ECOHYDROLOGY OF DOJRAN LAKE

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Abstract. In the Republic of Macedonia there are three natural lakes: Ohrid, Prespa and Dojran. Dojran Lake is the smallest one but not less significant as a water resource, natural wealth and scenic beauty. The last 15 years this place of natural heritage is threatened because the lake's water level decreased seriously. The lake watershed and the lake itself are shared by Macedonia and Greece. Since 1988 the lake surface area dropped from 42 km^2 to 31 km^2. This water declination together with the simultaneous deterioration of the water quality resulted with serious ecological impacts. How much the present state of this natural lake is under the impact of hydrology and climate, and how much this is due to some other, not clearly identified causes, should be main goals in future water management in both countries that share the lake and the watershed. A complete environmental assessment can not be made without serious analyzes of the basic hydrological, meteorological and water management data. The intention of the authors is to emphasize the vulnerability of the lake and its biodiversity and to initiate urgent and strong support of the international community in cooperation in water quantity and water quality management between both countries that share the lake and its watershed.

Keywords: hydrology, biodiversity, precipitation, evaporation, water level, water management, restoration

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1. Introduction

Most of the civilizations have been created near water and developed upon its variation in space and time. Many civilizations and rare spaces of flora and fauna have disappeared because of water catastrophes. Such catastrophes in the past can be explained mainly by the inexperience on water behavior and low level of technology development. Today's civilization has knowledge and new technologies to solve the problems regarding water and environment. Eco-hydrology as a new discipline gives a hand to other disciplines, such as biology, geography, forestry, agriculture, ecology, legislation, and to public, politicians, journalists and others (*Bonacci*, 2003). Interdisciplinary approach in use and protection of waters today is needed more than ever. The necessity of interstate cooperation regarding transboundary waters also can be pointed out. In the Republic of Macedonia almost all waters are transboundary. Up to today the activities related to ecohydrology mainly have been focused on the natural lakes.

In the last 15 years Dojran Lake as a place of natural heritage is threatened because the lake's water level decreased seriously. The lake watershed and the lake itself are shared by Macedonia and Greece. Recharge of the lake is from direct runoff, small rivers and groundwater. Since 1988 the lake surface dropped from 42 km^2 to 31 km^2, and more significantly the water volume decreased from 262 million m^3 to only 80 million m^3 in 2000.

This water declination together with the simultaneous deterioration of the water quality resulted with serious ecological impacts. Biodiversity diminished and the reduction of plankton led to a reduction of fish portion. Also the number of birds decreased dramatically. The attack on the ecosystem had a harmful impact on the economy in the region. Tourism had been the most important sector, but it completely stopped, and in year 2000 were only tenth of the level in the eighties.

On the Macedonian side various efforts were initiated to improve the quantity and quality of this water resource. A sewage collector system along the lake shore has been constructed. Also, the previous groundwater extraction for irrigation has been strongly reduced and the irrigated areas were converted to rain-fed farmland and to drip irrigation system.

2. Watershed Characteristics

Dojran Lake is a tectonic lake situated in the Balkan Peninsula in southeastern part of Macedonia at an average altitude of 148 m asl. The watershed and the lake itself are shared by two countries, Greece and Macedonia. The watershed of the lake belongs to the river basin of Vardar that gravitates towards Aegean See. The map of Dojran Lake watershed is shown in Figure 1.

The lake was formed in a karstified basin created by combination of Tertiary volcanic and tectonic activity. The sediments of the lake watershed are composed of mineral-rich ancient alluvial and limestone sediments. A minor part of the watershed on Macedonian side is composed of diluvia clay sediments. These areas are the only arable lands in the area, still with low agricultural quality. The northern and eastern belts of the watershed are rocky and covered with low forests and weeds. The agriculture is not well developed.

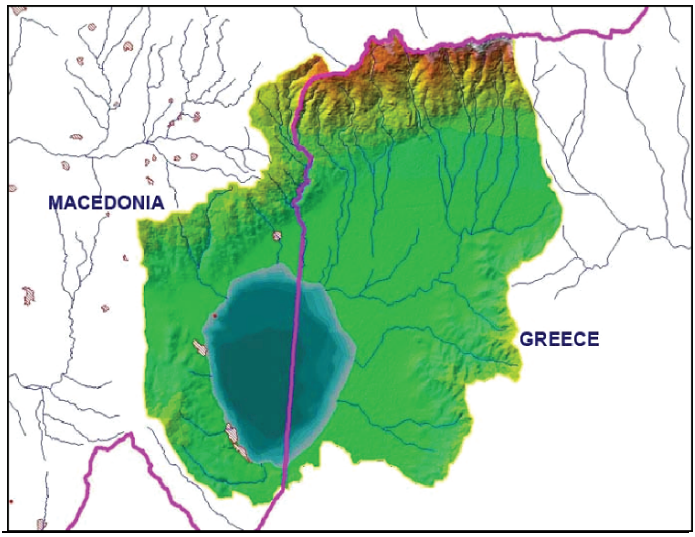


Figure 1. Map of the Dojran Lake watershed

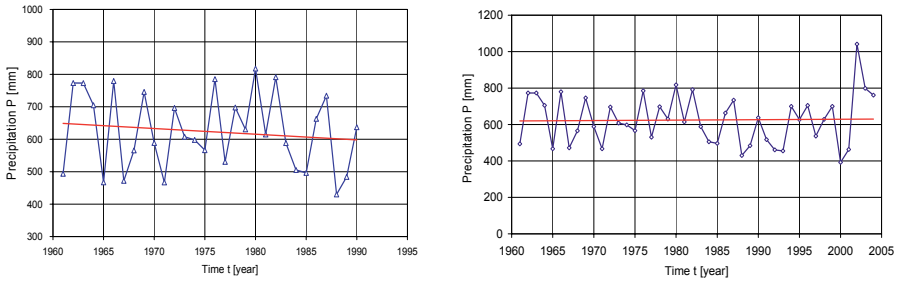
The geographic longitude of the lake is N41°23' and the latitude is E22°45'. The average altitude of the watershed is 362.9 m asl. Only a small part of about 50 km^2 or 18% is located at altitude higher of 500 m asl. Total watershed area is 271.8 km^2 out of which 92.1 km^2 or 32% belongs to Macedonia. Water surface area of the lake at normal elevation (147.34 m asl) is 42.2 km^2 out of which 27.1 km^2 or 63.6% belongs to Macedonia. The volume of the lake at normal water level is 262 million m^3 which corresponds to the average depth of 6.5 m (maximum depth 10.4 m). The maximum length of the lake is 8.9 km and the maximum width is 7.1 km. Dojran Lake doesn't have surface outflow and the only outflow is by the evaporation from the lake water surface.

2.1. CLIMATIC-METEOROLOGICAL CHARACTERISTICS

Dojran Lake valley together with Gevgelija – Valandovo valley is one of the warmest in this part of the Balkan. The precipitation and temperature regime

has been analyzed for the period 1961–2004 with data from hydrometeorological station at Nov Dojran. Precipitation and temperature regime mainly are under the Mediterranean influence from Aegean See. This influence causes the maximum precipitation in cold part of the year (November-December, 28% of the annual sum) and minimum precipitation in summer months (July-August, 17% of the annual sum). The average annual precipitation sum for the observed period is 624.7 mm and their range is from minimum 392.2 mm in 2000 to maximum 1041.5 mm in 2002.

The long-term annual precipitation sums with linear trend lines for two periods 1961–1990 and 1961–2004 are shown in Figure 2. It is obvious that for the first period the trend line has a declining trend with the equation $P = -1.7529 \cdot t + 4086.3$, while for the second extended period the trend line has a rising trend with the equation $P = 0.2263 \cdot t + 176.01$. This rapid change of the pluvial regime is due to extreme value 1041.5 mm registered in 2002. These graphs show relatively uniform distribution of the precipitation for the first period with maximum in December. The station Nov Dojran (180 m asl) is representative only for the pluvial regime on the lake surface, but is not representative for pluvial analysis of the entire watershed (mean 363 m asl., up to 1877 m asl.).



a) b)

Figure 2. Long-term annual precipitation sums with trend lines: a) 1961–1990, b) 1961–2004

The long-term monthly air temperatures for the period 1961–2004 are presented in Figure 3. Relative humidity in Dojran Lake valley in summer period is 60% and in winter months up to 80%. The highest frequency of 319% has the wind from northwest direction, while the average annual calm is 525%. The winds are frequent 47.5% of the year with the average speed between 1.4 and 3.8 m/s. The most frequent are north-west winds.

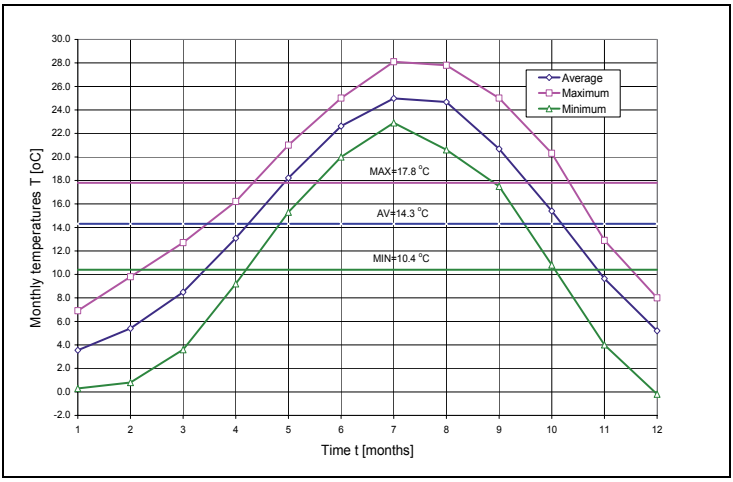


Figure 3. Long-term characteristic monthly air temperatures

TABLE 1. Evaporation from lake water surface

Months	[1961–1990]				[1961–2004]			
	T	Penman E	Rohwer E	Meyer E	T	Penman E	Rohwer E	Meyer E
	[°C]	[mm]	[mm]	[mm]	[°C]	[mm]	[mm]	[mm]
January	0.6	33.03	74.52	61.92	3.5	20.16	46.40	38.55
February	1.9	27.86	39.91	34.97	5.4	32.11	51.09	44.76
March	4.6	46.84	49.01	43.47	8.5	54.13	64.11	56.86
April	8.6	74.64	71.20	66.95	13.1	86.36	96.11	90.38
May	13.1	110.23	96.71	91.90	18.2	127.68	134.02	127.36
June	16.9	139.18	152.47	143.37	22.6	161.97	217.30	204.34
July	19.1	161.76	217.19	195.07	25.0	187.98	311.30	279.60
August	18.7	136.27	178.45	169.58	24.7	160.57	257.41	244.61
September	16.0	88.22	127.45	125.15	20.7	102.11	171.21	168.12
October	11.4	48.52	77.44	72.76	15.4	56.13	100.91	94.45
November	6.7	24.28	52.06	46.10	9.6	27.42	63.38	56.12
December	2.4	16.40	42.85	35.61	5.2	18.73	52.30	43.47
Sum		907.22	1179.56	1086.85		1035.35	1565.54	1448.62

The average annual sunshine is 2440 hours or 6.6 hours daily. The maximum sunshine is in July with 330 hours or 10.6 hours daily and the minimum is in January with 90 hours or 3.0 hours daily. The computed evaporation from lake water surface by the formulas of Penman, Rohwer and Meyer are presented in

Table 1. The computed annual evaporation varies from 907 mm (Penman) to 1179 mm (Rohwer). Maximum monthly evaporation has been obtained for July. These results show that within the observed period the computed annual evaporation sum (1179.56 mm) is almost twice of the annual precipitation sum.

For the period 1961–2004 the average values of the monthly temperatures have increased rapidly, for example in January from 0.6°C to 3.5°C, and in July from 19.1°C to 25°C, which leads to the increase of the evaporation annual sum for 15–35%. For the extended period the computed evaporation sum (1565.54 mm) has increased to 2.5 times of the observed average annual precipitation sum (624.7 mm).

3. Water Level Analysis

The analyses of water levels in Dojran Lake is carried out with the observed data at water gauge station at Nov Dojran. The average monthly data on maximum, average and minimum water levels for the period 1952–2004 are presented in Figure 4. The average long-term water level is 145.38 m asl that is about 2 m below the normal water level. It is obvious that very strong water level decreasing trend of Dojran Lake has started in 1988. Therefore, the total data series can be divided into the following two time sub-sets: 1) 1952–1987 and 2) 1988–2004.

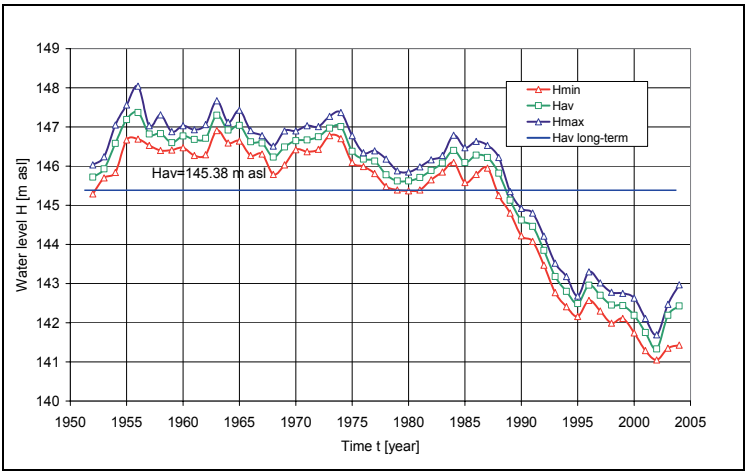


Figure 4. Characteristic water levels in Dojran Lake

The amplitude of observed maximum water levels for the first time sub-set is 148.06–145.85=2.21 m which defines the average water level decrease of 6.31 cm annually. For the first time sub-set pretty regular water level oscillations

can be noted with maximum and minimum values appearing every 5 years. The amplitude of observed maximum water levels for the first time sub-set is 148.06–145.85=2.21 m which defines the average water level decrease of 6.31 cm annually. For the first time sub-set pretty regular water level oscillations can be noted with maximum and minimum values appearing every 5 years.

For the second time sub-sets the amplitude of observed maximum water levels is 146.79–141.69=5.10 m which results the average water level decrease of 34.0 cm annually. This decreasing trend is alarming most of all because the causes have not been recognized clearly yet. It is most probable that drastic water level decrease within 1988–2002 might be a result of uncontrolled anthropogenic activities and partly due to the long draught period. The anthropogenic activities are mainly connected to water use in agricultural sector.

The amplitude of average water level oscillations in 2000 is 142.59–141.75=0.84 m, in 2001 is 142.08–141.32=0.76 m, in 2002 is 141.56–141.08=0.48 m, and in 2004 it is 142.44–141.90=0.54 m. These results show decreasing of the average monthly water level amplitudes. The exception is 2002 most probably due to the improved hydrological condition regarding the precipitation sum increase as shown in Figure 2, decrease of the water use from the lake, and partly due to the additional water transfer from Gjavato wells into the lake. The increase of rainfalls can be referred to the start of wet period in 2002 that lasts even today. This effect is not completely natural, and therefore can not be taken as a normal long-term monthly water level oscillation.

4. Water Quality

The most comprehensive analysis on water quality was performed in 2003 (*Smith&Petkovski*). The lake waters are characterized by a rather high alkalinity (pH values between 9.2 and 9.6) and elevated Carbonate and Magnesium hardness (total hardness about 330 mg/l as $CaCo_3$). Thus, the water is chemically well buffered. Still, there are a number of toxic substances, which are near or even beyond toxic levels. Ammonia (NH_3) is with 0.3 mg/l that is already 50% above the chronic toxicity level endangering the life of fish and other aquatic organisms. Lead is exceeding standard levels only at the shoreline, 0.030 mg/l measured against 0.014 mg/l chronic toxicity level. Other substances (chemical oxygen demand, electrical conductivity, iron, dissolved oxygen, phosphorus) are not toxic as such, but their concentrations may have indirect adverse effects on the lake ecosystem. Measured iron values are above the accepted level of 1 mg/l. Phosphorus concentrations are above standard values for lakes and reservoirs, thus indicate a highly eutrophic system. The level of total suspended solids is 37–142 mg/l that is 2–9 times the value of 15 mg/l considered as dangerous. Other measured chemical parameters did not appear to

cause any problems. This refers to elements like Arsenic, Boron, Cadmium, Chromium, Copper, Manganese, Sulphide and Zinc.

5. Flora and Fauna

Because of its geotectonic location and climate characteristics, Dojran Lake and its watershed have very rich biodiversity. No special data on vegetation is available on Macedonian side, except that the forests are in rather poor state. On the Greek side the Aquatic Forest of Mouria is rather rare forest and is declared as natural monument. This forest together with a small part of the lake has been proposed for inclusion in EU NATURA 2000 network. In the forest has been recognized habitat of extraordinary importance (number of plant taxa is 46). The condition of the habitat (mixed oak, elm and ash) is considered as unsatisfactory.

Fauna is also very rich in the lake and its watershed. On the Macedonian side fauna has been examined as follows: dragonflies 42 species, stoneflies 42 species, mosquitoes 51 species, amphibian 9 species, reptiles 23 species, birds 87 species out of which 17 species are water birds, and mammals 53 species. On the Greek side studies on fauna are limited to "Aquatic Forest of Mouria". According to this study three species of amphibians and three species of reptiles have been found. Birds found in the Greek part of the lake include at least 36 species. Two species, Pygmy Cormorant and Dalmatian Pelican, are recognized as endangered species worldwide.

6. Brief Problem Definition and Undertaken Activities

Main economy in the region is tourism and fishery. At present these activities are almost non-existent due to the environmental catastrophe that lasts over ten years. The lake and its biodiversity are influenced by uncontrolled human activities and climate. The result is rapid and large water level decrease. Since 1988 the lake is facing the extreme water level and water volume decrease. From 262 million m^3 in 1988 the volume has decreased to only 80 million m^3 in 2000. According to the biologists over 140 species of flora and fauna have disappeared.

In 2000–2001 the Ministry of Environment and Physical Planning of the Republic of Macedonia have funded and realized the project "Feasibility Study on Dojran Lake Salvation". Up to now, only the financial resources of the Macedonian Government have been mobilized on monitoring and water recharge from the wells system in Gjavato. The constructed system includes:

two-stage pumping from the wells in Gjavato, pipeline (L=19.3 km) with total pumping head of over 200 m and maximum capacity of 1000 l/s.

Currently the European Agency for Reconstruction is contracting authority of the project titled: Improvement of Management of Transboundary Water Resources. Some of the specific objectives related to Dojran Lake are: a) identification of the reason for lowering of Dojran Lake and potential measures to recover lake levels and improve water quality, b) establishment of regular monitoring system and exchange of monitoring information on all measured components of the water balance of Vardar and Dojran Lake between Macedonia and Greece, c) planning the management monitoring programme, including specific measures to recover Dojran Lake water levels.

6.1. PROBLEM SOLUTION

Besides the hydrological balance disturbance Dojran Lake has faced the environmental catastrophe as well, evidenced by recession of the shoreline accompanied by a complete loss of the litoral zone and its related biological communities (*Petkovski&Smith*, 2001). Litoral zooplankton community has reduction from 94 taxa in 1988 to only 28 taxa in 2001, but this community steel has genetic potential to be restored.

Dojran Lake and its basin need design and implementation of restoration and protection measures. For successful implementation of designed measures, development of a Management Plan is a necessity. Current monitoring is referring only to water level observation and meteorological parameters with rain gauge stations that are not in sufficient number and low elevated. Water quality monitoring is non-systematic, and water use monitoring does not exist.

The Management Plan has to be based on a reliable water balance that cannot be done with limited and incomplete data. Crucial parameter in Dojran Lake water balance is evaporation which is visible from the fact that when the lake surface area is 30 million m^2 and the annual evaporation amounts at least 30 million m^3.

The question which needs a reliable and scientific answer is: Can the disturbed natural balance of the lake be restored and put in state as before 1988? From hydrological aspect the answer is pretty certain. However, various and harmonized activities and measures should be undertaken by both countries that share the lake and its watershed. On the other side the answer on the question: how much the damages over the entire ecosystem can be restored, is very difficult because the scale consideration of the damages up to now has not been specifically defined, and accordingly restoration measures designed.

7. Conclusions

In the last decade Dojran Lake is facing the ecological catastrophe due to a rapid water level and volume decrease. The basic economy in the region, tourism and fishery, has stopped almost completely.

In this region the average yearly long-term precipitation sum is something over 600 mm. It is very important to establish rainfall measurements on higher altitudes in the lake watershed enabling more realistic rainfall-runoff regime. The temperature regime is the warmest in the country that results with very high evaporation from water surface (almost twice the annual precipitation sum). For reliable evaporation estimation direct measurements from water surface are necessary.

The authors would like to stress out the necessity of more intensive cooperation between the authorized institutions in both countries that share the lake basin and the lake itself. The international community and the financial mechanisms should help both countries in improvement of hydrological, meteorological, water quality, water use and environmental monitoring in the lake basin that will lead to better environment. If this will not be done in a very near future no doubt Dojran Lake will reach the point of no return.

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