HYDROMETEOROLGICAL ANALISIS OF DOJRAN LAKE

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ABSTRACT. – Dojran Lake with its hydrological basin is a closed hydrological system with natural inflow of water to the lake, but no natural outflow. Recharge of the lake is from direct surface and underground inflow. Within the period 1950-1960 the lake faced with extremely high water level that was not favorable for the development of fishing. It was built an artificial channel to regulate the water level in the lake and control the water use at Greek side of the lake. In the period 1988-2000, the water level in the lake continuously was declining. Water level declination caused ecological catastrophe for the flora and fauna in the lake and lake's basin that was inconvenience for the basic economy in the region, tourism and fishing. The reasons for declining the water level in the lake are not clearly identified, and they are located in unfavorable hydrological conditions expressed through longer dried period or uncontrolled usage the water from the lake.

In 2002, the Republic of Macedonia finished a project to build a system for bringing water from Gjavato wells near Vardar River with capacity of 1 m^3/s. The water level in the lake has recently increased. In order to define the causes of changes in the lake requires detailed hydrological and meteorological analysis. This paper will present the results of hydrological and meteorological analysis on the basis of historical data of measured water level, precipitation, and air temperature from hydrometeorological station New Dojran for the period 1961-2008. Some comments on impact factors will be presented as well.

Keywords: "hydrometeorology", "Dojran Lake", "precipitation", "temperature", "water level"

1. INTRODUCTION

Dojran Lake is the smallest natural lake in Macedonia, but is very important water resource for population in the region. Main economy in the region is turism and fishery.

It is located in southeast Europe between 41°9'30" and 41°20'10" north latitude and between 22°40'30" and 22°47'00" eastern longitude, in the Balkan Peninsula, in the southeastern part of Macedonia. The lake and its hydrological basin are located on the border between Republic of Macedonia and Greece.

During the 1950's the lake has extremely high water level that was not favorable for the development of fishing. In order to regulate the water level in the lake and control the water use at Greek side of the lake, it was built an artificial channel. The controlled outflow of water from the lake imposed regime of oscillations of the water level in lake in limited level (max. 147.34 m a.s.l. and min.146.14 m a.s.l.)

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In 1988 the lake has water level on the altitude 145.82 m a.s.l.,(0.32 cm under min.) the water surface area was 37.87 km^2, and water volume was 220 mil. m^3. The next period water level in the lake was rapid decreasing. In 2002 year water level was on altitude 141.33 m a.s.l.(4.51 m under min. altitude), water surface area was only 26.01 km^2, and water volume drooped to only 54 mil. m^3. Water level declination caused ecological catastrophe for the flora and fauna in the lake and lake's basin that was inconvenience for the basic economy in the region, tourism and fishing. The reasons for decreasing the water level in the lake are not clearly identified, and they are located in unfavorable hydrological conditions expressed through longer dried period or uncontrolled usage the water from the lake.

In 2002, the Republic of Macedonia finished a project to build a system for bringing water from Gjavato wells near Vardar River with capacity of 1 m^3/s. The water level in the lake has recently increased. Because the system for bringing water to the lake works with 30-40% of its capacity, the resons for increasing is not clear.

To define the causes of changes in the lake, it is need detailed hydrological and meteorological analysis. Based on the data collected, analysis of the hydrometerological data was conduted to undestand the reson for fluctuations the water level in the lake.

In this paper will be present the results of hydrological and meteorological analysis on the basis of historical data of measured water level, precipitation, and air temperature from hydrometeorological station New Dojran for the period 1961-2008.

2. DATASETS USED IN THE STUDY

Hydrometeorological analysis require various types of data from different sources. Topography data (digital elevation model-DTM), meterological (precipitation, air temperature, radiation, wind speed, relatic humidity), hydrological (lake stage) and GIS layers (soils and watershed boundary) were used to conduct the analysis and study the effect of these variables on fluctuations of water levels in the lake. Table 1 summarizes description of the types of data used in the study.

A 30-m DEM was processed using grid GIS tools to determines the hydrologic parameters (watershed, flow accumulation and stream network), nessesary for computing upstream runoff inflow.

Meteorological data (precipitation, air temperature, radiation, wind speed, relative humidity) are observing at few meterological stations in Greece (Muries, Ahmatovo, Evzoni, Policastro, Kukush, Sterna) and at one meterological station in Macedonia (Nov Dojran). Because there are no available data from stations in Greece, are used only data from meteorological station at Nov Dojran.

Table 1. ***Summery of Data Used in the Study***

Type	Data	Year	Format	Resolution	Station
Topographic	Digital elevation model, DEM		Raster	30 m	
Meteorogical	Precipitation	1951-2008	Point data	1 station	Nov Dojran
	Air temperature	1961-2008	Point data	1 station	Nov Dojran
	Wind Speed	1961-1990	Point data	1 station	Nov Dojran
	Relative humidity	1961-1990	Point data	1 station	Nov Dojran
	Duration	1961-1990	Point data	1 stations	Nov Dojran
Hydrological	Lake stage	1951-2008	Point data	1 station	Nov Dojran

Precipitation and air temperature data observed at the meteorological station Nov Dojran, were used to analyse the effect of precipitation and air temperature on fluctuations of water levels in Lake. The precipitation has been analyzed with data for average monthly sums of rainfall and average annual long-term rainfall sums. The temperature regime has been analyzed with data for average monthly and average annual long-term temperature. Wind speed, relative humidity and radiation data were used to computed the evaporation from water lake surface.

2. DOJRAN LAKE CHARACTERISTICS

Dojran Lake is smallest natural lake in Macedonia, which was formed in a karstified basin created by tectonic activity. Dojran Lake with its hydrological basin is a closed hydrological system with natural inflow of water to the lake, but no natural outflow. Recharge of the lake is from direct surface and underground inflow.

Fig. 1. ***Watershed of the Dojran Lake***

By using DTM-Digital Terrain Model, Model of Geographic Information System-GIS, is given shape and size of the hydrological basin, Figure 1.

Total watershed area of Dojran is 265.59 km^2, which belongs to both countries, 66% of Greece (175.28 km^2), and 34% of the Republic of Macedonia (90.30 km^2).

The average altitude on the watershed is 365 m a.s.l. The maximum altitude of the watershed of Lake Dojran is 1820 m.a.s.l. at the mountain Belasica, and minimum altitude is 148 m.a.s.l., at the water level of the lake (maximum water level). About 212.23 km^2 (80%) of watershed is located between altitude 148 m.a.s.l. and 500 m.a.s.l.. The lower part, 53.36 km^2 (20%) is located at altitude greater than 500 m. By morphological analysis can be concluded that most of the watershed is flat.

Lake bottom of Dojran on Macedonian side using ehosonder was recorded by the official institution of Macedonia (Vodostopanstvo na Makedonija). Recorded data from Macedonian side together with measured data from the topographic map (1:5000) of bottom of the lake on Greek side, were digitally processed and formed curve of lake surface area and curve of volume, (Figure 2).

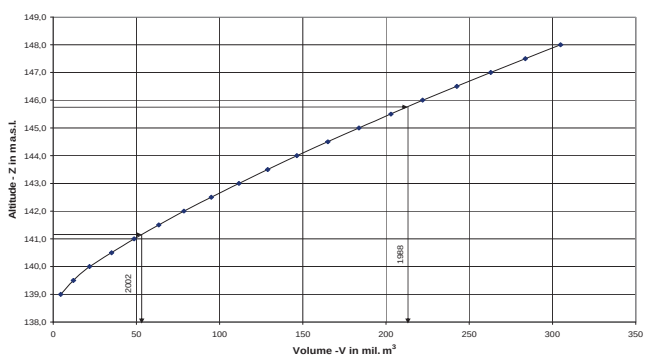

Fig. 2. ***Curve of volume***

Water surface of the lake at normal elevation (147.34 m a.s.l.) is 41.66 km^2 out of which 35% (14.63 km^2) and belongs to Greece, and 65% (27.03 km^2) of the Republic of Macedonia. In 1988 the lake water level was on the altitude 145.82 m a.s.l.,(0.32 cm under min.) the water surface area was 37.87 km^2, and water volume was 220 mil. m^3. In 2002 year water level was on altitude 141.33 m a.s.l.(4.51 m under min. altitude), water surface area was only 26.01 km^2, and water volume drooped to only 54 mil. m^3.

3. HYDROMETEROLOGICAL ANALYSIS AND DISCUSSION

Precipitation. The average annual precipitation sums for the period from 1951 to 2008 (missing data for 1997, 1998 and 2001) are presented in Figure 3. Minimal average annual precipitation sum for this period is 392 mm in 2000,

maximum average annual precipitation sum is 1041 mm in 2002 year. The average annual precipitation sum for the observed period is 648.6 mm. The minimum precipitation is in the summer months (July, August), and maximum precipitation is in the cold months (November, December).

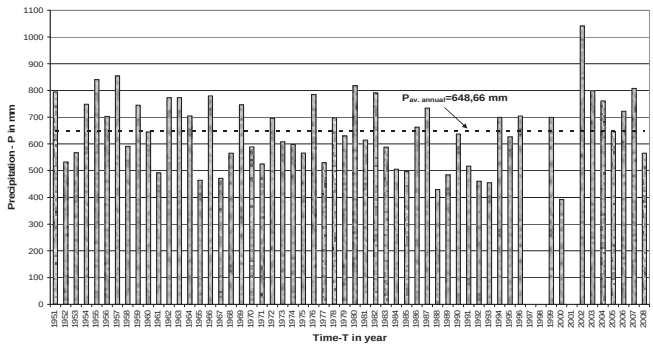

Fig. 3. ***Average annual precipitation sums (1951-2008)***

Temperature. The average annual air temperatures for the period from 1961 to 2008 are presented in Figure 4. Minimum air temperature is 12.16 ^{o}C in 1997, maximum air temperature is 17.06 ^{o}C in 2001 year. The trend line indicates that air temperature has increased by the all period of observed, with the larger oscillations in the second part of period. The minimum air temperatures are in December and January and maximum air temperatures appear usually in July and August, when the precipitation is minimum.

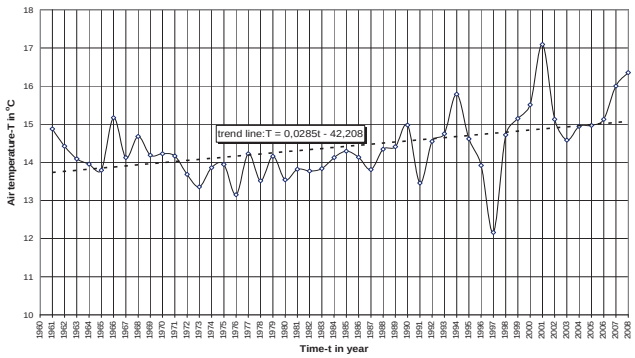

Fig. 4. ***Average annual air temperature (1961-2008)***

Evaporation. Evaporation from the lake surface is very important component of water balance of the watershed of Dojran Lake. Because it is not measured in the past, the evaporation from lake water surface has been computed by the empirical equation (Penman), using the data of air temperature, wind speed, relative humidity and radiation.

The average annual evaporation sums are 768.29 mm (18% bigger than average annual precipitation for same period). The trend line indicates that evaporation has increased by the all period of observed. The maximum evaporation appear usually in July and August, when the temperature is maximum.

The annual evaporation sums for all periods have bigger values than annual precipitation, (Figure 5).The trend line of the annual precipitation sums during all period is slowly decreasing and the oscillations for some periods are more remarcable. The trend line of the average annual evaporation is increasing for all period of time.

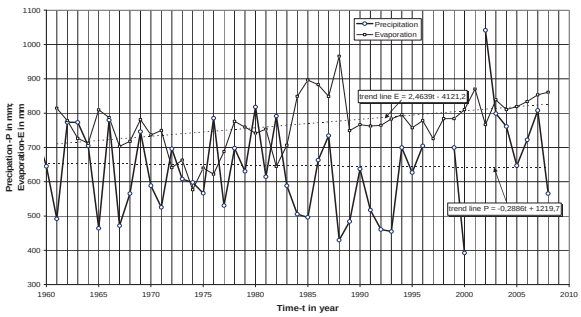

Fig. 5. ***Annual evaporation sums, annual precipitation sums***

Water level analysis. The analysis of water level in Dojran Lake were made with the observed data at water gage station at Nov Dojran. In this analysis were used the average monthly and average annual data for the maximum, average and minimum water levels for the period 1951-2008.

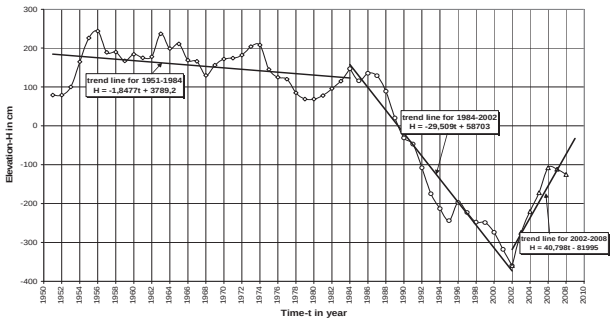

Fig. 6. ***Average annual water level of lake***

The average annual levels of the lake from 1951 to 2008 (Figure 6) showed a great variation. This variation can be shown by dividing time of record into three periods. The first period is from 1951 to 1984, when it can be noted that the water

level oscillations is regular, and trend line is slowly downward. During 1984 to 2002 a strong downward trend of water level appears in the lake. After 1984 water level continuously decrease and the level reached the lowest elevation measured in 2002 (-360 cm or 141,05 m a.s.l.)

Since 2002 there is a growing trend of water level. However, it should be noted that in 2002, the Republic of Macedonia finished a project to build a system for bringing water from Gjavato wells near Vardar River with capacity of 1 m^3/s. Therefore we can say that natural mode of Dojran Lake has been disturbed. To understand the oscillations of water level need to be analyzed the condition of the lake for 1988-2002 with the average monthly levels oscillations (Figure 7).

From the period 1988 to 1995 there were downwards of the level for 395 cm, the period from 1995 to 2002, downwards for 217 cm. From 1988 when the level has been decreasing until 2002, the total observed decreasing of the level of lake is 512 cm.

If we analyze the amplitude of average water level oscillations within one year, we can say that the level of lake increasing in spring and fall, and decreasing in summer time. During the critical period (1988-2002) when the water level continuously was decreasing, the level in summer time was decreasing, but in spring and fall the level was rising little or the level had no changes.

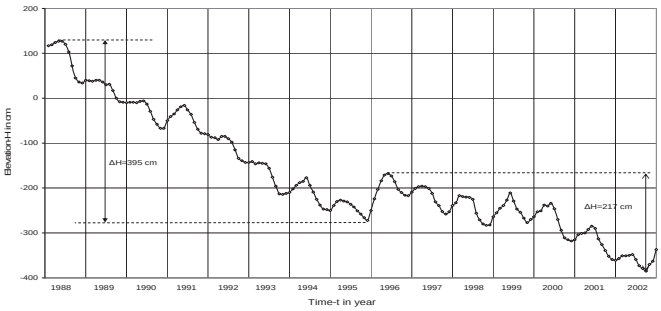

Fig. 7. ***Average monthly water level in lake (1988-2002)***

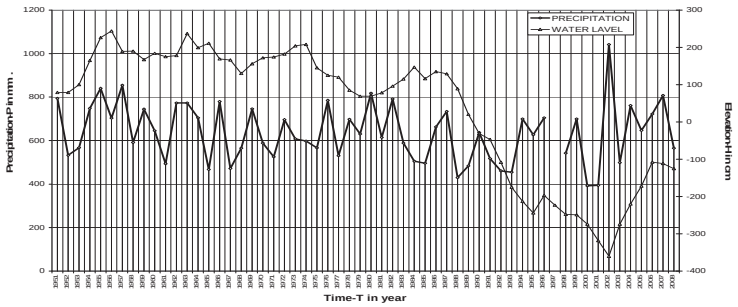

Fig. 8. ***Average monthly water level in lake and annual sums of precipiation***

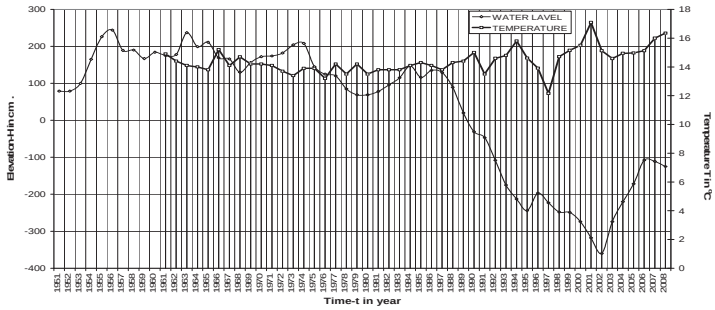

Fig. 9. ***Average monthly water level in lake and average annual temperature***

Correlation between annual sums of precipitation and water level can be analysed if compare the changes of precipitation and its trend line for all period and water level changes (Figure 8). It can be noted that generally the level of the lake is responding to changes in precipitation, before 1988. The reactions of water level of the lake are mostly late reactions. The period after 1988, it can be noted the conecton is disturbed.

Correlation between average annual air temperature and water level is shown in Figure 9. The analysis of long term air temperature date indicates that the temperature in Nov Dojran increases by all period, but decreasing of water level for period 1988-2002, is not responding to changes on air temperature.

5. CONCLUSIONS

The main objective of this paper is to present the results of hydrological and meteorological analysis and give hydrological explanation for conditions of Dojran Lake in past.

Hydrometeorological analysis of the available historical data of the study area shows season variability in the hydrological response.

Dojran Lake is closed hydrological basin with natural inflow of water to the lake mainly driven by rainfall on its watershed and directly to the lake. The natural outflow is not existed, and the loss of water from the lake is expressed with evaporation from water surface and the water which used for melioration at Greece side. The average annual sum of evaporation from water surface of the lake during all period is bigger than precipitation.

We can conclude that the reasons for decreasing the water level of the lake are not only unfavorable hydrological conditions. The manly reason for decreasing can be located in uncontrolled usage of the water from the lake. To define the total loss of water from the lake it is necesary to make the water balance of Dojran Lake with its hydrological basin.

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