# Water Level Fluctuations as an Indicator of Tufa Barrier Growth Dynamics in the Plitvice Lakes

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**Abstract:** The dynamical processes of tufa formation define the morphological and other characteristics of the Plitvice Lakes system. To indicates tufa barrier growth dynamics in the Plitvice Lakes hydrological methods are used – analysis of water discharge and water level fluctuations.

**Key words:** Plitvice Lakes, tufa formation, hydrological methods

## Introduction

The Plitvice Lakes are a unique natural phenomenon of the Dinaric karst that was inducted into UNESCO's World heritage list in 1979. The 16 lakes separated with tufa barriers are divided into two groups with a total volume of around 400000 $m^3$. The origin of the lakes and also their evolution are connected with intensive tufa formation processes. These processes have been studied and documented by numerous scientists (a short review was given in the work of Božičević and Stilinović (1998). It has been found that biogenic factors play an active role in tufa formation. Results of tufa dating with $^{14}C$ method showed that active barriers were formed during the last 6000 – 7000 years (Srdoč et al., 1985). The age of paleo tufa located on the old river banks out of the water course was determined using the $^{230}Th/^{234}U$ method. The results showed that these barriers are between 90000 and 130000 years old (interglacial period Riss-Würm). There have been detected some tufa samples which are between 250000-300000 years old from earlier Mindel-Riss interglacial period (Obelić et al., 2000). The biggest, and also the deepest lakes are Prošćansko and Kozjak Lake. The depth of Kozjak Lake is 45 m, with a surface of 0.83 $km^2$. In this lake was found the biggest flooded tufa barrier with a peak around 5-6 m under the water surface. This barrier is around 22 m high on the upstream side and as much as 37 m high on the downstream side. Faster tufa growth on the profile of the existing barrier at the end of Kozjak Lake caused the upstream water level to rise, flooding the barrier and joining two previously divided lakes. According to the research results of Srdoč et al. (1985) based on $^{14}C$ analyses of a spruce trunk taken out of Kozjak Lake with a dated age of 710 years, it has been determined the that average rate of water level rise was 1.35 cm per year during that period. That is 17 times faster than the sedimentation of calcite mud at the lake bottom during the same period.

*Short scientific paper*

Since there has been no assessment of lake level rising dynamics or tufa barrier growth, especially in recent years, in this paper we present an analysis of available hydrological data. Analyzed hydrological stations located on the biggest lakes (Kozjak and Prošćansko Lake) suffered long-term discontinuity in their work due to war operations in this area during the early 1990's. Therefore data collected from the period 1952-1990 were taken into consideration.

## RESULTS AND DISCUSSION

Analyzed fluctuation trends of minimal and average annual water levels in Prošćansko and Kozjak Lake show an increasing trend (Figure 1). Minimal and average annual discharges at station Kozjak were analyzed to explore if the increasing trend is a result of changes in the discharge regime. Discharge was measured and monitored only at hydrological station Kozjak. It has been determinated that the movement of discharge trends are in opposition to fluctuation trends of characteristic water levels. In other words, through the system of Plitvice Lakes a decrease in water discharge is present, which is characteristic for the whole area of the Dinaric karst, but also wider. The calculated trend of annual average water discharge decrease is 0.041 $m^3s^{-1}$/year (1.15%), and the minimal discharge is 0.0042 $m^3s^{-1}$/year (0.4%).

To estimate the influence of water discharge decrease trends on Kozjak Lake (for which discharge dara were available) on water level changes data for consumption relations obtained at station Kozjak-were used most. It is calculated that discharge decrease trends through the 39 year period resulted in a decrease of annual average discharge of 0.165 $m^3s^{-1}$. If we place this data from station

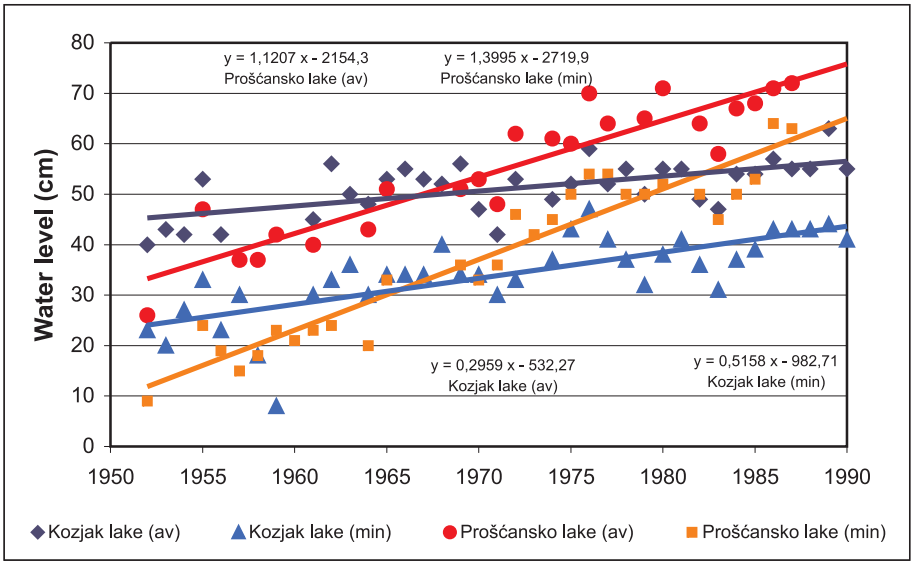


**Figure 1.** Overview of fluctuations of average (av) and minimal (min) annual water level in Prošćansko and Kozjak lakes, and related trends

Kozjak for the last available year (1990) in a consumption relation, the average annual discharge decreasing trend, in relation to the correspondent water level, caused a decrease of the water level of around 10 cm on the basis of annual average data, or around 2 cm on the basis of average minimal annual values. Because of the faster elevation of the tufa barriers, this component of water level decrease in the lakes wasn't noticed, but on the contrary, an overall water level increase was observed. Therefore it is necessary to add this data to data obtained from the analysis of water level increasing trends on Kozjak Lake throughout the 39 year period (on average 0.30 cm/year for the mean and 0.53 cm/year for minimal annual water level). It was determined for both analyzed series that the total real increase of the water level in Kozjak Lake caused by the tufa barrier growth was 22 cm, or on average 0.56 cm/year. It is calculated that the total increase was 12+10 cm for annual average water levels or 20+2 cm for minimal annual levels.

Water discharge data for Prošćansko Lake weren't available so an overall estimation of water level changes could not be done, as it was for Kozjak Lake. Without that component, using only analyses of average annual water level variation it was calculated that there was an increase in water level for 44 cm or even 55 cm according to the analyses of minimal annual values. This indicates that tufa barrier growth in Prošćansko Lake is three times higher, or 1,5 cm/year. It is very close to the before estimated value of 1.35 cm/year (Srdoč et al., 1985) but for Kozjak Lake. At the end of the 90's water level measurements on both lakes were resumed. New results show an even more emphasized increase in water level (possibly because of increased vegetational overgrowth of the tufa spillover). However, this series could not be included in this paper because of the small amount of data.

## Conclusion

This paper demonstrated that with relatively simple hydrological analyses of available hydrological data very valuable results of recent tufa growth dynamics on Plitvice Lakes can be obtained. It was determined that tufa growth is 0.56 cm/year on Kozjak Lake whereas on Prošćansko Lake is three times higher.

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