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CLIMATE-METEOROLOGICAL AND ANTHROPOGENIC INFLUENCE ON THE FALL OF THE WATER LEVEL IN LAKE PRESPA

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ABSTRACT

R. N. Macedonia has more than 160 lakes. Fifty of them are natural. According to the way their basins were formed, the three largest natural lakes in the territory of the Republic of Macedonia, namely, Lake Ohrid, Lake Prespa and Lake Dojran, are of a tectonic type.

A common feature of tectonic lakes is that they age naturally. The term aging means filling of their volume space with sediments as well as reduction of their water quantity and water level.

The subject of this paper are the changes in the water level of Lake Prespa, manifested by large fluctuations in the past. The absolute maximum water level of Lake Prespa was registered on July 15, 1963, at an elevation of H = 851.83 m above the sea level (a.s.l.), while in August 2021, the level was at elevation H = 842.24 m a.s.l, which is the absolutely measured minimum. At such registered water levels, an amplitude of 959 cm is observed.

The reasons for the decrease in the water level of the lake have not been clearly defined. There are numerous studies and papers that point out the causes and these are mainly located in the climate-meteorological changes and the increased anthropogenic effects.

Through analysis of available information on climate-meteorological characteristics (air temperature, precipitation), hydrological data (change of water level in the lake) and information on the use of water from the lake, only at the measuring stations on the Macedonian side, for the period from 1951 to 2020, the water balance has been defined in order to identify the factors that are dominant and are the reason for the current state of the lake.

Keywords: Lake Prespa; Water level; Water balance; Precipitation; Air temperature.

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1. INTRODUCTION

The water level in Lake Prespa, which was once (in the Neogene) part of the Great Desaret Lake, has been steadily declining for the last 30 years. According to geologists, Lake Prespa, like other lakes in Macedonia (Macedonia, Bulgaria and Greece), has long been involved in the process of "aging". The former Great Desaret Lake was reduced to the borders of Prespa, Ohrid, Korça and Bilishtana valleys (the last two are in the territory of Albania), Figure 1. The process of "aging" continued and time took its toll. The last remnants of the Great Desaret Lake are Lake Ohrid and Lake Prespa.

Lake Prespa consists of the Great Lake and the Small Lake that communicate with each other, Figure 2. Lake Prespa has a relatively large amount of water and basin and has a permanent groundwater outflow, which connects it with Lake Ohrid, whose free water area is located lower than that of Lake Prespa for about 150 m. The catchment area of the Great Prespa Lake covers 1,110 km^2 (278 km^2 area of the lake), and the catchment area of the Small Prespa Lake covers 253 km^2 (48.5 km^2 area of the lake) at lake level of 844 m above the sea level. The Macedonian part of the catchment area represents 52.1%, and 65.7% of the lake area in the Macedonian part. The northern and eastern parts of the catchment area are hydrographically well developed unlike the western part, which is poorly developed. The main rivers in the Macedonian part of the catchment area are: Golema (A = 174 km^2) and Istochka (A = 90 km^2) to the north and Kranska (A = 74 km^2), Kurbinska / Pretorska (A = 8.6 km^2) and Brajchinska (A = 74 km^2) to the east. High mountains rise around the lake, namely, Mount Galichica (2,262 m a.s.l.), Mount Suva Planina (1,863 m a.s.l.) and Petrinska Mountain (1,660 m a.s.l.) in the west, Mount Baba (2,601 m a.s.l.) in the east and Mount Bigla (1,990 m a.s.l.) in the north.

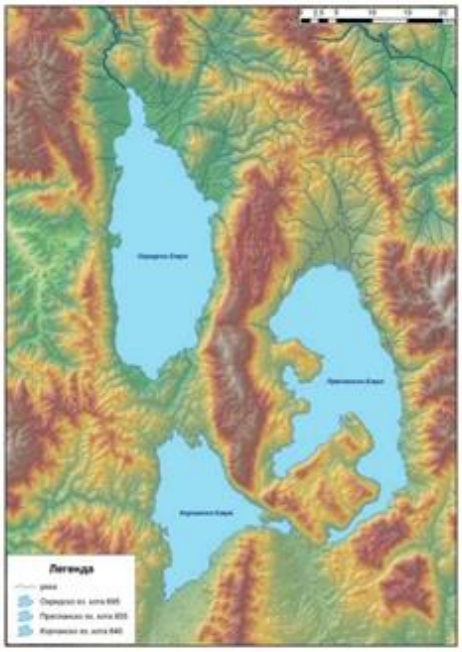

Fig.1 Remains of the great Neogene Desaret Lake

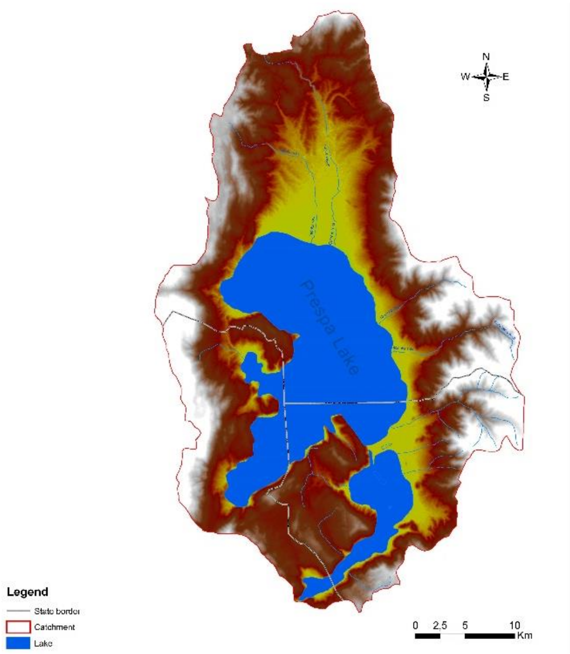

Fig.2. Great and Small Prespa Lake (*source: Hydrogeological Study for the Lake Prespa Watershed UNDP Restoration of Prespa Lake Ecosystem (2014)*)

For the last thirty years, Lake Prespa has suffered a great loss of its water reserves, the water level of this lake being lowered according to some information. The proof of this are the remains of the pile settlement near the village Nakolec, which were spotted on the lake shore with the withdrawal of the lake. It is assumed that, in the past, due to the desire of the inhabitants to obtain more agricultural land in this region, the level of the natural drainage ditch at the Small Prespa Lake, at the exit from the Grlo Gorge, was lowered, and the water from the lake flowed into Bilishtansko Pole field.

Also, for the same purpose, there was an attempt to place explosives in order to increase the openings where the water from the lake was lost in the abysses of the Mount Galichica and Suva (Zavir). Recently, by reaching and exceeding the lowest recorded level of the lake, in Albania near Zavir, an anthropogenic structure has emerged that dates back a thousand years ago according to assumptions.

The change of the water level in Lake Prespa, including all the components that affect it, the way of using the water from the lake basin and directly from the lake, the climatic-meteorological characteristics, etc., have been the subject of numerous scientific studies and papers in the past. The results from enviromental isotope measurements indicate that 52% of the main discharge of the Tushemish springs is recharged from Lake Prespa while 48% are due to the precipitation infiltration in Suva Planina (Mali and Tate) and Galichica Mountains, ("Study of Underground Communication of Prespa-Ohrid Lakes Using Environmental Isotopes of Hydrogen and Oxygen of Water", Zoto et al., (2013)). For the Macedonian part of the watershed, it is estimated that about 42% of the springs at St. Naum are fed by Lake Prespa (Anovski et al. (1988)).

The annual water demand on the Macedonian side is estimated at 1.5 million m3, and 2.5 million m3 together with Greece and Albania (KfW Feasibility Study (2005)). The crop water demand is estimated at 24.76 million m^3 (Report on Irrigation Systems and Crop Water Demand (RFP 10/2013) Hydrogeological Study for the Lake Prespa Watershed).

2. USE OF THE WATER FROM LAKE PRESPA

Today, Lake Prespa is divided between three countries. The population living in the Prespa Region, regardless whether on the Macedonian, Greek or Albanian side, have always used the waters of the Prespa Lake watershed to irrigate their agricultural arable land. As in the past, to this day, local gaps and canals have been used to bring, by way of gravity, the waters from the upper intakes of the rivers to their arable land and plantations of apples and other fruits around the lake. Without consideration of the consequences, large amounts of sediments were dumped in the small Lake Prespa, which practically accelerated the process of eutrophication of this part of the Small Lake Prespa. The use of water officially continued until 2004, but due to the high water level of Lake Mala Prespa and the decrease of the water level of the Big Lake, there are indications that the leaks through the locality called Grlo have continued after 2004.

In the late fifties of the last century (Project Preparation & Development of the Transboundary Prespa Park Project), on the Macedonian side, there began an organized pumping of the water from the lake, with installation of pumps near the villages Asamati and Sirhan (1.0 + 0.8 = 1.8m / s), from where the pumped water entered the irrigation system leading to the Resen Field. This system is not working today. As a replacement for the old pumping system (Asamati-Sirhan), a number of pumps have recently been installed in the Lake Prespa basin. Their number has been increasing constantly.

In 1969, an artificial dam was built on the Small Prespa Lake, with a concrete canal and an outlet, whose threshold was at an elevation of 849.60 m) (FIFA Report on Assessment of Habitat Vulnerability to Climate Change (LIFE15 NAT / GR / 000936)) to regulate the outflow of the waters from the Small to the Big Lake, Figure 3, but no control was exercised over the waters coming out of the Small Lake towards the Albanian side (locality called Grlo in Albania, Figure 4). According to a study by KfW Bank (Project Preparation & Development of the Transboundary Prespa Park Project), in 1953, the Albanian State Government developed a system for using the waters of Mala Prespa and connecting them to the Korça irrigation system, which were used annually by 20 to 45 million m^3 of water.

While the water was used for irrigation in summer, in winter, the excess water from the Devol River was poured into the lake as a compensation. In 1985, tablet closures/stop logs were placed on the dam near the Little Prespa Lake to control the outflow even in the case of higher water levels. For a longer period of time, the difference in levels between the two lakes has been about 8.00 m. The use of the lake waters on the Greek side is mainly for irrigation of the agricultural areas located around the lake.

Fig. 3. Location of the dam on Mala Prespa
(source: Google Earth)

Fig.4. Location of the exit of the waters from Mala Prespa towards Albania
(source: Google Earth)

3. CHANGE OF THE WATER LEVEL IN THE LAKE

The level of the lake in Macedonia was measured before the Second World War, but there was constant monitoring organized by the Hydrometeorological Service of Macedonia (UHMR) from 1951 to 2020, Figure 5. The graph shows the characteristic water levels of the Great Lake (GL), Stenje measuring station, as well as the minimum annual water levels-Hmin-GL, the average annual water levels-Hsr-GL and the maximum annual water levels-Hmax-GL for the period from 1951 to 2020 (source: UHMR).

The same graph shows the minimum annual water levels-Hmin-SL, the average annual water levels-Hsr-ME and the maximum annual water levels-Hmax-SL in the Small Lake (SL), measured in the period from 1969 to 2016, (Final Report on Assessment of Habitat Vulnerability to Climate Change (LIFE15 NAT/GR/000936)). The graph shows that the water levels of the Small Lake are constantly rising, unlike the Great Lake where there is a decline.

Following the analysis of the registered levels of the lake, it can be noticed that the absolute maximum water level in Lake Prespa was registered on July 15, 1963, at an elevation of H = 851.83 mn, when the lake covered an area of A = 278.5 km^2 and its volume was V = 4865.0 * 10^6 m^3. The chart on the water levels of Lake Prespa shows a large trend of decreasing levels starting in 1988, while the minimum water level was recorded at an elevation of H = 842.75mn, registered on November 26, 2008. Then, the lake covered an area of A = 226.8km^2 and its volume was V = 2475.0 * $10^6 m^3$. In August 2020, the level was at an elevation H = 842.61m a.s.l., i.e., -4.99 m below the zero elevation of the lake which is H = 847.6m a.s.l.. In November 2020, the water level in the lake was recorded at H = 842.30 m a.s.l. (-5.3 m), and in August 2021, the level was at an elevation H = 842.24 m a.s.l. (-5.36) which is the absolute minimum level since data from measurements of Lake Prespa have been recorded.

The change of the water level in the lake has been analyzed in comparison with the change of the annual amount of precipitation, the change of the average annual temperature of the air and the change of the annual amount of evaporation from the lake for the period from 1951 to 2010, based on available data from measurements done at the measuring station in Resen, Figure 6, Figure 7 and Figure 8, respectively. From these graphs, it can be seen that the fall of the water level follows the decline of the annual amount of precipitation, while the air temperature and evaporation from the lake have an increasing trend. This shows that climate-meteorological changes have a logical impact on the change of the water level, i.e., the lack of rainfall, the increased air temperatures and the increased evaporation of water from the lake contribute to the decreasing trend of the water level of the lake.

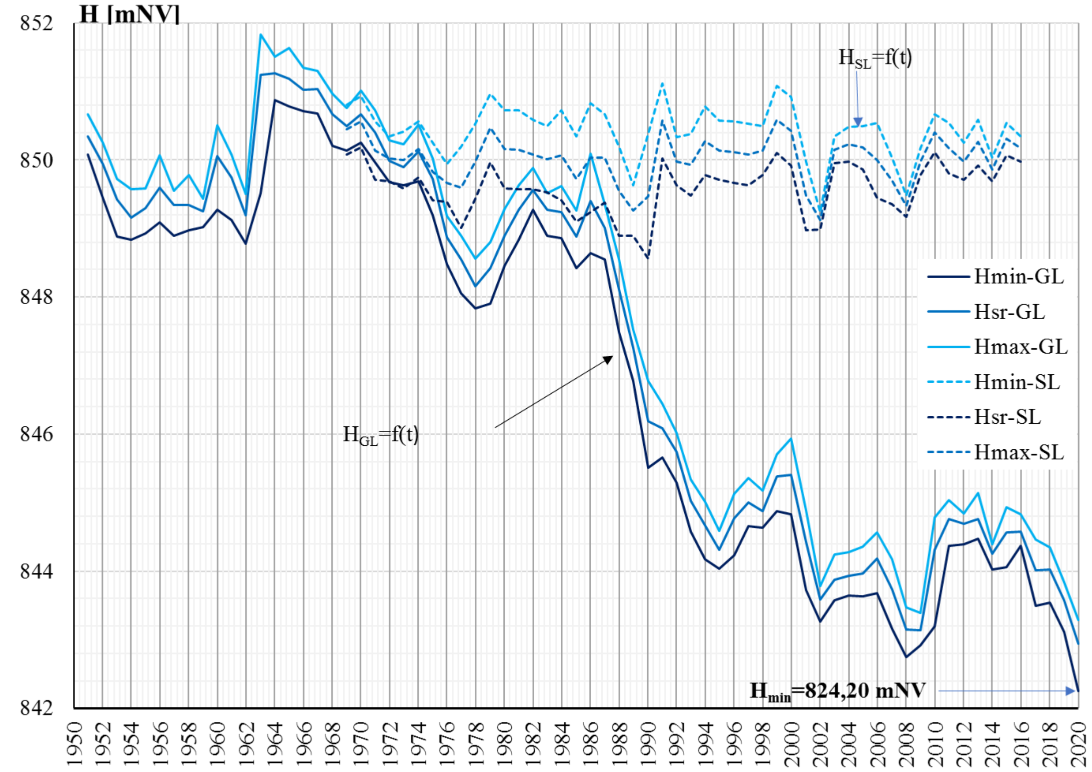

Fig. 5. Water level oscillations of Great and Small Prespa Lake (period 1951- 2020).

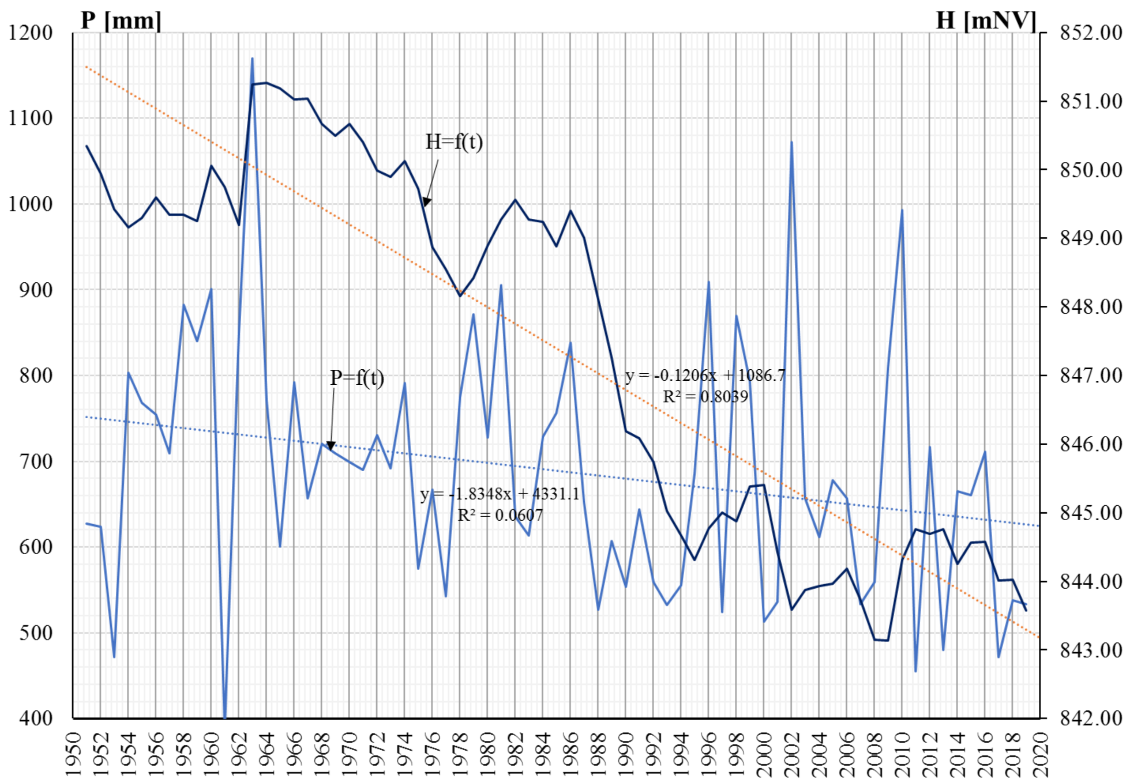

Fig.6. Change of the water level of Lake Prespa, m.s. Stenje, compared to the annual amount of precipitation measured at m.s. in Resen (period 1951-2020).

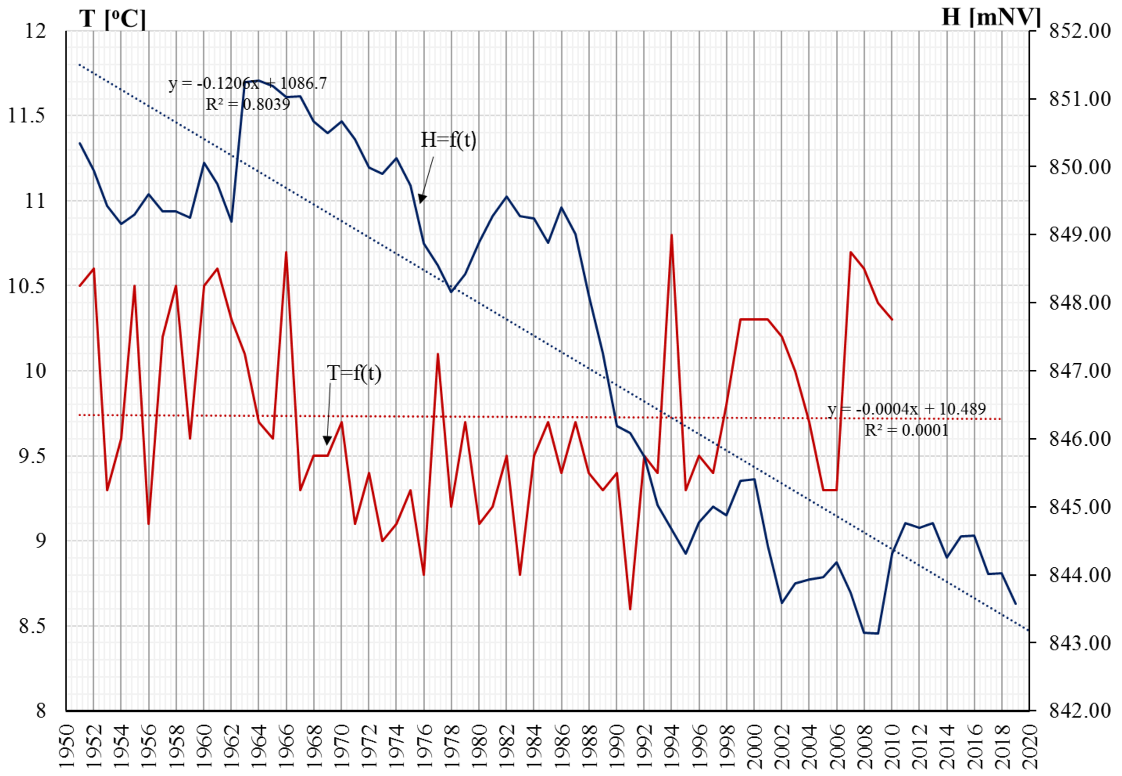

Fig.7. Change of the water level of Lake Prespa, m.s. Stenje, compared to the change in the average annual air temperature in Resen (period 1951-2020).

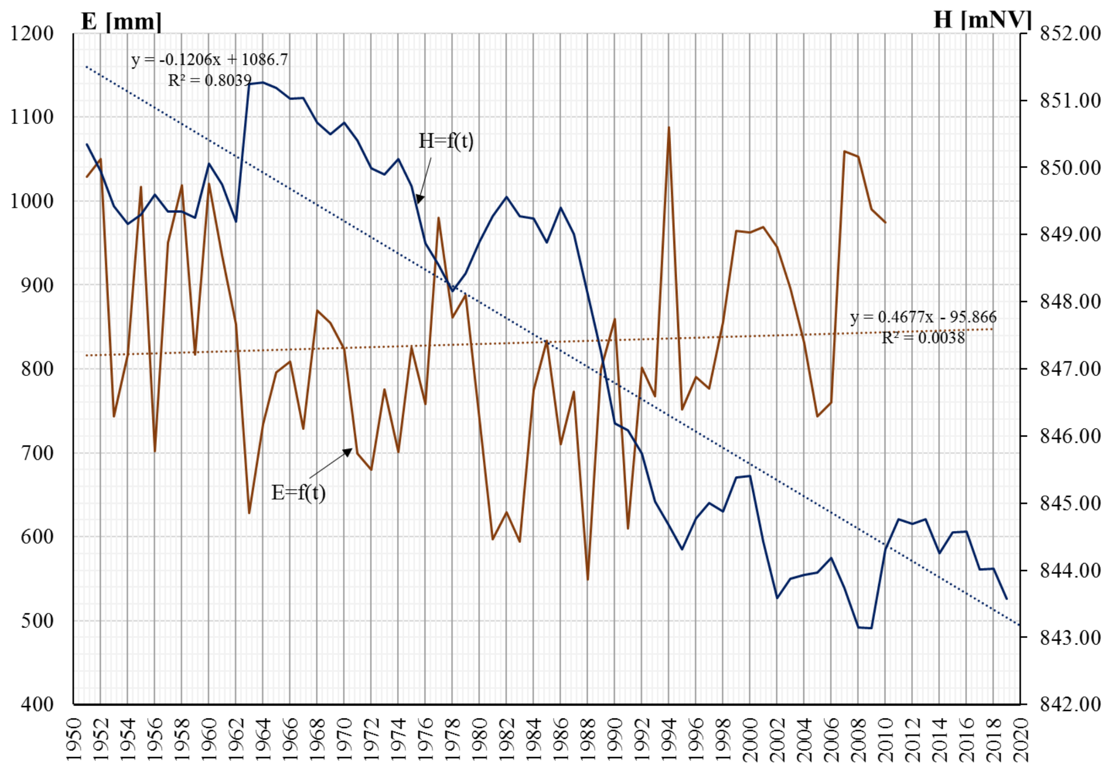

Fig.8. Change of the water level of Lake Prespa, m.s. Stenje, compared to the annual amount of evaporation (period 1951-2020)

4. WATER BALANCE

The water balance of the Prespa Lake watershed can be presented as a change in water reserves and can be written as:

$$St+(P+Qin+Gin)-(E+ET+Qout+Qws+Qir+Gout)=St+\Delta t \qquad (1)$$

where: (St) is the initial amount of water in the watershed at the beginning of the analyzed period, (P) are inflows into the watershed as a result of precipitation, (Qin) are surface inflows into the watershed from another watershed, (Gin) are inflows from groundwater, (E) is evaporation from water bodies, (ET) is evapotranspiration, (Qout) is water leakage into another basin, (Qws) is water used by the population and industry, (Qir) is water used for irrigation, (Gout) is groundwater runoff, and (St + Δt) are water reserves in the catchment at the end of the analyzed period. The components of the water balance are determined according to the available data on the Macedonian part of the Prespa Lake watershed.
The total amount of rainwater in the catchment area has been calculated according to the following expression:

$$V_p = \sum P_{\Delta t} \cdot A \qquad (2)$$

where: $\sum P_{\Delta t}$ is the average amount of precipitation in the catchment area for the time period (Δt), and (A) is the catchment area.

The evaporation from the free water surfaces in the Prespa Lake catchment area has been calculated empirically, using data on air temperature, saturated water vapor pressure, solar radiation, solar duration, wind speed and albedo effect (Penman equation). The total evaporation from the surface of the Prespa Lakes has been calculated according to the following equation:

$$I_E = \sum E_{\Delta t} \cdot \sum A \qquad (3)$$

where: $\sum E_{\Delta t}$ evaporated water from the surface of the lakes for the period (Δt), and $\sum A$ is free surface at normal water level (surface of the Great Lake A = 278 km^2 and surface of the Small Lake A = 48.5 km^2 at 844 m a.s.l.).

The amount of evaporation from the soil surface in the catchment area of Lake Prespa has been calculated according to the following equation:

$$I_{ET} = \sum ET_{\Delta t} \cdot A_{ET} \qquad (4)$$

where: $\sum ET_{\Delta t}$ is evapotranspiration from the catchment area and (A_{ET}) is the area in (km2) under evapotranspiration process. Evapotranspiration has been calculated using the Penman equation. Climate data referring to the period 1991-2010 have been taken from the Pretor station.

There is no surface runoff from Lake Prespa. Presented in the paper "Study of Underground Communication of Prespa-Ohrid Lakes Using Environmental Isotopes of Hydrogen and Oxygen of Water" Zoto et al., (2013) are certain results from enviromental isotope measurements. The results indicate that 52% of the main discharge of the Tushemish springs is recharged from Lake Prespa while 48% are due to the precipitation infiltration in Suva Planina (Mali and Tate) and Galichica Mountains. These results are comparable to those obtained by Anovski et al., (1988) for the Macedonian part of the watershed, according to which it is estimated that about 42% of the springs at St. Naum are fed by Lake Prespa. The assessment of the components Gin = 15,57,10^6 m^3 (groundwater inflow) and Gout = 97,41.10^6 m^3 (groundwater outflow) was made within the Hydrogeological study for the Prespa Lake Watershed (UNDP Project RFP 10/2013) where a simple "bucket" model has been applied. The water resources of the Prespa Lake basin are used by the population and industry. According to the KfW Feasibility Study (2005), it has been estimated that the annual water demand on the Macedonian side is 1.5 million m^3, i.e., 2.5 million m^3 together with Greece and Albania. The crop water demand data have been taken from the report on Irrigation Systems and Crop Water Demand (RFP 10/2013 Hydrogeological Study for the Lake Prespa Watershed) where the total irrigation water demand has been estimated at 24.76 million m^3. Considering the efficiency of the irrigation systems of 70%, it is estimated that the gross need for irrigation water is 24.76 / 0.70 = 35.37 million m^3 per year. The surface inflow from the Brajchinska River shown as an average annual volume is 28.86 million m^3 (data from the KFl study). The results on the water balance for the period from 1951 to 2020 are shown in Table 1.

By applying a simple relation for the water balance V - I = ± ΔV, where (V) are inlet waters, (I) are outflow waters and (ΔV) is a change in water reserves for the Prespa Lake watershed, based only on data on the Great Prespa Lake for the period from 1951 to 2010, the water reserves have been estimated at -53 million m^3 per year, Table 2, (Stojov V.(2011)) and (Eftimi R., Stevanović Z. & Stojov V., (2021)). In this model, the input components are represented by lake precipitation (Ve), inland precipitation (Vk), inland lake inflow (Vp / p) (surface and underground), while the output components are inland evaporation (Ik), evaporation from the lake (Ie) and outflow to Lake Ohrid (Io). The data used for this calculation are presented in the paper of Stojov V. "Climatic and Anthropogenic Impacts on the Water Resources of Lake Prespa", published on the website of MoEPP (2020). Additionally, in the calculations in Table 2 (column 2), new data on precipitation for the period 2011-2020 are included, wherat, for the period 1951-2020, it is obtained that 71 m m3 are annually missing in the lake basin. This difference compared to the period from 1951 to 2010 is due to the reduced amounts of rainfall in the watershed of the Great Prespa Lake in the period from 2010 to 2021.

Table 1. Water balance in the Prespa Lake watershed

Water balance component	MMK
Rainwater inflow-P	953.58
Surface water inflow-Qin	28,86
Groundwater inflow –Gin	15.57
Evaporation from free water surface-E	247.38
Evapotranspiration in the watershed-ET	658.21
Leakage through the karst into the underground-Qou	97.47
Water used for water supply-Qws	2.50
Water used for irrigation-Qir	35.37
Water volume change (inflow-outflow) V-I=S_t-$S_{t+\Delta t}$	(-42,93)

Table 2. Water balance in the Prespa Lake (Stojov V.(2011), (2020))

Water balance component	MMK	
	1951-2010	1951-2020
Lake precipitation (Ve)	189	185
Inland precipitation (Vk)	610	596
Inland lake inflow (Vp / p)	229	215
Inland evaporation (Ik)	381	381
Evaporation from the lake (Ie)	223	223
Outflow to Lake Ohrid (Io)	248	248
Water volume change (inflow-outflow) -V-I= ΔV	(-53)	(-71)

5. ANALYSIS OF RESULTS AND CONCLUSION

The water balance procedure for the Prespa Basin shown in this paper refers to a one-year water balance model. The water balance has been defined in accordance with the adopted model developed during the preparation of the study: Hydrogeological Study for the Lake Prespa Watershed, UNDP Restoration of Prespa Lake Ecosystem, (2014), prepared by the Faculty of Civil Engineering in Skopje. The results on the water balance for the period of up to 2010 show that the water reserves in the watershed estimated in this study amount to 220 million m^3. The water level in the lake has been drastically declining for the last 10 years, with a slight improvement, an increase in the period from 2010 to 2016.

For the needs of this paper, the water balance has been defined by a simple "bucket" model, whose components have been determined by data on precipitation in the period 1951-2020, supplemented with new data that have been recorded at the measuring station in Resen for the last 10 years, Table 1. From the results, it can be noticed that the annual water reserves in the watershed in this period are reduced, i.e., they have a negative sign -42.93 million m3 per year.

The losses shown in the second way of balancing the water reserves show that, in the period 1951-2010, in the basin of the Great Prespa Lake, 53 million m^3 are missing per annum (Stojov, 2010), while with the additionally analyzed precipitations for the period 1951-2020, about 71 million m^3 of water is missing per year, meaning that the water reserves in the Great Prespa Lake have been reduced for additional 18 million m^3. This increase in lack of water reserves can be attributed to the reduced rainfall in the basin, increased evaporation and the fact that water reserves have continuously been used uncontrollably, directly from the lake, from the groundwater reserves and generally from the basin for different purposes and needs.

The decreasing trend of the water level in Lake Prespa in recent years, observed by the measured characteristic water levels in the lake, has been confirmed by the water balance. It can be concluded that, in this period, the fall of the lake level is due to larger amounts of water that occur as loss in the watershed, compared to the waters that are noted in the water balance as input or inflow into the watershed.

If we analyze the changes in precipitation at the measuring station in Resen for the past 10 years as an input parameter in the water balance, we can see a significantly lower precipitation compared to the average annual amount of precipitation. In the period from 1951 to 2010, the average annual amount of precipitation calculated for the watershed on the Macedonian side (measuring stations: Asamati, Stenje, Izbishta, Carev Dvor, Nakolec, Brajchino, Resen, Pretor) determined by the method of isohiets is 900 mm. At the measuring station Resen, the average annual amount of precipitation for the period from 1951 to 2010 is 705 mm, for the period from 2010 to 2019, it is 581 mm, and for the period from 1951 to 2019, the average is 689 mm. It can be noticed that the average annual rainfall in the last 10 years has been lower than the average annual rainfall for the whole period for about 108 mm.

If the graph of air temperature change is analyzed, one can notice a rising trend. In conditions of reduced rainfall, increased air temperatures, the evaporation components of the water from the basin and the lake are expected to grow. The water needs of the population as well as for irrigation of plants in such climate change (increased temperatures, reduced precipitation) are also increasing. All the analyzes, i.e., noticed changes only confirm the conditions referring to the water level of Lake Prespa.

The differences and the mistakes that can be made during the implementation of the procedure for definition of the water balance of the lake basin can be considered from three aspects. The first aspect is related to the model that is applied and the assessment of the components of the water balance in relation to the available data (application of appropriate hydrological methods for assessment of each of the components in terms of quality and quantity). The second aspect is related to possible mistakes that can be made in the process of measuring and evaluating the relevant data that determine the appropriate components of the water balance (adequate measuring network and sufficient number of measuring points, type of measuring instruments and professional implementation of the procedure of measuring, archiving and data processing). The third aspect is related to the time period for which the water balance is defined (daily, monthly, seasonal, annual, multi-year, etc.).

The analysis of the available hydrological data necessary for hydrological modeling and development of water balance models and plans for integrated watershed management has shown the need to improve both the quality and quantity of data. This is essential to clarify the reasons for the rapid decline of the lake water levels that began in the early 1990s and has become alarming and worrying in the past few years.

It should also be emphasized that, in order to fully define the cause of this condition of Lake Prespa, it is necessary to analyze all possible scenarios of water use and water resources management in all three countries that share the Lake and its basin. And finally, in order to assess how much human activity has influenced the fall of the water level and how much it is due to natural causes (climate change), it is necessary to take into account all hydrological data necessary for hydrological modeling of the Prespa Lake basin recorded in all three countries (Macedonia, Greece and Albania).

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