:

- Simple linear and nonlinear regression models,
- Multiple linear and nonlinear regression models,
- 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; Záková et al., 1993; Komarkova and Hejzlár, 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 the 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; Gökkürt, 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).

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Kurtboğazi and Çamlıdere 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 (NO$_2$-N), nitrate-nitrogen (NO$_3$-N), ammonia-nitrogen (NH$_3$-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, $i=1,...,24$) 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

<table>
<thead>
<tr>
<th>Step</th>
<th>Multiple R</th>
<th>R²</th>
<th>F (Equ.)</th>
<th>P</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.898</td>
<td>0.81</td>
<td>87.9</td>
<td>0.001</td>
<td>In(Phyto)</td>
</tr>
<tr>
<td>2</td>
<td>0.947</td>
<td>0.90</td>
<td>88.1</td>
<td>0.001</td>
<td>In(Phyto), EC</td>
</tr>
<tr>
<td>3</td>
<td>0.967</td>
<td>0.94</td>
<td>92.7</td>
<td>0.001</td>
<td>In(Phyto), EC, H</td>
</tr>
<tr>
<td>4</td>
<td>0.975</td>
<td>0.95</td>
<td>89.7</td>
<td>0.001</td>
<td>In(Phyto), EC, H, T</td>
</tr>
</tbody>
</table>

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

\[
(13.98) \quad (1.05) \quad (0.05) \quad (0.11) \quad (0.06) \quad (\text{Equ. 1})
\]

\* p < 0.05; **p < 0.01

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

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted</td>
<td>0.75</td>
<td>18.32</td>
<td>6.39</td>
<td>1.08</td>
</tr>
<tr>
<td>Residual</td>
<td>-1.08</td>
<td>2.27</td>
<td>0.00</td>
<td>0.24</td>
</tr>
<tr>
<td>Z Predicted</td>
<td>-1.09</td>
<td>2.31</td>
<td>0.00</td>
<td>0.21</td>
</tr>
<tr>
<td>Z Residual</td>
<td>-1.47</td>
<td>1.78</td>
<td>0.00</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Durbin-Watson Stat. = 1.31

The highest values for Cook D_i and Mahalonobis 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 Çamlıdere reservoir were analysed with Stepwise variable selection method with four variables selected for multiple regression analysis (Table 4).

\[
\ln(Zoo), H, \text{NH}_3-N \text{ and OM were selected between the total 17 independent variables. Then, the multiple regression equation was developed to predict chlorophyll a (Equ. 2).}
\]

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

The variance influence factor was calculated for each variable showed that multicolinearity 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 Çamlıdere 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 Çamlıdere reservoir. These two reservoirs were different from the point of trophic level and water quality. Kurtboğazi reservoir was classified as eutrophic while Çamlıdere reservoir as mesotrophic according to Secchi depth (USEPA, 1974).

Table 3. VIF statistic for variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>In(Phyto)</td>
<td>1.24</td>
</tr>
<tr>
<td>EC</td>
<td>1.58</td>
</tr>
<tr>
<td>H</td>
<td>1.03</td>
</tr>
<tr>
<td>T</td>
<td>1.57</td>
</tr>
</tbody>
</table>

\[1\] The standard error of the regression coefficients were given in the paranthesis.
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 Çamlıdere reservoir. These two reservoirs were different from the point of trophic level and water quality. Kurtboğazi reservoir was classified as eutrophic while Çamlıdere 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 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 (Equs. 3 and 4).

Phyto, Zoo, TP and SD variables were selected for Kurtboğazi while Phyto, H and SD were selected for Çamlıdere'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

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1 The standard error of the regression coefficients were given in the paranthesis.
related or unrelated over time in Missouri reservoirs. In Kurtboğa'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.

Nonlinear regression model (Kurtboğa)

\[ \text{Chl a} = a + b(\ln(\text{Phyto}) + \ln(\text{Zoo})) + c(\text{TP}) + d(\text{SD}) \] (Equ. 3)

Nonlinear regression model (Kurtboğa)

\[ \text{Chl a} = a + b(\ln(\text{Phyto}) + c + d(\text{TP}) + e(\text{SD}) \] (Equ. 4)

<table>
<thead>
<tr>
<th>Kurtboğa</th>
<th>Çamlığı</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>-52.62 ± 13.58</td>
<td>9.10 ± 2.47</td>
</tr>
</tbody>
</table>

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

* p < 0.05; ** p < 0.01

References


The determination coefficients and standard error of the residuals were 86% 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.