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Hydrological and Meteorological Characteristics for the Modrac Basin

Omer Kovčić, Civ. Eng.[1], Nedim Sladić, B.Sc.[2]
[1] Asst. Prof. Ph.D.,Faculty of Mining, Geology and Civil Engineering, University of Tuzla and
PE "SPREČA" for water resources dd TUZLA
[2]International University of Sarajevo, Sarajevo, Bosnia and Herzegovina

Abstract:- Climate change is having a major impact on the amount of water in the reservoir as well as the appearance of large flood waves. One of the key elements for monitoring climate change is temperature changes and the amount of evapotranspiration. Even slight changes in temperature affect the distribution of precipitation throughout the year and the amount of precipitation.

The catchment area network of the multi-purpose reservoir Modrac is made up of three larger streams: Spreča River, Oskova River, and Turija River. In the design and construction of the dam and the multi-purpose reservoir Modrac, it was planned that it serves as a multi-use water management system.

This paper provides information on temperature change trend (minimum and maximum temperatures), amount of precipitation, and evapotranspiration and analyzed maximum flood waves for the reservoir Modrac for the period 2001-2020. Available data will be extensively tested using a variety of inferential statistical methods between predictor and response variables in order to prove/disprove the formed hypothesis based on the obtain statistical test results.

***Keywords**:- Hydrological, Meteorological, Change and Variability, Reservoir Modrac, Temperature, Precipitation, Evapotranspiration, Flood Waves.*

I. INTRODUCTION

Climate change is predicted to significantly impact the availability of water resources around the world. The scientific consensus is that increasing temperature will alter both the quantity and timing of regional precipitation, evapotranspiration, and soil moisture, which will in-turn affect hydrologic flows into lakes and streams. Climate change is also predicted to increase precipitation intensity, which could lead to higher rates of surface runoff causing an increased risk of floods. Increasing temperature will enhance the evapotranspiration rate, which may increase the demand for water availability during the peak growing season. With more than one-sixth of the earth's population relying on glaciers and seasonal snowpacks for their water supply, the consequences of climate change and interrelated hydrological changes for future water availability are likely to be severe. In order to better tackle these future water resource management issues, the impact of climate change on components of the water balance must be quantified from regional to local scales (Muhammad et al., 2020).

Climate change and the underlying surface of the watershed are the two dominant factors that impact streamflow change. The impact of climate change on the hydrological cycle will be a change in the global hydrology distribution. Of all of the climate factors, precipitation and potential evapotranspiration are the most important for the determination of climate characteristics (Ma et al., 2008).

There are many factors that influence the underlying surface characteristics of a watershed, including land-use change, hydraulic engineering, water resources development, and others. The underlying surface condition of a watershed has been reported to have a more important function than climate change on the hydrological cycle, and it contributed more than 50% to streamflow change (Zheng et al., 2009).

II. GENERALLY ABOUT MODRAC CATCHMENT AND MULTI-PURPOSE RESERVOIR MODRAC

The current way of producing energy is the main "culprit" for human activity caused by climate change, while the water regime, with all its consequences, the first major "victim". High waters are increasing and occurring more and more often, while low water and drought reduced last longer.

Multi-purpose reservoir "Modrac" is formed in 1964 with the construction of a dam in the gorge Modrac. It is formed by the rivers Spreča and Turija with its river tributaries. The total catchment area in the profile of the dam is approximately 1189 km2, which accounts for over 60% of the entire river basin to prevent this. Of the total area of the basin, river Spreča occupies 832 km2, river Turija occupies 240 km2, while the rest of the basin belongs to the immediate basin reservoirs 117 km2 (Kupusović, Vučijak and Kovčić, 2015).

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For the dimension of normal backflow 200.00 (m.a.s.l.) reservoir provides, on average, 2,30 m3/sec of raw water and 4,70 m3/sec as hydro biological minimum for the river Spreča, looking downstream from the dam (projected state) (Kupusović, Vučijak and Kovčić, 2015).

Multi-purpose reservoir “Modrac” solves several hydrologic and extremely economic aspects as supply of population, industry and thermal capacity of Tuzla and Lukavac with technological water, dilution of wastewater discharges Tuzla and Kladanj industry, the increase of flow of Spreča river downstream of the reservoir during the summer, electricity production in a small hydropower, mitigates high water flood flows with retention influence of reservoir and prevent or significantly reduce flooding in the river valley Spreča downstream of the reservoir.

However, the actual amount of water in the reservoir may vary over the short term depending on rainfall and other conditions (Kupusović, Vučijak and Kovčić, 2015).

Flood control dams store all or a portion of the flood waters in the reservoir, particularly during peak floods, and then release the water slowly.

According to the Law on the Protection of accumulation "Modrac" uses of reservoir “Modrac”, in order of priority, are (Kupusović, Vučijak and Kovčić, 2015):

- The provision of water for the population,
- The provision of water for industry,
- Protection from flooding downstream of the dam,
- The provision of hydro biological minimum for river Spreča, downstream of the reservoir,
- Development of tourism, recreation and water sports, in accordance with the Law,
- The production of electricity on small hydroelectric using excess water in the profile Modrac.

According to the latest geodetic and hydrographic measurements reservoir "Modrac" has the following morphometric characteristics (Kupusović, Vučijak and Kovčić, 2015):

- Total area of the reservoir “Modrac” is 16,69 km2,
- Total volume of water in reservoir “Modrac” is 102.759.629,92 m3,
- Useful volume of water in reservoir “Modrac” is 66.522.627,23 m3,
- Maximum depth of the reservoir Modrac is 14.94 m (bed elevation),
- The average depth of the reservoir “Modrac” is 5.32 m,
- Maximum width of the reservoir “Modrac” is 2.411,17 m,

The Modrac dam is multi-armored reinforced concrete with 11 counterframes, with the following basic characteristics, Figure 1:

Construction height of dam H = 33.35 m;
Dam length in crown L = 205,0 m;
Level of the upper edge of the structure of the dam 205,00 m.a.s.l.;
Designed level of maximum downfall 203,00 m.a.s.l.;
Level overflow fields of the dam - angle of normal slowdown 200,00 m.a.s.l.;
Minimum operating level: 194,00 m.a.s.l.;
The four bottom outlets (number: 2, 6, 7 and 8). The maximum capacity (maximum shutter openness) of the basic drains is about 80.00 m3/s (Kupusović, Vučijak and Kovčić, 2015).

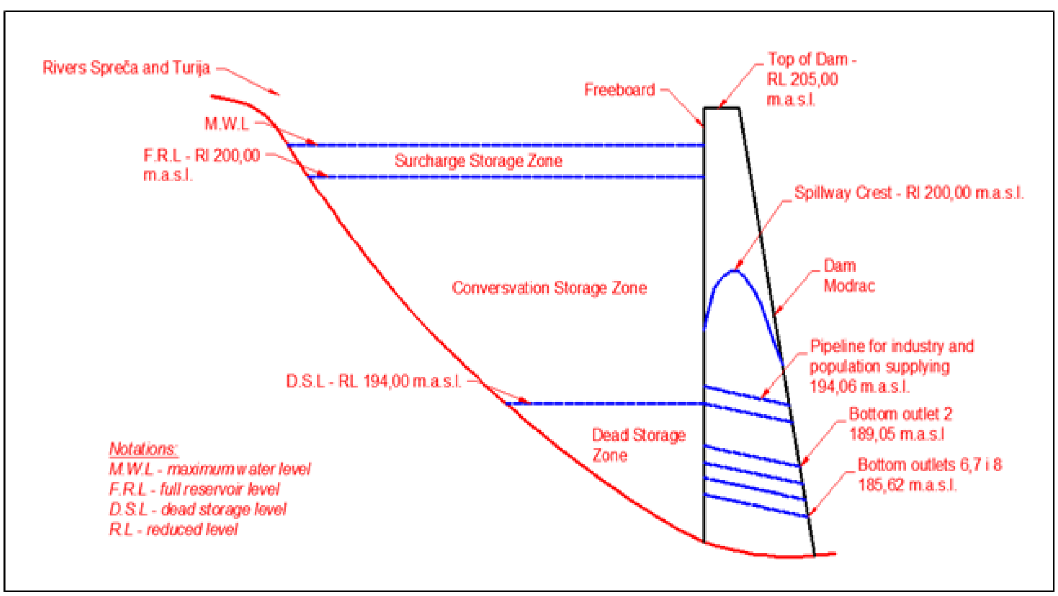

Fig. 1. Charateristics of dam „Modrac“ (Suljić and Kovčić, 2018)

The emergence of high water is an extreme hydrological phenomenon defined by an unusually high-water level, flow, or volume of water at a certain place at a certain time period. The causes and consequences of flooding are usually not be predicted but can be mitigated. The consequences of floods vulnerability of human lives and material goods, huge damage, the involvement of a large number of people and resources in the field, social insecurity of the population, etc (Suljić and Kovčić, 2018)

Climate changes are having a major impact on the amount of water in the multi-purpose reservoir as well as the appearance of large flood waves. One of the key elements for monitoring climate changes is temperature changes. Even slight changes in temperature affect the distribution of precipitation throughout the year, and the precipitation amount (Kupusović, Vučijak and Kovčić, 2015).

This paper provides information on the movement of precipitation changes in the catchment area of multi-purpose reservoir "Modrac" for the period from 2001 – 2020.

Due to climate change in the period from the formation of the multi-purpose reservoir ''Modrac" to the present day, all major flood waves have been recorded. April 1985, July 1986, May 1987, June 2001, March 2006, May/June 2010 and May 2014 (Kupusović, Vučijak and Kovčić, 2015).

Time to appear of flood wave [date]	**Maximum level H [m.a.s.l.]**	**Inflow Qinf [cms]**	**Outflow Qout [cms]**	**Retention of reservoir [%]**	**Rainfall [mm]**
14th -24th April 1985.	201.09	406.50	201.10	50.53	81.16
15th – 25th July 1986	200.74	272.10	154.90	43.07	117.57
3rd – 13th May 1987	201.60	730.00	331.45	54.60	112.30
17th – 27th June 2001	202.12	619.10	466.36	24.56	60.20
29th May – 8th June 2010	201.18	411.11	252.54	38.57	92.60
14th – 23rd May 2014	203.42	1602.00	1137.00	29.00	213.90
22nd – 29th June 2020	200.74	367.27	164.17	55.00	92.90

Table 1. Review of the characteristics of registered flood waves (Kovčić, 2017)

The hydrographs of flood waves are determined on the basis of the natural flow into the reservoir. The hydrograph of outflows is determined by the discharge through the discharge facilities on the dam Modrac.

The discharge volume is controlled over the flow curve at the Modrac downstream station.

The amount of discharges is regulated by the bottom outlets and spillway facilities and depends on the level of water in the reservoir. Since the amount of discharge is limited by the appearance of large flood waves, there is a rise in the water level in the reservoir (accumulation charge), and thus absorbs part of the volume of the flood wave, ie it makes the reduction of the maximum flow. The reduction of maximum flow downstream ranges from 24 to 55% depending on the size of the water wave and the state of the reservoir Modrac level (Kupusović, Vučijak and Kovčić, 2015).

III. STATISTICAL DATA ANALYSIS FOR MODRAC CATCHMENT AND MULTI-PURPOSE RESERVOIR MODRAC

The aim of this paper is the following that to: (1) Analyze maximum surface evapotranspiration in the treated series of flood waves for the period 2001-2020 for the reservoir Modrac; (2) Analyze maximum quantitative evapotranspiration in the processed series of flood waves for the period 2001-2020 for the reservoir Modrac; (3) Analyze maximum monthly recorded precipitation in the processed series of flood waves for the period 1990-2020 for the reservoir Modrac; (4) Analyze maximum monthly recorded precipitation in the processed series of flood waves for the period 2001-2020 for the reservoir Modrac; (5) Analyze maximum annual recorded precipitation in the treated series of flood waves for the period 2001-2020. for the reservoir Modrac; (6) Analyzed maximum flows for processed series of flood waves for the period 1980-2020; (7) Minimum measured air temperature for the period 2001-2020; (8) Maximum measured air temperature for the period 2001-2020. Statistical data analysis is performed using R programming language and the results are presented in the next subsections of this paper.

3.1. Inferential Statistical Methods

To prove/disprove the significant difference between the observed group parameters as a potential link to the climate change influence, inferential statistics is extensively used based on the analytically formed initial (H_0) and the alternative hypothesis (H_1) from the common data characteristics, such as a river flow, surface evapotranspiration, total evapotranspiration, precipitation rate, etc. In order to detect the possible significant difference between more observed groups, a one-way analysis of variance (ANOVA) is used to compare the variances within the observed groups. For the variables whom statistical difference is detected with ANOVA, F-test is further performed in order to prove/disprove the significant difference

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between the observed group variances, as well as Welch t-test if F-test indicates the prescribed criterium for rejecting the initial hypothesis (H_0), in order to verify the significant difference between the group sample means. Analytically the focus is concentrated around the variables that are pivotal for the dam, such as flow, surface evapotranspiration and total evapotranspiration, and monthly and annual precipitation), since the assumption is those abovementioned variables will be dependent mostly on the specific meteorological and hydrological conditions, which include the maximum and minimum thermic variables. The correlation matrix is used to determine which meteorological parameters are linearly related to the characteristics of the observed region of Modrac Lake, taking into consideration their significance measurements based on the Pearson correlation test (p-value).

3.2. Results

For the obtained results, initial hypothesis states that there is no significant difference between the sample means (all sample means are equal), or:

$$\mu_1 = \mu_2 = \cdots = \mu_n = 0 \quad (1)$$

while the alternative hypothesis states that there exists significant difference between the sample means (sample means are not equal), or:

$$\mu_n \neq 0; \, for \ at \ least \ one \ n \quad (2)$$

Obtained one-way ANOVA results for the analyzed groups are enlisted in Table 2. Evapotranspiration_T (total evapotranspiration) and Evapotranspiration_S (surface evapotranspiration show the persistence of significant difference between the observed groups (denoted by *), where $p \leq 0.05$. Hence, further focus is put on the corresponding associating variables that are obtained using the correlation matrix and their measurements (p-value) derived from the Pearson's correlation test.

Groups	μ	σ^2	F-value	Pr(>F)	Sign.codes
Flow	233.08	97791.92	2.724	0.1499	
Precipitation_M	72.93	302.12	3.763	0.1005	
Precipitation_Y	944.46	38029.78	0.024	0.8815	
Evapotranspiration_T	2.74	0.22	10.632	0.0172	*
Evapotranspiration_S	449.86	36.79	10.632	0.0172	*
Maximum	36.38	4.69	1.199	0.3156	
Minimum	-16.49	25.38	1.165	0.3220	

Table 2. Observed results from one-way ANOVA method. Significance level at p = 0.05 indicated by *; <0.01 **, <0.001 ***.

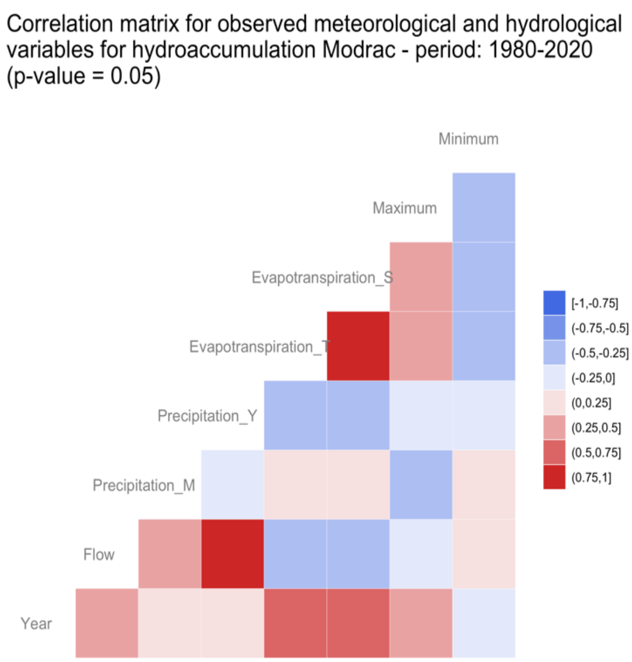

Fig 2. Correlation matrix for the observed meteorological and hydrological variables.

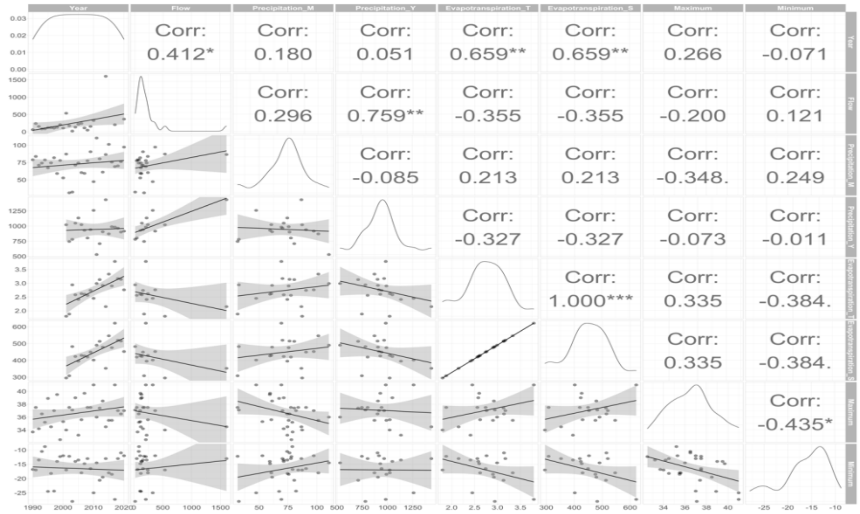

Fig. 3. Scatterplot matrix with the correlation coefficients for the analyzed dataset. Significance correlation denoted by * for p <0.05, ** <0.01, *** < 0.001.

From the correlation and the scatterplot matrix it is visible that the linear relation between some variables is in the strong positive correlation, (i.e. Year with Evapotranspiration_T and Evapotranspiration_S, Flow with Precipitation_Y), that is, both variables move in the same direction. However, a negative correlation is observed between Flow and Year, indicating that as one variable rise, the other decreases, which link may be described using precipitation rates that are influenced by the meteorological conditions. As expected, the thermic variables show a negative correlation. Based on ANOVA results and correlation matrix, our main interest to prove/disprove the significant difference between the sample groups is focused on the flow, evapotranspiration, and precipitation rates. Figure 3 shows the scatterplot matrix with the correlation coefficients for the analyzed dataset. F-test is used to prove/disprove the existence of the statistical difference between the variances of the sample groups and the results are enlisted in Table 3. By the criterion of the F-test, for eight observed groups there exists a significant difference between sample variances, hence the Welch t-test (t-test assuming unequal variances) is used to verify the significant difference between the sample means. For all eight observed groups, the significant difference is verified after satisfying the criterion of the Welch t-test, thus we confirm that there is a significant difference between the sample means. The results of the Welch t-test is enlisted in Table 4.

Groups tested with F-test	F-value	F-critical	p-value	CI [95.0%]	Sign.codes
Evapotranspiration_T → Maximum	0.049	2.168	<0.00	[0.02, 0.12]	
Evapotranspiration_T → Minimum	0.009	2.168	<0.00	[0.00, 0.02]	
Evapotranspiration_T → Precipitation_Y	<0.00	2.168	<0.00	[<0.00]	
Evapotranspiration_T → Precipitation_M	0.0005	2.168	<0.00	[0.000, 0.001]	
Evapotranspiration_T → Flow	<0.00	2.55	<0.00	[<0.00]	
Evapotranspiration_S → Maximum	1342.5	2.168	<0.00	[531.36, 3391.66]	***
Evapotranspiration_S → Minimum	245.06	2.168	<0.00	[96.99, 619.12]	***
Evapotranspiration_S → Precipitation_Y	0.16	2.168	<0.00	[0.06, 0.41]	
Evapotranspiration_S → Precipitation_M	14.43	2.168	<0.00	[5.71, 36.46]	***
Evapotranspiration_S → Flow	0.036	2.55	<0.00	[0.01, 0.10]	
Precipitation_Y → Precipitation_M	88.82	2.168	<0.00	[35.15, 224.41]	***
Precipitation_Y → Flow	0.227	2.55	0.004	[0.07, 0.62]	
Precipitation_Y → Maximum	8260.9	2.168	<0.00	[3269.7, 20870.8]	***
Precipitation_Y → Minimum	1508	2.168	<0.00	[596.87, 3809.83]	***
Precipitation_M → Flow	0.002	2.55	<0.00	[0.0008, 0.006]	
Precipitation_M → Precipitation_Y	0.01	2.168	<0.00	[0.004, 0.03]	
Precipitation_M → Maximum	93.00	2.168	<0.00	[36.81, 234.96]	***
Precipitation_M → Minimum	16.97	2.168	<0.00	[6.72, 42.89]	***

Table 3. Observed results from the F-test. Significance level at p = 0.05 indicated by * where F-test satisfied the criterion; < 0.01 **, < 0.001 ***.

Groups tested with Welch t-test	t-value	t-critical	p-value	CI [95.0%]	Sign.codes
Evapotranspiration_S → Maximum	23.49	2.09	<0.00	[376.31, 449.92]	***
Evapotranspiration_S → Minimum	26.50	2.09	<0.00	[429.98, 503.67]	***
Evapotranspiration_S → Precipitation_M	20.73	2.09	<0.00	[339.08, 414.55]	***
Precipitation_Y → Precipitation_M	19.87	2.09	<0.00	[779.79, 963.08]	***
Precipitation_Y → Maximum	20.81	2.09	<0.00	[816.44, 998.99]	***
Precipitation_Y → Minimum	22.04	2.09	<0.00	[870.13, 1052.7]	***
Precipitation_M → Maximum	7.79	2.09	<0.00	[26.55, 46.00]	***
Precipitation_M → Minimum	18.90	2.09	<0.00	[80.09, 99.88]	***

Table 4. Observed results from the Welch t-test (t-test assuming unequal variances). Significance level at $p = 0.05$ indicated by *; <0.01 **, <0.001 ***.

Meteorological parameters	Base period	Linear trend [start-end range]	Mean	Percentage change [%]	Maximum	Minimum
Evapotranspiration_T	2001-2020	[2.24, 3.25]	2.74	45.08%	3.79 mm (2017)	1.8 mm (2001)
Evapotranspiration_S	2001-2020	[336.70, 533.01]	320.14	58.30%	621.56 mm (2017)	295.2 mm (2001)
Precipitation_M	1990-2020	[67.76, 78.11]	72.93	15.27%	110.43 mm (2011)	31.3 mm (2002)
Precipitation_Y	2001-2020	[928.38, 960.53]	944.46	3.46%	1434 mm (2014)	530.5 mm (2011)
Flow	1980-2020	[92.15, 403.92]	320.14	338.32%	1602 m^3/s (2014)	22.47 m^3/s (2003)
Maximum	2001-2020	[36.67, 37.42]	37.05	2.05%	41.0 ºC (2011, 2017)	33.2 ºC (2005)
Minimum	2001-2020	[-17.62, -16.32]	-16.97	7.37%	-28 ºC (2003)	-11 ºC (2019)

Table 5. Observed change in meteorological parameters for the hydroaccumulation Modrac (based periods: 1980-2020 for maximum flows; 1990-2020 for maximum monthly precipitation; 2001-2020 for other parameters).
Meteorological

Linear trends show the increase in most of the analyzed meteorological and hydrological variables, albeit the highest increase is registered in variable Flow, which may be connected to the recent 2014 flooding that is considered as an outlier datum due to the fact that this heavy rainfall episode has not been registered since the official start of meteorological monitoring, resulting in significant percentage change increase, in this particular case, of 338.32% in the last 40 years. Besides the flow, the surface and quantitative evapotranspiration rates increased by 45.08 and 58.30%, respectively, mainly due to the increase in the maximum monthly precipitation rate (Precipitation_M) for at least 15% in the last thirty years (cca. 2% by a year), as a result of recent weather extremization that led to heavier precipitation amounts in a shorter period of time, which is not the case with the annual precipitation (Precipitation_Y) that has a slight increase over the last twenty years. Thermic variables also show some changes, especially the minimum temperature which increased by 7.37% in the last twenty years, albeit the maximum temperature has a slight increase of 2.05%, which is mostly related to the decline in the number of cold days, especially during winter months. Based on the observation, we can confirm that the Tuzla Canton region, including Lake Modrac, has a presence of climate change, especially in surface and quantitative evapotranspiration rates, and maximum monthly precipitation amounts due to the weather extremization. Figures from 4 to 10 show: a) Maximum surface evapotranspiration in the treated series of flood waves for the period 2001-2020; b) maximum quantitative evapotranspiration in the processed series of flood waves for the period 2001-2020; c) maximum monthly recorded precipitation in the processed series of flood waves for the period 1990-2020; d) maximum annual recorded precipitation in the processed series of flood waves for the period 2001-2020; e) maximum flows for the processed series of flood waves for the period 1980-2020; f) maximum measured air temperature for the period 2001-2020; g) minimum measured air temperature for the period 2001-2020.

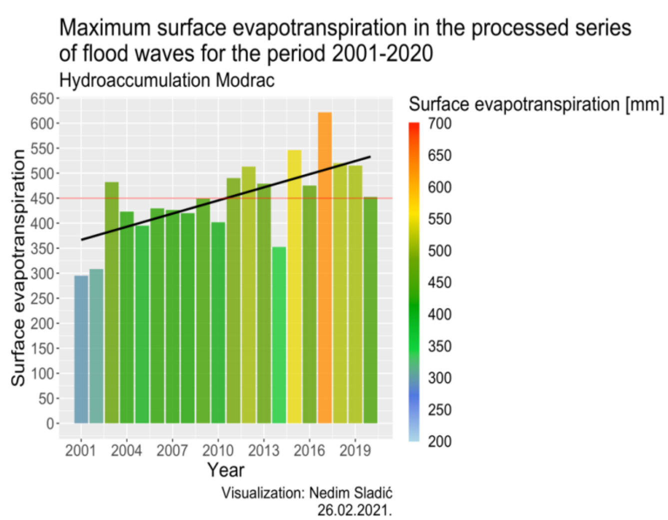

Fig. 4. Maximum surface evapotranspiration in the treated series of flood waves for the period 2001-2020

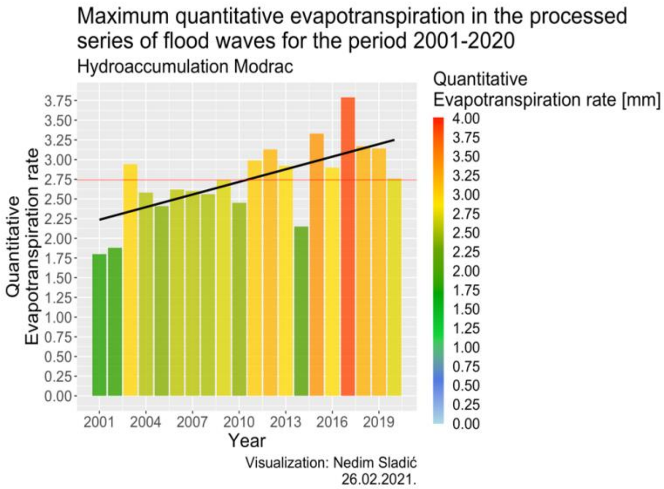

Fig 5. Maximum quantitative evapotranspiration in the processed series of flood waves for the period 2001-2020

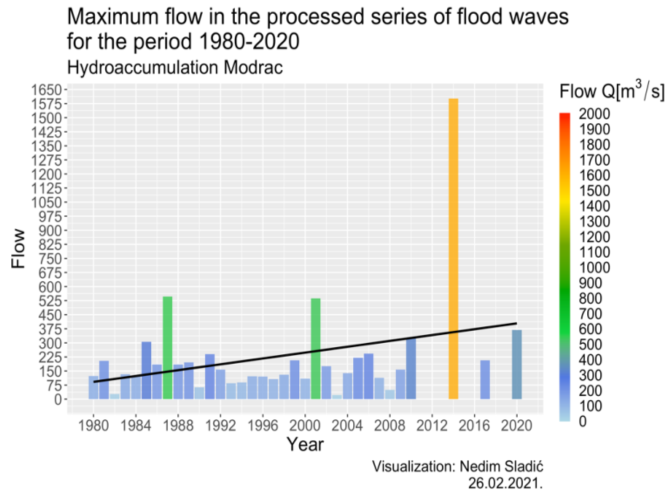

Fig 8. Maximum flows for the processed series of flood waves for the period 1980-2020

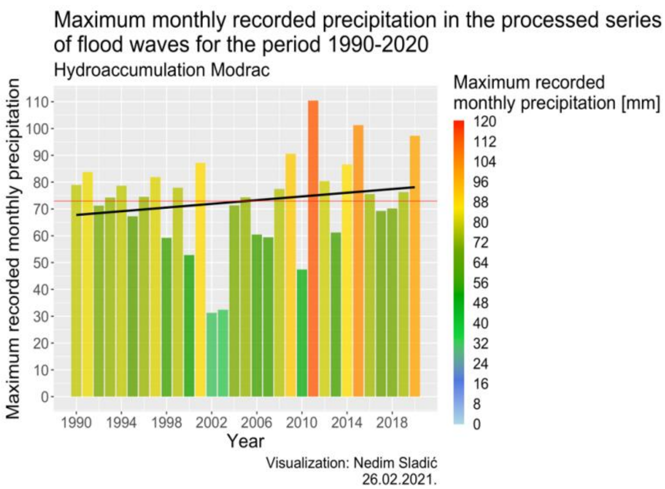

Fig 6. Maximum monthly recorded precipitation in the processed series of flood waves for the period 1990-2020

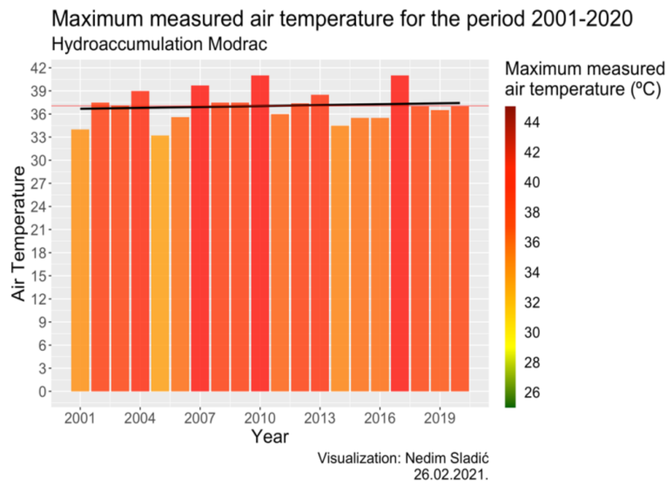

Fig 9. Maximum measured air temperature for the period 2001-2020

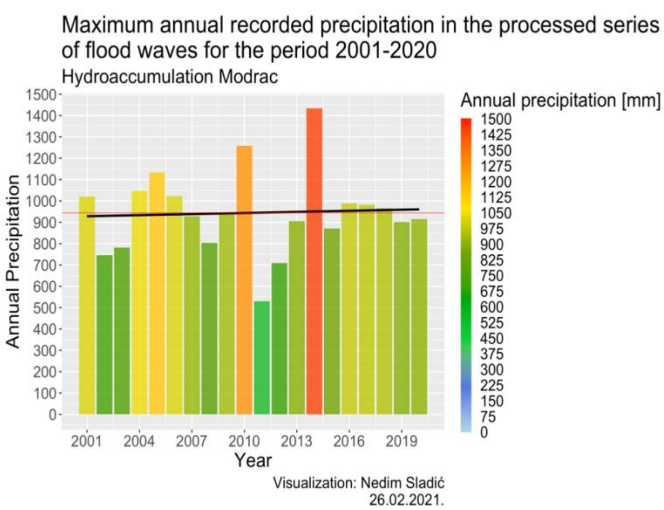

Fig 7. Maximum annual recorded precipitation in the processed series of flood waves for the period 2001-2020

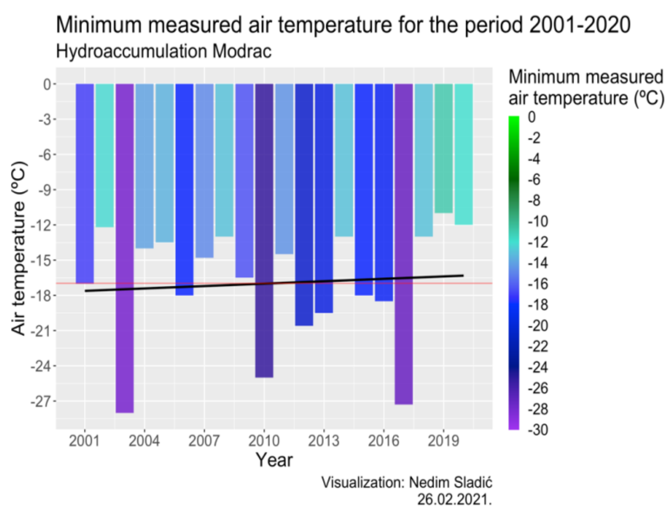

Fig 10. Minimum measured air temperature for the period 2001-2020

IV. CONCLUSION

In this paper linear trends show the increase in time for most of the analyzed meteorological and hydrological variables, albeit the highest increase is registered in variable Flow which may be connected to the recent 2014 flooding that is considered as an outlier datum due to the fact that this heavy rainfall episode has not been registered since the official start of meteorological monitoring, resulting in significant percentage change increase, in this particular case, of 338.32% in the last 40 years.

Also it can be concluded that the surface and quantitative evapotranspiration rates increased by 45.08 and 58.30%, respectively, mainly due to the increase in the maximum monthly precipitation rate for at least 15% in the last thirty years (cca. 2% by a year), as a result of recent weather extremization that led to heavier precipitation amounts in a shorter period of time.

Besides, thermic variables also show some changes, especially the minimum temperature which increased by 7.37% in the last twenty years, albeit the maximum temperature has a slight increase of 2.05%, which is mostly related to the decline in the number of cold days, especially during winter months.

Also, the largest flood waves occur in the spring time in the months of April, May, and June. In this period there is a filling of reservoir and in most cases the activation of dam bodies.

In this paper, according to the presented analysis of changes in maximum and minimum temperatures and changes in the amount of precipitations, we observe a slight increase in maximum flows at the reservoir Modrac dam profile.

It can be concluded, according to the maximum flow rates analyzed for the period from 1980 to 2020, we see a slight increase in the inflow hydrogram into reservoir Modrac, which has resulted in some changes in the flow curve of the lake Modrac dam profile, as well as changes in the volume curve.

Analysis of climate changes shows that the global climate changes are also reflected in the catchments area of the reservoir Modrac.

Based on the observation, we can confirm that the Tuzla Canton region, including Lake Modrac, has a presence of climate change, especially in surface and quantitative evapotranspiration rates, and max-imum monthly precipitation amounts due to the weather extremization.

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