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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

VERTICAL AND SEASONAL CHANGES OF WATER QUALITY IN KEBAN DAM RESERVOIR

Kenan Alpaslan[1], Ahmet Sesli[1], Rıdvan Tepe[1], Nurten Özbey[1], Nevin Birici[1], Tünay Şeker[1], Mehmet Ali Turan Koçer[2*]

[1] Fisheries Research Station, Elazığ, Turkey

[2] Mediterranean Fisheries Research Production and Training Institute, Dosemealti, Antalya, Turkey

Abstract: This study aimed to reveal the vertical and seasonal fluctuations in water quality of Keban Dam Reservoir, which is the second largest dam of Euphrates Basin in Turkey. Temperature, dissolved oxygen, pH, electrical conductivity, some cations and anions content were monthly monitored in water column between 0 and 30 meters over a twelve-month period from February 2010 to January 2011. The thermal stratification was observed between June and August. Epilimnion extended up to depth of 10 meters and hypolimnion occurred below a depth of 20 meters. A decrease was recorded for dissolved oxygen below the epilimnion whereas for calcium and bicarbonate in the epilimnion during thermal stratification. The other cations and anions were nearly uniform in water column. The study showed significant relations of physico-chemical variables in water column of the reservoir.

Keywords: Keban Dam Reservoir, Water column, Temperature, Dissolved oxygen, Cations, Anions

Özet: **Keban Baraj Gölü Su Kalitesinin Vertikal ve Mevsimsel Değişimi**

Bu çalışmada Fırat Havzasının ikinci büyük baraj gölü olan Keban Baraj Gölü'nün su kalitesindeki vertikal ve mevsimsel değişimlerin açıklanması amaçlanmıştır. Şubat 2010 ve Ocak 2011 arasında yürütülen çalışmada aylık olarak yüzey ve 30 metre derinlikler arasındaki su kolonunda sıcaklık, çözünmüş oksijen, pH, elektriksel iletkenlik, bazı katyonlar ve anyonlar izlenmiştir. Keban Baraj Gölü'nde Haziran ve Ağustos arasında sıcaklık tabakalaşması gözlenmiştir. Epilimnion 10 metre derinliğe kadar genişlemiş ve hipolimnion 20 metre derinliğin altında oluşmuştur. Çalışma süresince sıcaklık tabakalaşması döneminde epilimnionda kalsiyum ve bikarbonat, epilimnionun altında ise çözünmüş oksijen belirgin şekilde azalmıştır. Diğer katyon ve anyonlar yıl boyunca su kolonunda neredeyse tekdüze miktarlarda belirlenmiştir. Çalışma Keban Baraj Gölü'nün su kolonunda fizikokimyasal değişkenler arasındaki önemli ilişkileri açığa çıkarmıştır.

Anahtar Kelimeler: Keban Baraj Gölü, Su kolonu, Sıcaklık, Çözünmüş oksijen, Katyonlar, Anyonlar

* **Correspondence to: Mehmet Ali Turan KOÇER**, Mediterranean Fisheries Research Production and Training Institute,Yeşilbayır Mah. Akdeniz Bul. No:2 Döşemealtı, Antalya-TURKEY

Tel: (+90 242) 251 05 85 **Fax:** (+90 242) 251 05 84

E-mail: matkocer@akdenizsuurunleri.gov.tr

Introduction

Dam reservoirs, which are constructed for many reasons including flood control, navigation, water storage for water supply and irrigation, hydropower, fisheries and recreation, show the characteristics of both rivers and lakes. The physicochemical and biological characteristics of water in reservoirs are mostly influenced from seasonal variations of inflowing river water, water level fluctuations, and the hydraulic residence time (Gikas, 2009).

In a reservoir, currents and the structure of the thermocline mainly control the vertical distribution of heat, dissolved substances, and nutrients in the water column. Understanding thermal stratification is of great importance for the pattern of mixing in lakes and reservoirs (Elçi, 2008). She exposed that stratification alters velocity profiles drastically and thus affects water quality in the reservoir and the water-quality parameters are correlated with temperature profiles in the vertical. Recently, Lindim et al. (2011) determined that the particular geomorphological and hydrological characteristics of the reservoir together with local climate features are responsible for nutrient distribution. They showed that wet season ecology governing feature is the nutrients input through the main tributaries whilst dry season ecology is governed by water thermal stratification. Therefore, determination of seasonal mixing and stratification patterns are contribute to better understanding of vertical changes in water quality parameters.

The Keban Dam Reservoir, which was formed at the confluence of the rivers Munzur, Peri, Murat and Karasu, is among the most notable reservoirs of the world with a storage volume of about 30.6 billion cubic meters. The maximum water depth is 163 meters at the high supply level (Akbay et al., 1999). The maximum operation level of the reservoir is 845 meters above the sea level. The surface and drainage areas of the reservoir are 675 square kilometres and 64100 square kilometres respectively (Soyupak et al., 1999).

State Hydraulic Works (DSI), the primary executive state agency of Turkey for water resources planning and management, documented the first limnological report regarding the reservoir (DSI, 1983). Subsequent studies have focused on pollution of the reservoir due to municipal waste water discharge (Ekiz et al., 1988; Topkaya, 1992; Topkaya and Şen, 1992). Soyupak et al. (1999, 2003) modelled the spatial and vertical changes in dissolved oxygen and total phosphorus. Although some studies have been carried out mostly on water pollution and nutrient loading, there is limited data with regard to physicochemical changes in water column of the reservoir.

In this context, this study aimed to investigate the vertical and seasonal fluctuations of physicochemical properties, namely temperature, dissolved oxygen, cations and anions, in water column of Keban Dam Reservoir.

Materials and Methods

The study was carried out over a twelve-month period from February 2010 to January 2011. The samples were collected from five different depths (0, 5, 10, 20 and 30 m) at the six monitoring stations (Figure 1).

Temperature (T) and dissolved oxygen (DO) was measured in situ using a portable instrument with optical sensor (HQ30D model), while pH and electrical conductivity (EC) using HQ40D model (Hach, Loveland, USA). Bicarbonate (HCO_3^-) and carbonate (CO_3^{-2}) were determined with potentiometric titration (Radtke et al., 1998). Lithium (Li^+), sodium (Na^+), potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), fluoride (F^-), chloride (Cl^-), bromide (Br^-), phosphate (PO_4^{-3}) and sulphate (SO_4^{-2}) were determined using a Dionex ICS-1000 ion chromatography system (Dionex, UK) .

The dimensionless parameter relative water column stability (RWCS) or the other expression relative thermal resistance to mixing which indicates the degree of water column stability as a whole was calculated by comparing density differences between the bottom and surface water layers with the density difference between 4 and 5 °C pure water (Padisák et al., 2003):

$$RWCS = \frac{D_b - D_s}{D_4 - D_5}$$

where D_b, D_s, D_4, and D_5 are the density of the bottom waters, the density of the surface water, and the densities of pure water at 4 °C and 5 °C, respectively. Water density (D) was calculated as a function of the water temperature (T) using the Krambeck equation (Xu et al., 2011):

$$D = 0.999869 + 6.67413 \, x \, 10^{-5}T - 8.85556 \, x \, 10^{-6}T^2 + 8.23031 \, x \, 10^{-8}T^3 - 5.51577 \, x \, 10^{-10}T^4$$

Normality of data was checked by Shapiro-Wilk's test. The differences of variables with normal distribution among the sampling depths were tested using analysis of variance (ANOVA), whereas in case of non-normality, the signed rank test (Wilcoxon) followed by Student's t-test was used.

Results and Discussion

The mean values of monitored variables and their correlations are presented in Tables 1 and 2, respectively. Temperature showed statistically significant differences among the depths (F=8.13, p<0.001). These differences were also reflected by seasonal and vertical variations in RWCS (Figure 2). From February on, temperature displayed a homogenous trend until mid-spring and then thermal stratification occurred between 10 and 20 meters during summer. In agreement with a common phenomenon that epilimnion changes from 2 m to >20 m in lakes (Goldman and Horne, 1983), we observed the epilimnion between depths of 8 m and 10 m in the present investigation in Keban Dam Reservoir (Figure 3). Likewise, the mean depths of epilimnion in the deep subalpine lakes Orta, Como, Maggiore, Garda, Iseo and Lugano were 6.4 m, 7.7 m, 6.9 m, 10.0 m, 5.3 m, and 6.3 m respectively (Ambrosetti and Barbanti, 2001).

Table 1. The variance analysis results and mean values of monitored variables in water column of Keban Dam Reservoir (temperature as °C; electrical conductivity as µS/cm; dissolved oxygen, cations and anions as mg/l).

	Depth (m)*					
	0	5	10	20	30	p
T	18.6^{a}	17.5^{a}	16.6^{ab}	14.8^{b}	13.9^{b}	<.001
pH	8.77^{a}	8.72^{a}	8.60^{b}	8.49^{b}	8.53^{b}	<.001
EC	336	338	344	349	344	>0.05
DO	9.15^{a}	9.09^{a}	8.74^{ab}	8.43^{bc}	7.90^{c}	<.001
HCO_3^-	111^{a}	110^{a}	110^{a}	122^{ab}	125^{b}	0.003
CO_3^{2-}	30.1^{a}	30.9^{ab}	31.6^{ab}	32.8^{ab}	33.6^{b}	0.010
Li^+	0.0080	0.0083	0.0081	0.0079	0.0075	>0.05
Na^+	17.6^{ab}	17.9^{a}	17.8^{ab}	16.6^{bc}	15.9^{c}	<.001
K^+	2.0^{ab}	2.1^{a}	2.1^{a}	1.9^{ab}	1.8^{b}	0.010
Ca^{2+}	33.0^{a}	33.6^{a}	33.7^{a}	38.3^{b}	40.8^{b}	<.001
Mg^{2+}	12.6	12.7	12.6	12.4	12.9	>0.05
NH_4^+	0.020	0.020	0.018	0.020	0.015	>0.05
NO_2^-	0.051	0.053	0.056	0.058	0.049	>0.05
NO_3^-	0.413^{ab}	0.407^{ab}	0.388^{a}	0.670^{b}	1.249^{c}	<.001
PO_4^{3-}	0.049	0.051	0.047	0.046	0.049	>0.05
F^-	0.163	0.160	0.149	0.139	0.149	>0.05
Cl^-	20.4	20.3	20.0	19.1	17.9	>0.05
Br^-	0.026	0.027	0.025	0.024	0.023	>0.05
SO_4^{2-}	31.8	31.4	31.5	32.1	34.2	>0.05

* (depths not connected by same letter in same line are significantly different)

Table 2. Spearman's correlation coefficients among variables ($p<0.05$).

	pH	EC	DO	HCO_3^-	CO_3^{2-}	Li^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	F^-	Cl^-	Br^-	SO_4^{2-}
T	0,43	-0,28	-0,56	-0,56	0,19		0,13		-0,61	-0,13	0,45	-0,55	-0,27	-0,28	-0,29	-0,30	-0,66	-0,27
pH		-0,14		-0,29			0,27	0,17	-0,40			-0,33		0,19				
EC			0,23	0,32		-0,25		-0,39	0,50	0,56	-0,27		0,49	0,16		0,33	0,22	0,65
DO				0,44	-0,27			0,16	0,33		-0,40	0,30	0,19	0,55	0,50	0,41	0,70	0,26
HCO_3^-					-0,34	-0,34	-0,24	-0,22	0,63	0,21	-0,51	0,29	0,44	0,31	0,31	0,17	0,39	0,45
CO_3^{2-}								-0,18			0,18	-0,17	0,30	-0,17	-0,30	-0,27	-0,22	-0,11
Li^+							0,54	0,60	-0,44	-0,32	0,32	0,15		-0,20		0,26	0,13	-0,48
Na^+								0,47	-0,34		0,25				0,15	0,60		
K^+									-0,51	-0,65	0,19		-0,41	0,19	0,43	0,33	0,29	-0,61
Ca^{2+}										0,48	-0,46	0,29	0,75	0,22			0,28	0,61
Mg^{2+}											-0,22		0,21	-0,20	-0,26	0,11		0,83
NH_4^+												-0,32	-0,29	-0,38	-0,39	-0,21	-0,34	-0,45
NO_2^-															0,17	0,24	0,42	0,12
NO_3^-														0,32	-0,34			0,30
PO_4^{3-}															0,64	0,38	0,60	0,18
F^-																0,55	0,61	
Cl^-																	0,57	0,35
Br^-																		0,16

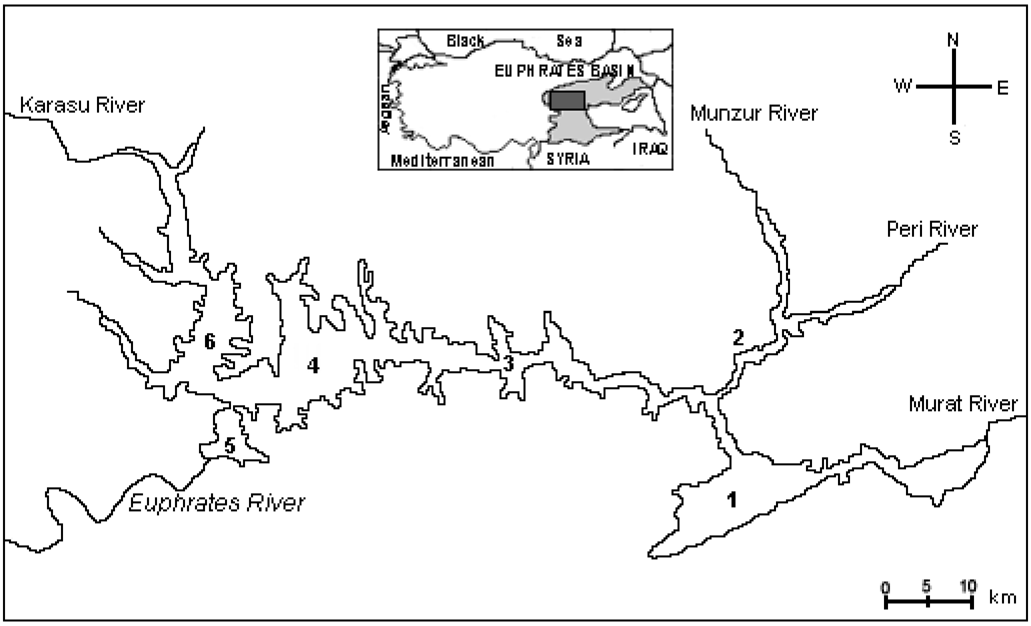

Figure 1. Keban Dam Reservoir and sampling stations

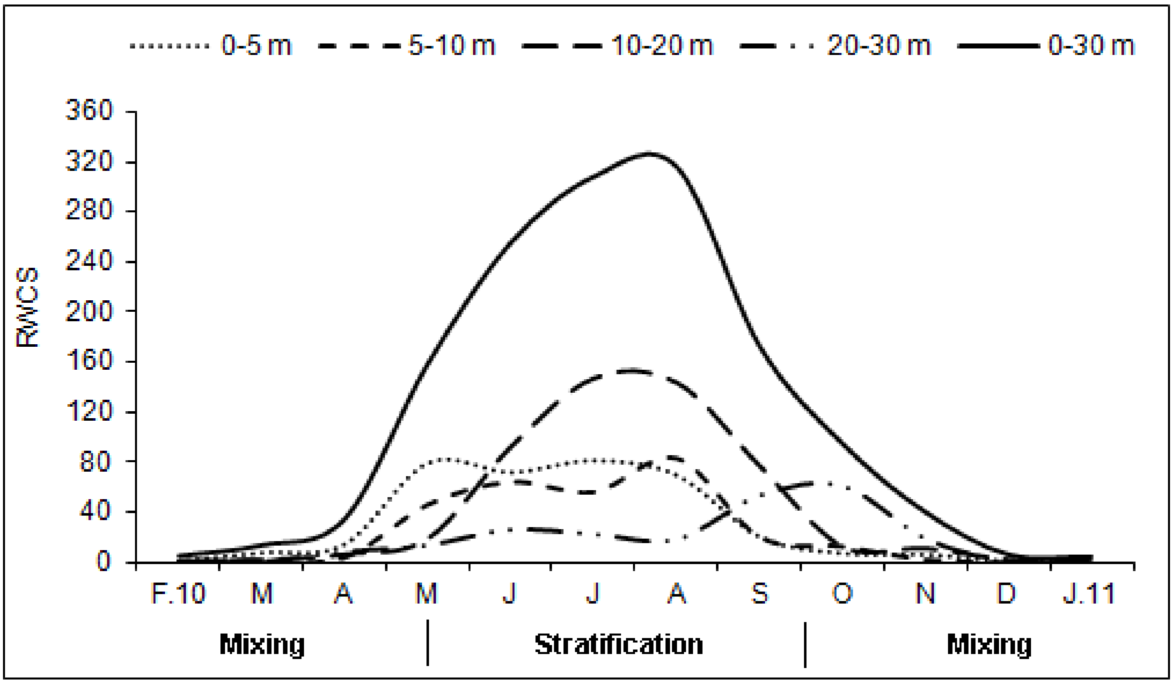

Figure 2. Seasonal variation of relative water column stability (RWCS) in Keban Dam Lake during study period.

The stratum down to 20 meters depth below epilimnion exhibited relatively marked thermal discontinuity, suggesting metalimnion which is characterized by a steep thermal gradient with a temperature decrease more than 1 °C per meter (Wetzel, 2001). In Lake Orta, the rises of thermal gradient reached 2.93, 3.07 and 2.73°C respectively in July, August and September (Ambrosetti and Barbanti, 2001). However, the rises in the thermal gradient between depths of 10 and 20 meters in June, July, August and September were 0.41, 0.54, 0.53 and 0.29 °C respectively in Keban Dam Reservoir. Although these values appear to be lower than the widely accepted gradient (>1 °C per meter), RWCS parameter in 10-20 m depths was separated from the other depths as suggested above. Hypolimnion in Keban Dam Reservoir lay below depths of 20 meters during the study period.

It was observed a breakdown of thermal stratification in October. After completion of mixing from convection currents, temperature in water column was uniform from November to early-spring (Figure 3).

pH was higher in epilimnion than hypolimnion, but no significant differences were detected in electrical conductivity among the monitored depths. Unexpectedly pH did not show strong correlations with cations and anions, but there was a significant correlation, although weak (r^2= 0.50), between electrical conductivity and calcium. The strongest correlation of electrical conductivity was detected with sulphate (r^2= 0.65), the second major anion in the reservoir.

While vertical distribution of dissolved oxygen during the mixing and stagnation periods was relatively uniform, the concentrations in water column gradually decreased from mid-spring to late autumn (Figure 4). However, low oxygen saturation values were observed below the epilimnion (Figure 5) which is a typical characteristic of mesotrophic/eutrophic lakes (Wetzel, 2001). Nevertheless, there was no anoxic zone down to 30 m depths.

A general trend with Ca^{+2}>Mg^{+2}>Na^{+}>K^{+} and HCO_3^{-}>SO_4^{-2}>CO_3^{-2}>Cl^{-} was determined in Keban Dam Reservoir. It is well-known that there may be distinct tendencies for composition of major cations and anions in lake waters depending on various factors such as drainage basin geology, atmospheric sources, precipitation and evaporation, human activities, exchange with sediments within the water body etc. (Goldman and Horne, 1983; Wetzel, 2001). The tendencies of major cation and anion concentrations in water column of Keban Dam Reservoir are consistent with general trend of open lake systems where the dominance by calcium and bicarbonate ions prevails (Wetzel, 2001).

Vertical changes of magnesium, chloride and sulphate were not statistically significant. Although sodium and potassium showed increasing tendencies in hypolimnion, they were not clearly distinguishable among the depths (Figures 6 and 7). Calcium, dominant cation, highly differed among the depths and was lower in epilimnion compared to deeper parts (Figure 8). The vertical changes in calcium were more pronounced during thermal stratification, suggesting that an epilimnetic decalcification took place.

Similarly, bicarbonate, dominant anion, showed an increasing trend in hypolimnion. Despite a nearly uniform concentration during mixing period, bicarbonate decreased in epilimnion during thermal stratification (Figure 9). This finding implies that the epilimnitic decalcification in Keban Dam Reservoir occurs. Indeed, there was negative correlations (respectively r^2= -0.61 and r^2= -0.56) between temperature and these two ions. Wetzel (2001) states that major cations and anions are separated into two types: conservative ions and dynamic ions. Magnesium, sodium, potassium, sulphate and chloride are relatively conservative both in their chemical reactivity and small biotic requirements under typical freshwater conditions while calcium and carbonate are more reactive and can exhibit marked seasonal dynamics.

Vertical changes of minor cation (lithium and ammonium) and anion (nitrite, phosphate, fluoride and bromide) concentrations did not exhibit a significant difference in the present study. Nitrate was significantly higher in hypolimnion, presumably as a result of a few measurements of high concentrations in deep water. A weak but significant linear relation (r^2=0.32) between nitrate and phosphate which are available forms of main nutrients for algae may be indicative for active photosynthesis down to 20 m depth.

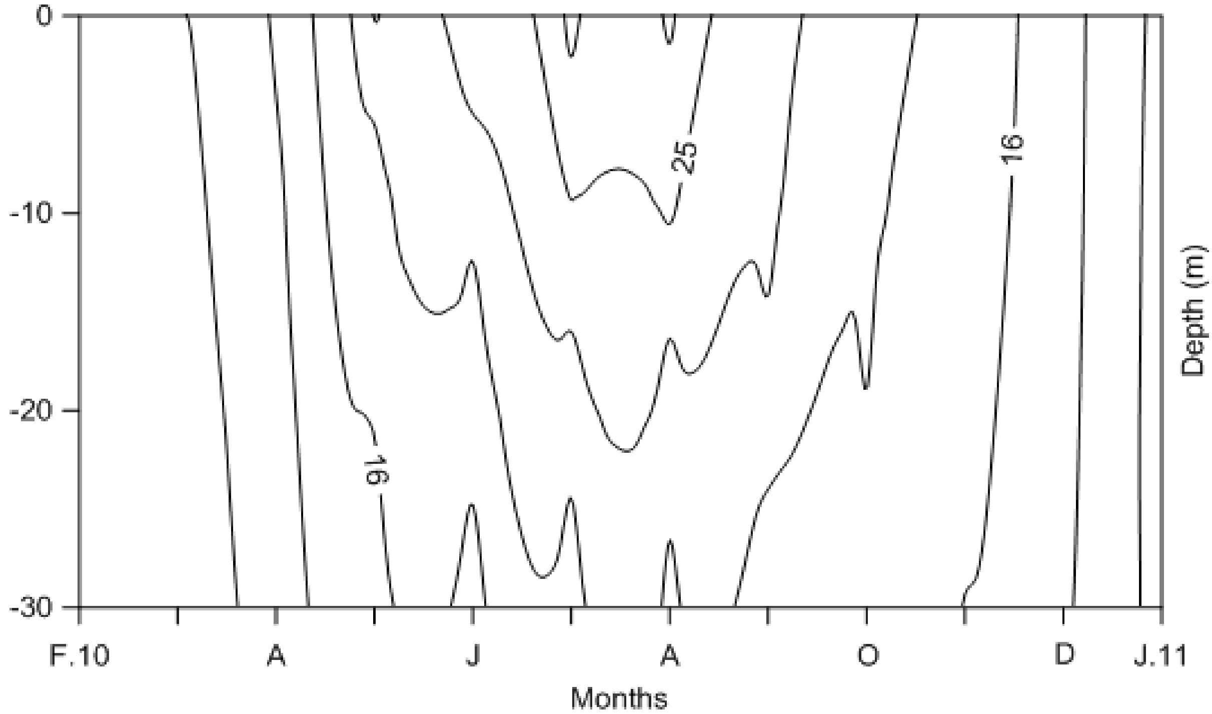

Figure 3. Depth-time contour plot of temperature in Keban Dam Lake during study period.

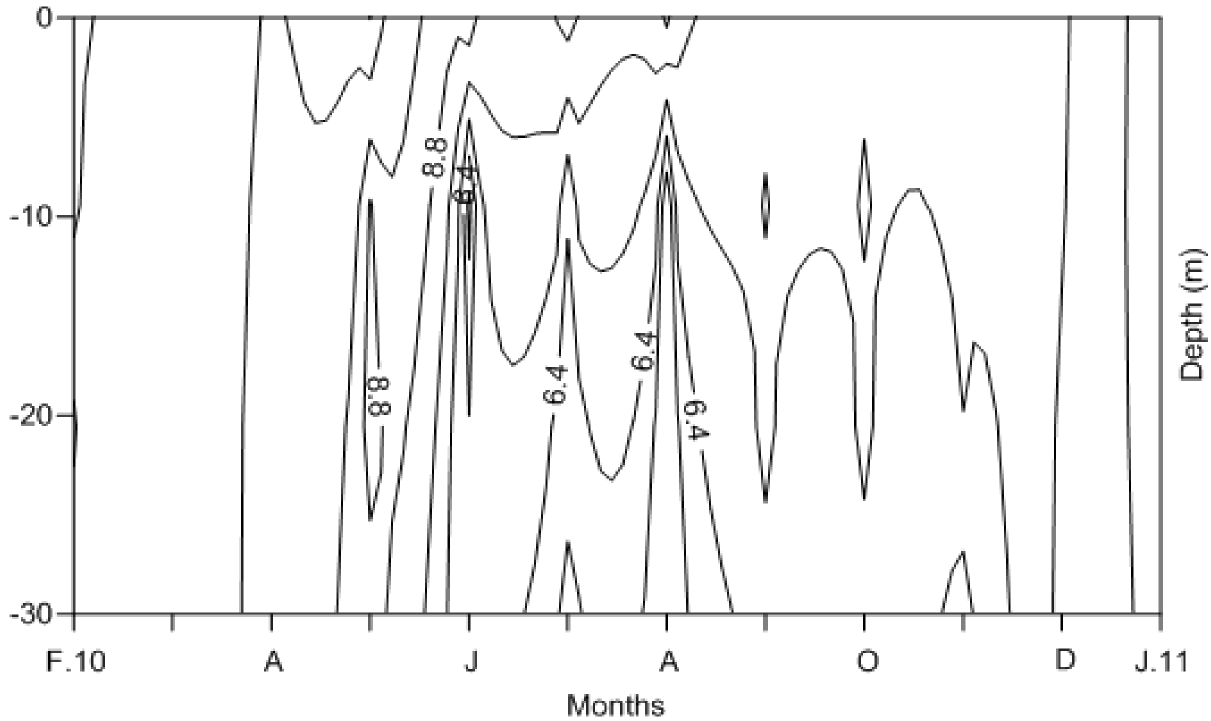

Figure 4. Depth-time contour plot of dissolved oxygen in Keban Dam Lake during study period.

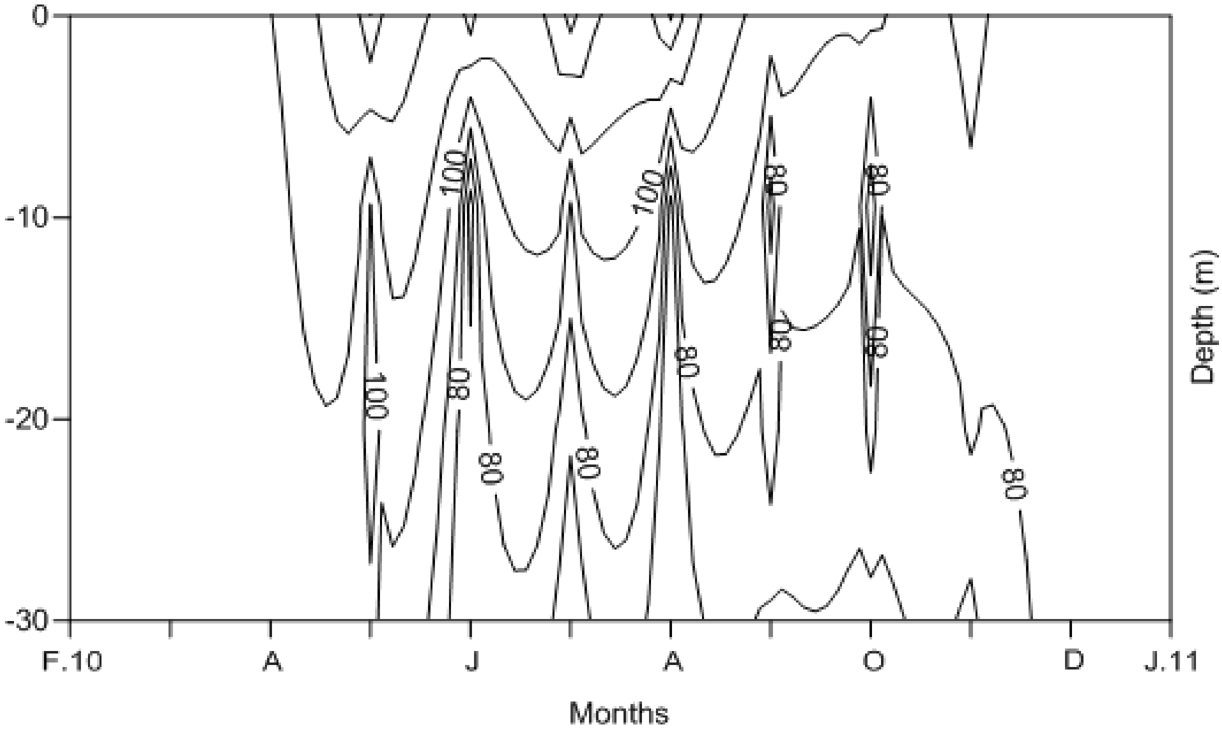

Figure 5. Depth-time contour plot of dissolved oxygen saturation in Keban Dam Lake during study period.

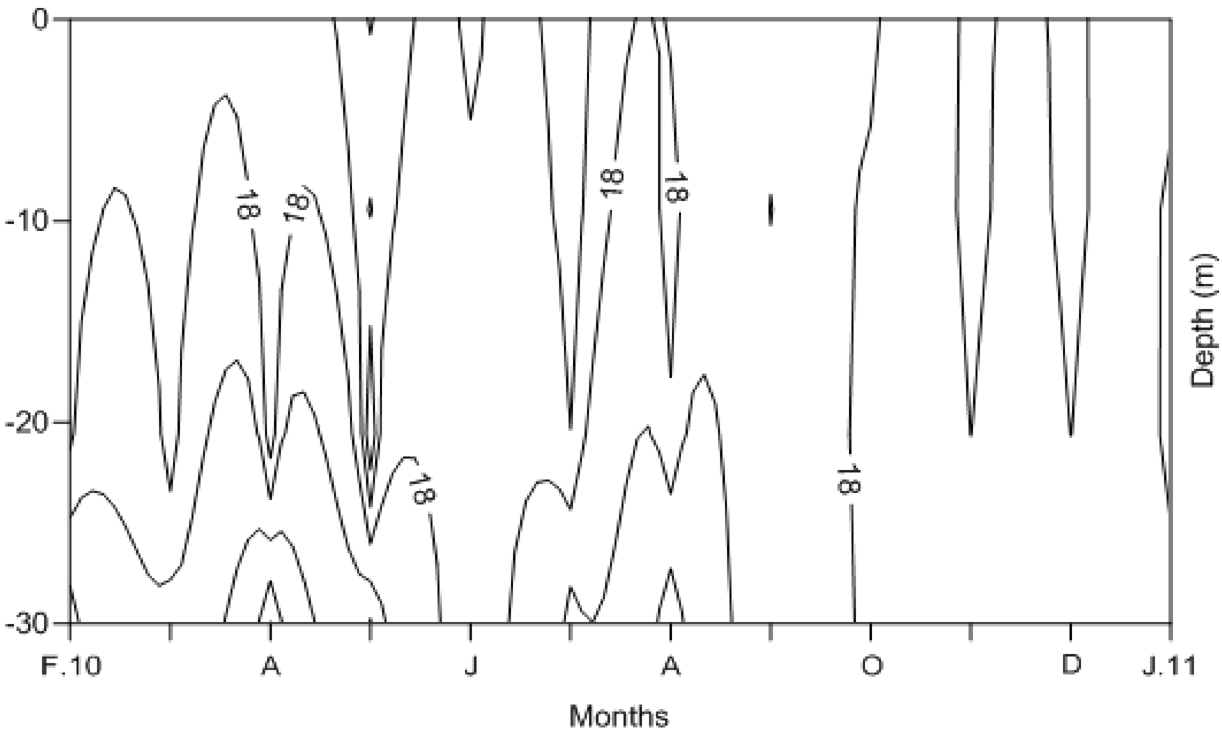

Figure 6. Depth-time contour plot of sodium in Keban Dam Lake during study period.

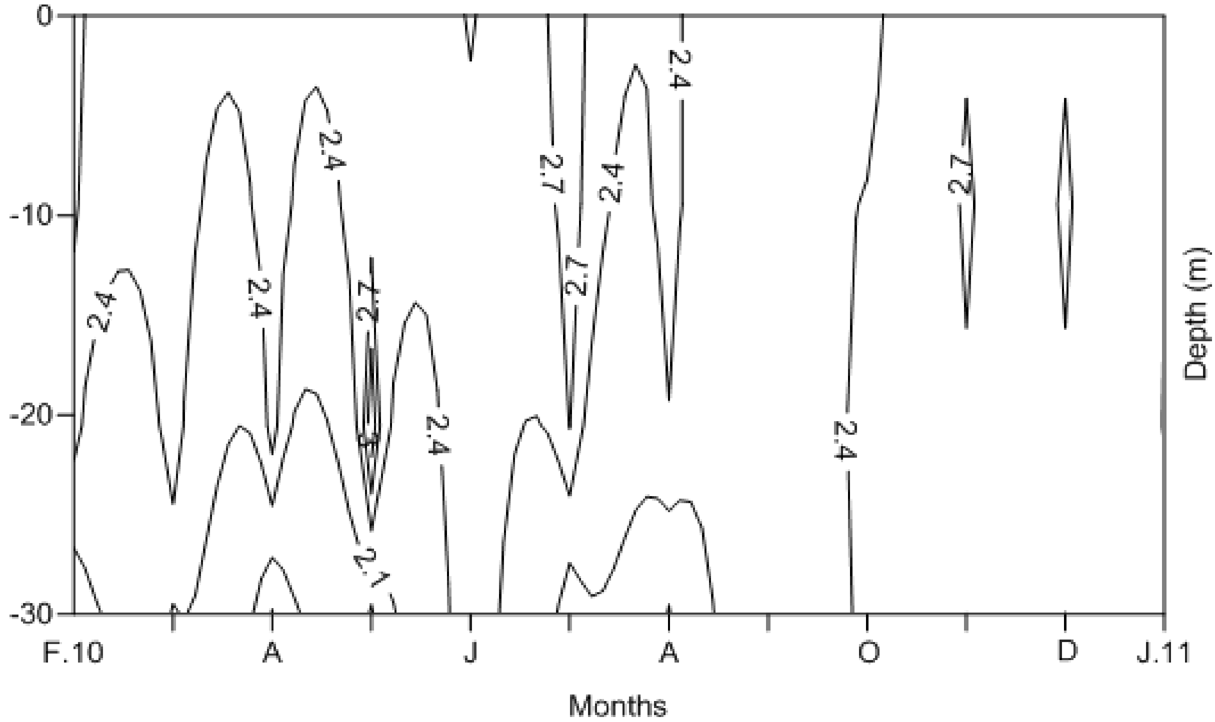

Figure 7. Depth-time contour plot of potassium in Keban Dam Lake during study period.

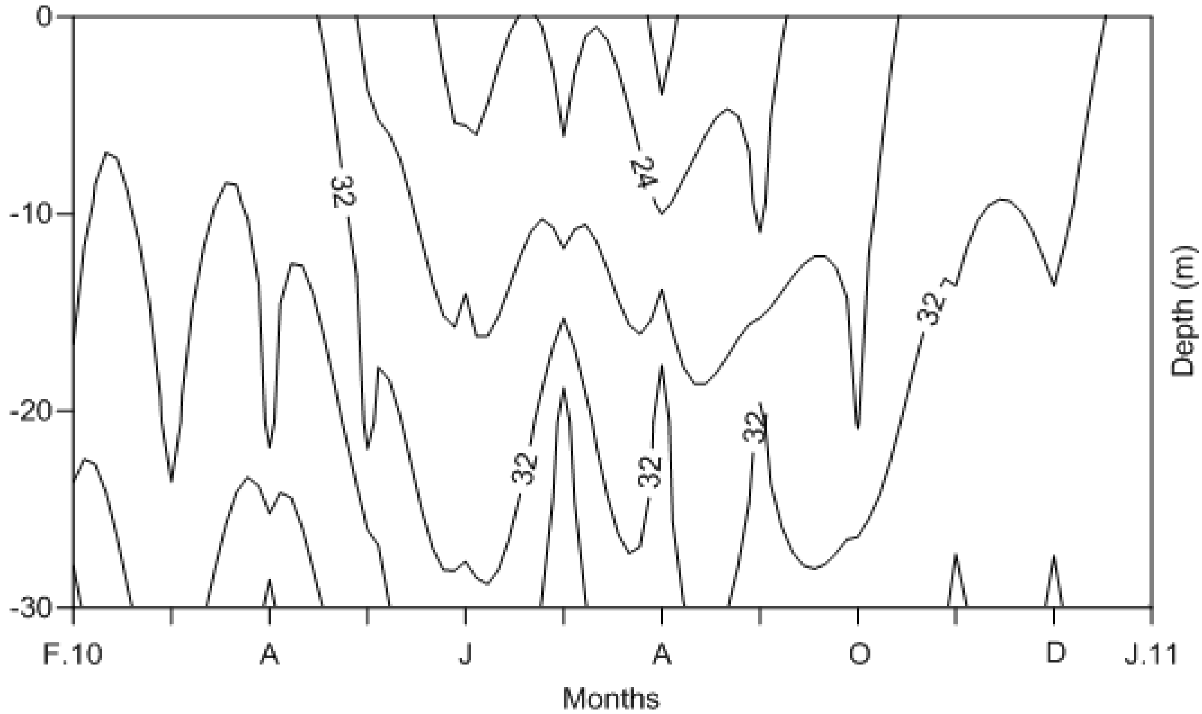

Figure 8. Depth-time contour plot of calcium in Keban Dam Lake during study period.

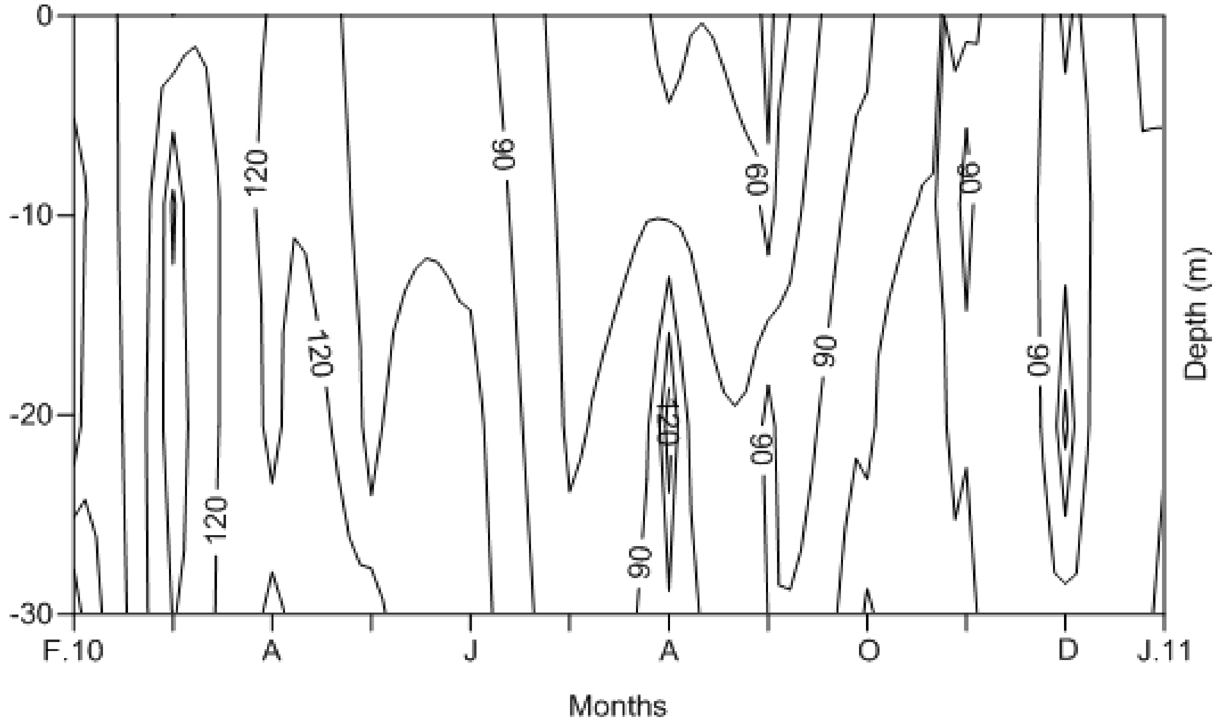

Figure 9. Depth-time contour plot of bicarbonate in Keban Dam Lake during study period.

The present investigation indicates that a clear thermal stratification between June and August occurred in Keban Dam Reservoir. Dissolved oxygen concentrations in water column were recorded at around saturation levels during winter and mixing periods but decreased in metalimnion and hypolimnion during thermal stratification. The decrease in calcium and bicarbonate indicated the epilimnitic decalcification during thermal stratification. The other major/minor cations and anions were nearly uniform in water column and they did not exhibit clear temporal and spatial distribution patterns.

Conclusions

The results of this study revealed significant relations of physicochemical variables, which have not been taken into consideration so far, in Keban Dam Reservoir. The seasonal distribution in water column of dissolved oxygen and major ions determined in this study may also help to explain the seasonal changes in algae and productivity of the reservoir when the other key parameters such as total nitrogen and phosphorus, and chlorophylls are monitored by future studies.

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