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VARIATION AND TREND OF ANNUAL MAXIMUM DAILY RAIN IN MACEDONIA

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ABSTRACT

Annual maximum daily rainfall is defined as extreme rainfall for the formation of flood waves in a certain area (basin, region, country, etc.) with direct consequences on agricultural land, roads, sewers, etc. Therefore, analysis of changes and trend of annual maximum rainfall based on relevant measured data is considered extremely necessary and important in hydrology for elaboration of appropriate hydrological studies.

The subject of the analysis presented in this paper have been changes in annual maximum daily precipitation (AMDP) at eight measuring stations in the R. N. Macedonia (Skopje, Shtip, Prilep, Bitola, Ohrid, Demir Kapija, Lazaropole) for the last 65 years.

The variation and trend of annual maximum daily precipitations have been analyzed on the basis of data on precipitation measured in the period from 1956 to 2020. The analysis has included testing of the homogeneity of the sequences, statistical analysis, defining the distribution of extreme values and the probability of occurrence for different return periods as well as the spatial distribution of the annual maximum daily precipitation in the territory of the R. N. Macedonia for 50 and 100 year return periods.

The analysis of the series of measured data on the annual maximum daily precipitation at all eight measuring stations shows logical variability with an increasing trend of precipitation in the last 30 years.

Keywords: Precipitation; Probability of occurrence; Return period; Statistical analysis; Precipitation trend

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1. INTRODUCTION

The annual maximum daily rainfall is defined as an extreme instance, with critical duration for a river basin, state or region, with immediate consequences to agriculture, soil conservation, roads, dams and drainage, [1], [2]. Rainfall is a fundamental element of climate which is, for several decades, in perpetual mutations. For most regions around the Mediterranean, these changes resulted in significant rainfall deficits, [3], [4] accompanied by an increase of exceptional events such as severe droughts and devastating floods, [5], [6]. In the hydrological year, the daily maximum rainfall is the parameter considered to assess the immediate impact on the hydrological response of streams, flooding cities, soil erosion, dams silting, and agricultural production, [7], [8]. Annual maximum daily precipitation data represent one of the most important and readily available measures of extreme rainfall and are used frequently as inputs to assessments of flood risk, [9], [10], [11]. Observational studies of this variable form a critical line of evidence into how precipitation extremes have changed over the instrumental record, and recent findings are showing that at global or continental scales, extreme precipitation events have been increasing in intensity and/or frequency. For example, Alexander et al. (2006) used gridded precipitation data based on 5948 stations globally and found that precipitation changes exhibited a widespread and significant increase, [12]. Min et al. (2011), using the same dataset but a different analysis approach, found that 65% of the data-covered areas have positive trends for annual maximum daily precipitation over the period from 1951 to 1999, [11].

In the second half of the eighties of the last century, data on precipitation in the period from 1956 to 1988 were analyzed and intensity, duration and recurrence curves (IDR curves) were defined for the territory of the R.N. Macedonia, [13]. For the last 30 years, intensive precipitations of a short duration have relatively been poorly analyzed in the R. N. Macedonia. Namely, in the period following 1988, the analysis of data on measured precipitation in the territory of our country has been reduced to research that has not fully covered this issue. Therefore, there is a need for complete analysis of the annual maximum daily rainfall precipitation in the period from 1988 till present, in order to define the real intense precipitations and their return periods that will be used for both scientific and professional needs.

This paper deals with analyses of data on measured annual maximum daily precipitation at eight measuring stations in the R. N. Macedonia. The existing series of data from the measurements (1956-1988) have been updated with new data and the series for the period from 1956 to 2020 has been completed, [14]. This has created a series of 65 data, which represents a sound basis for analysis from a hydrological point of view. The sequences have been tested for homogeneity, statistically processed and defined by the distribution of extreme values and the probability of occurrence for different return periods. The data from the performed analyses are presented on maps in order to show the spatial distribution of the annual maximum daily precipitation with a certain return period.

2. STUDY AREA/MATERIALS AND METHODS

2.1. Study area

Meteorological observations in R.N. Macedonia are performed at 19 main meteorological stations, 7 climatological, 24 phenological, 87 rain gauge stations and 55 automatic meteorological stations (AMS), Fig. 1.

Fig. 1. Network of meteorological stations in R.N. Macedonia (Source: UHMR)

2.2. Available data

Annual maximum daily rainfall strips for the period of 1956 to 2020 registered by an ordinary rain gauge at measuring stations Skopje (SK), Shtip (SH), Prilep (P), Bitola (B), Ohrid (O), Kriva Palanka (KP), Demir Kapija (DK) and Lazaropole (L) have been processed and analysed within the investigations presented in this paper. In Skopje, the measurement of precipitation is performed at three locations: Skopje-Old airport-(1956-1966), Skopje-Petrovec (1967-1988) and Skopje-Zajcev rid (1988-2020).

The variations of the annual maximum daily precipitation and their trend lines, for all analyzed measuring stations are presented graphically, Fig. 2-9.

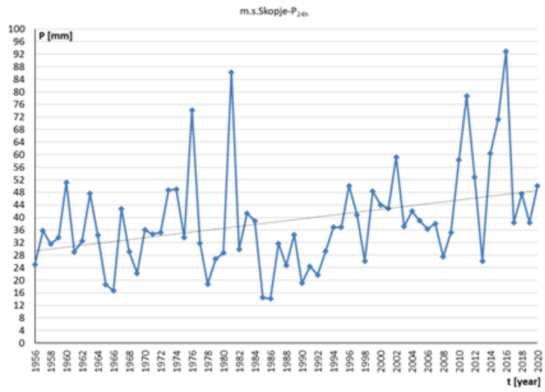

Fig. 2. Annual maximum daily rainfall registered at measuring stations Skopje

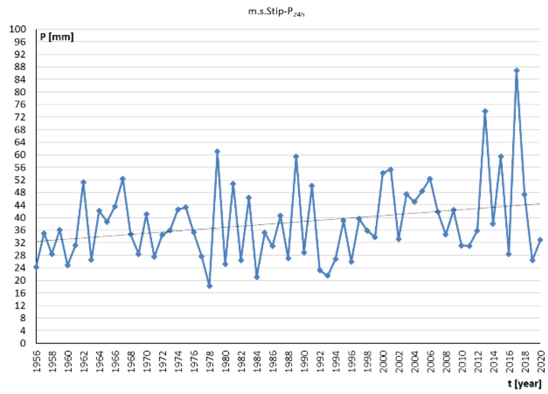

Fig. 3. Annual maximum daily rainfall registered at measuring stations Stip

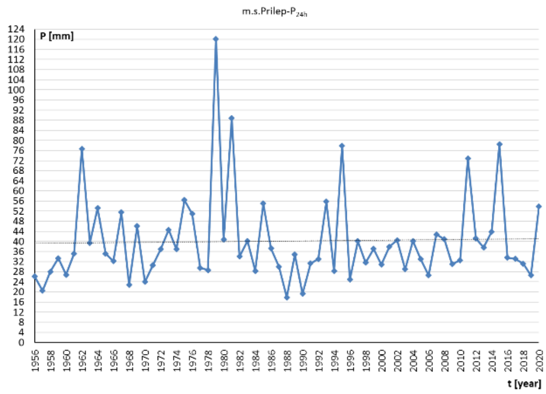

Fig. 4. Annual maximum daily rainfall registered at measuring stations Prilep

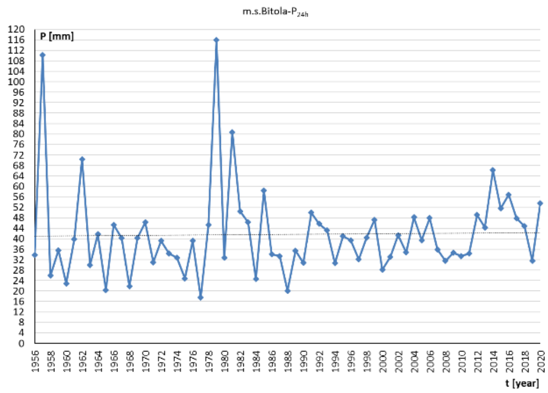

Fig. 5. Annual maximum daily rainfall registered at measuring stations Biola

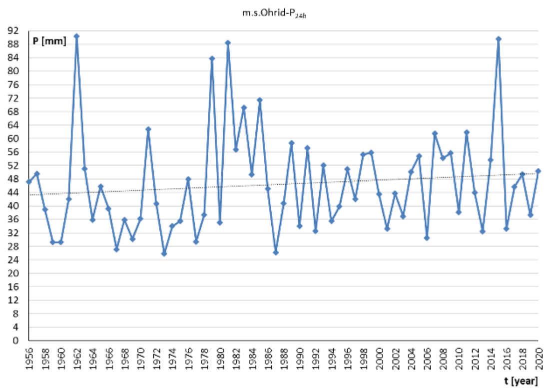

Fig. 6. Annual maximum daily rainfall registered at measuring stations Ohrid

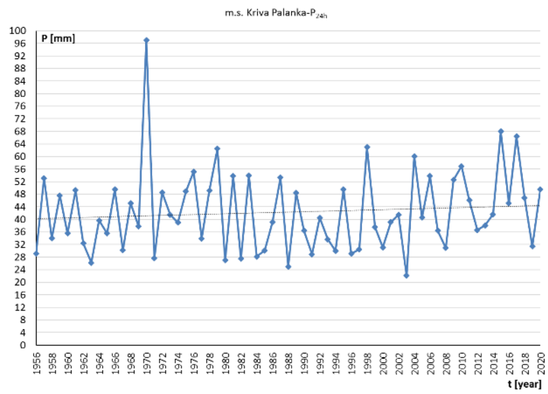

Fig. 7. Annual maximum daily rainfall registered at measuring stations Kriva Palanka

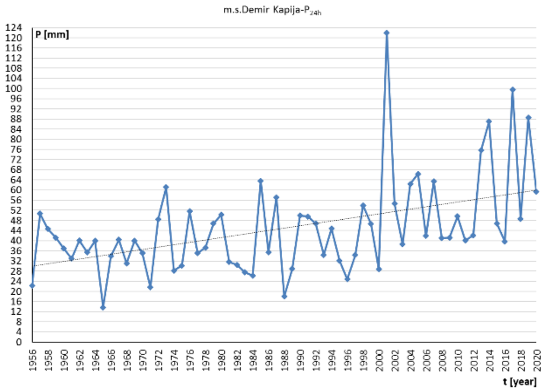

Fig. 8. Annual maximum daily rainfall registered at measuring stations Demir Kapija

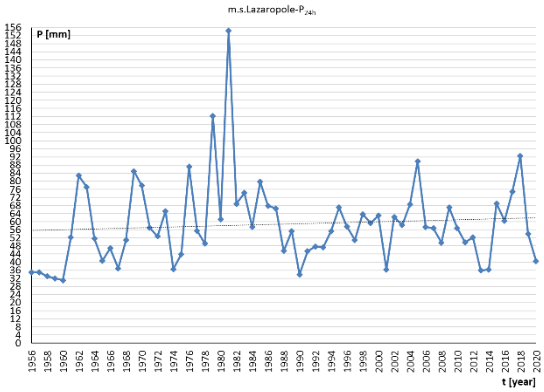

Fig. 9. Annual maximum daily rainfall registered at measuring stations Lazaropole

2.3. Statistical analysis

The statistical processing of the established series of data on annual maximum daily precipitation for all measuring stations consists of determination of the basic statistical parameters: mean arithmetic value (P_{avr}) by Eq. 1, mean square deviation (σ) by Eq. 2, coefficient of variation (Cv) by Eq. 3 and coefficient of asymmetry (Cs) by Eq. 4, Table 1.

$$\bar{x} = \frac{x_1 + x_2 + x_3 + ... + x_{n-1} + x_n}{n} = \frac{\sum_{i=1}^{i=n} x_i}{n} \quad (1)$$

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} \quad (2)$$

$$C_v = \frac{\sigma}{\bar{x}} = \sqrt{\frac{\sum (K_i - 1)^2}{n}} \quad (3)$$

$$C_s = \frac{\sum_{i=1}^{i=n} (K_i - 1)^3}{n C_v^{\ 3}} \quad (4)$$

Table 1. Statistical parameters for the series of the AMDP

parameters	Sk	S	P	B	O	KP	DK	L
P_{avr}	38.97	38.44	40.14	41.68	46.48	42.30	44.95	58.75
P_{min}	14.20	18.20	17.80	17.50	25.80	22.10	13.70	31.00
P_{max}	92.90	86.90	120.20	116.00	90.40	97.00	121.90	154.40
σ	16.26	12.84	17.79	17.35	15.16	13.05	18.87	20.60
C_V	0.42	0.33	0.44	0.42	0.33	0.31	0.42	0.35
C_S	1.28	1.24	2.21	2.36	1.22	1.31	1.71	1.85

From the statistical analysis, it can be noticed that the calculated mean arithmetic values of the AMDP arrays exhibit variations within the limits of the minimum value of 38.97 mm at the measuring station Skopje to 58.75 mm at the measuring station Lazaropole.

The minimum AMDP values are in the range of 13.7 mm measured at the measuring station in Demir Kapija up to 25.8 mm measured at the measuring station in Ohrid. The maximum values are in the range of 86.9 mm measured at the measuring station in Stip up to 120.2 mm measured at the measuring station in Prilep.

The calculated statistical parameters show a small variability of the variation coefficient (Cv): a minimum of 0.31 for Kriva Palnka to 0.44 for Prilep. The coefficient of asymmetry (Cs) shows a great variability, namely, 1.24 for Skopje to 2.36 for Bitola.

2.4. Sequence homogeneity testing

To examine the homogeneity of the formed sequences of annual maximum daily precipitation, parametric tests have been carried out: normalized Z-test of mean value, student t-test and Fisher's test, [15].

Mean value normalized Z-test. For two arrays with (n_1) and (n_2) data, mean values ($\overline{P}_1$) and ($\overline{P}_2$), standard deviations (σ_{P1}) and (σ_{P2}), respectively, the test is based on assuming a normal distribution of array members:

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{\frac{x^2}{2}} \tag{5}$$

and checking whether the mean values of the arrays belong to the same population. The null thesis or hypothesis is ($\overline{P}_1 = \overline{P}_2$), while the test criterion is:

$$Z = \sqrt{\frac{\overline{P}_1 \cdot \overline{P}_2}{\sigma_{P_1-P_2}}} \tag{6}$$

where: $\sigma_{P_1-P_2} = \sqrt{\frac{\sigma_{P_1}^2}{n_1} + \frac{\sigma_{P_2}^2}{n_2}}$.

The null hypothesis is accepted if condition ($Z_{\alpha/2} < Z < Z_{1-\alpha/2}$) is met for test significance (α) (recommended value $\alpha = 0.05$).

Student t-test. The test consists of checking whether the mean square deviation of the two arrays belongs to the same population. The zero thesis is ($\sigma_{P1} = \sigma_{P2}$), and the test criterion is:

$$t = \frac{\overline{P}_1 - \overline{P}_2}{\sqrt{n_1\sigma_{P1}^2 + n_2\sigma_{P2}^2}} \cdot \sqrt{\frac{n_1 \cdot n_2 \cdot (n_1 + n_2 - 2)}{n_1 + n_2}} \tag{7}$$

The null hypothesis is accepted if condition ($t_{\alpha/2} < t < t_{1-\alpha}$) is met for test significance (α=0,05) and ($\nu = n_1 + n_2 - 2$) degrees of freedom.

Fisher's test. The Fisher's test for checking the homogeneity of members of a population consists of checking the equality of standard deviations. The zero thesis is ($\sigma_{P1} = \sigma_{P2}$), and the test criterion is:

$$F = \frac{\sigma_{P1}^2}{\sigma_{P2}^2} \quad \text{for } \sigma_{P1} > \sigma_{P2} \tag{8}$$

The null hypothesis is accepted if the condition ($F < F_{1-\alpha}(\nu_1, \nu_2)$) is met for ($\nu_1 = n_1 - 1$) and ($\nu_2 = n_2 - 2$) degrees of freedom.

Homogeneity testing for all arrays has been done by dividing the arrays into two periods, namely, the period from 1956 to 1988 (n_1 = 33) and the period from 1989 to 2020 (n_2 = 32). The results obtained for the calculated values according to the z, t and F criteria for each of the sequences and for all measuring stations are shown in Table 2.

Table 2. Sequence homogeneity testing

parameters	SK	S	P	B	O	KP	DK	L	limit values
z	-2.15	-1.97	1.96	0.14	-0.43	-0.17	-3.46	0.78	**±1.96**
t	-0.27	-0.25	1.99	0.02	-0.05	-0.17	-0.43	0.10	**±1.99**
F	0.86	0.46	1.84	6.56	2.06	1.49	0.29	3.48	**±1.84**

The general impression from the sequence homogeneity testing is that all sequences meet the requirements set in the basic hypothesis in at least one of the tests. Arrays can therefore be treated as homogeneous and can be used for analysis as data from the same population with a 95% probability.

2.5. The functions of probability of AMDP

The theoretical probability density function, which is adequate to the empirical frequency, and the probability distribution function apply to the whole population, i.e., the existing arrays of limited data (n=65) are treated as arrays of unlimited data (n=∞), which cover all possible future occurrences.

Several probability density functions have been analysed: Gumble distribution, Pearson type III, Log-normal two-parameter, and Log-Pearson. By testing the adaptability of these functions to the empirical frequency of the random variable by applying the χ2-test at a test significance of α = 5%, the best adjustment has been shown by the Gumble function.

The probability of occurrence of maximum intensive precipitation for all rain gauges of precipitation has been defined by applying the Gumble distribution, according to data from 1956 to 1988, Table 3 and according to data from 1956 to 2020, Table 4.

Table 3. Maximum precipitation for different return period (T) and probability of occurrence (p) for all stations (1956-1988)

T [year]	p [%]	z	SK	S	P	B	O	KP	DK	L
2	50	0.367	32.31	30.76	32.35	32.42	37.68	35.55	35.63	48.36
5	20	1.5	45.85	39.04	44.26	48.71	52.33	49.01	45.92	64.72
10	10	2.27	54.82	44.53	52.15	59.50	62.02	57.92	52.73	75.55
25	4	3.199	66.15	51.45	62.12	73.12	74.27	69.17	61.34	89.24
50	2	3.902	74.55	56.59	69.52	83.24	83.36	77.52	67.72	99.39
100	1	4.6	82.90	61.70	76.86	93.27	92.38	85.81	74.06	109.47
1000	0.1	6.908	110.47	78.55	101.11	126.44	122.19	113.20	95.00	142.77

Table 4. Maximum precipitation for different return period (T) and probability of occurrence (p) for all stations (1956-2020)

T [year]	p [%]	z	SK	S	P	B	O	KP	DK	L
2	50	0.367	36.307	36.335	37.225	38.841	43.992	40.158	41.861	55.372
5	20	1.5	50.671	47.675	52.941	54.167	57.384	51.685	58.530	73.566
10	10	2.27	60.432	55.382	63.622	64.583	66.486	59.518	69.859	85.932
25	4	3.199	72.210	64.681	76.508	77.150	77.467	68.970	83.526	100.850
50	2	3.902	81.122	71.717	86.259	86.659	85.777	76.122	93.869	112.139
100	1	4.6	89.971	78.703	95.941	96.101	94.028	83.223	104.138	123.348
1000	0.1	6.908	119.230	101.804	127.956	127.322	121.310	106.705	138.095	160.412

The maximum precipitation intensity for different return periods (T) and probability of occurrence (p) for all stations according to the data from 1956 to 2020 are shown in Table 5. The established graphical dependencies between precipitation intensity and probability of occurrence (i-p curve) for all measuring stations are shown graphically, Figure 10.

Table 5. Maximum precipitation's intensity for different return period (T) and probability of occurrence (p) for all stations

T [year]	p [%]	SK	S	P	B	O	KP	DK	L
2	50	1.513	1.514	1.551	1.543	1.833	1.673	1.744	2.307
5	20	2.111	1.986	2.206	2.195	2.391	2.154	2.439	3.065
10	10	2.518	2.308	2.651	2.638	2.770	2.480	2.911	3.580
25	4	3.009	2.695	3.188	3.172	3.228	2.874	3.480	4.202
50	2	3.380	2.988	3.594	3.576	3.574	3.172	3.911	4.672
100	1	3.749	3.279	3.998	3.978	3.918	3.468	4.339	5.140
1000	0.1	4.968	4.242	5.331	5.306	5.055	4.446	5.754	6.684

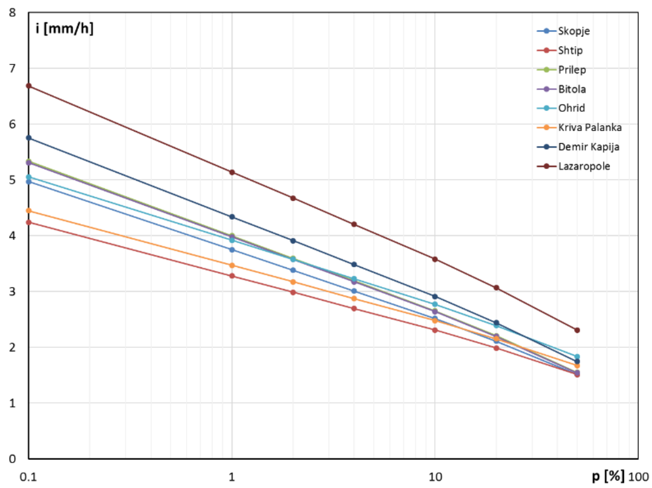

Fig. 10. i-p curves for AMDP

Comparing the maximum values of precipitation intensity for p = 0.1%, it can be noticed that the probability lines for different station have different positions in relation to the other stations. Thus, for the rains, the lowest intensity is observed at station Shtip, then Kriva Palanka, Skopje, Ohrid, Bitola, Prilep, Demir Kapija while the highest intensity is observed at m.s. Lazaropole.

3. ANALYSIS AND DISCUSSION

The complex orographic structure of the R.N. Macedonia conditions an uneven spatial distribution of precipitation and affects the pluviometric regime. One of the most important conditions that has an impact on the amount of precipitation is the geographical location of the considered location, i.e., latitude and longitude as well as altitude.

The smallest amounts of precipitation occur in the central areas, namely, in Gradsko, Tikvesh and Ovche Pole, which are the driest areas in the territory, with average amounts of precipitation between 400-500 mm per year. The highest amounts of precipitation are registered in the highest mountain massifs in Western Macedonia, amounting to about 1000 mm per year. In other areas in our Republic, an average annual rainfall of 600-1000 mm has been measured, Fig. 11.

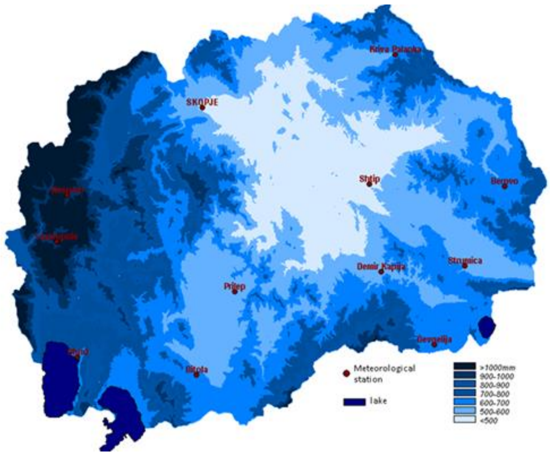

Fig. 11. Spatial distribution of average annual rainfall for the period 1981-2010. (Source: UHMR)

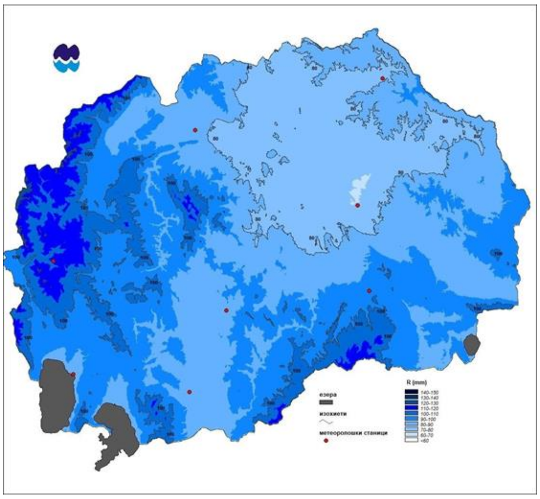

Fig. 12. Spatial distribution of maximum precipitation with a return period of 50 years

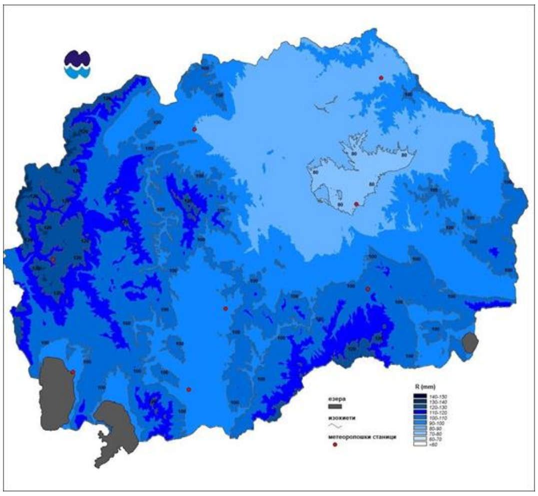

Fig. 13. Spatial distribution of maximum precipitation with a return period of 100 years

If a comparison is made with the spatial distribution of the calculated extreme values of annual maximum daily precipitation with a return period of 50 or 100 years, Fig. 12 and Fig. 13, respectively, the situation is similar. Maximum rainfalls take place in Lazaropole, while the least rainfall is characteristic for Shtip.

If we analyze the sequences of annual maximum daily precipitation in the period from 1956 to 2020, Figures 2-9, a rising trend can be noticed at all measuring stations. This shows that the values of the measured annual maximum daily precipitation have increased in recent years.

The same conclusion is drawn if a comparison is made between the calculated values of extreme precipitation with different return periods for AMDP for the period from 1956 to 2020, Table 3 and the extreme precipitation calculated for the period from 1956 to 1988, Table 4. From these analyses, it can be seen that the differences, Table 6, are mainly with a positive sign, which shows that the precipitation has an increasing trend.

The biggest differences are observed at the measuring station in Demir Kapija, where the difference for the precipitation with a return period of 100 years and 1000 years is 40.61%, i.e. 45.36%, respectively. The smallest differences are observed at the station in Kriva Palanka. Here, the differences for the precipitation of a shorter return period are positive, i.e., there is an increasing trend, while for the precipitation of a longer return period, the difference is negative, i.e., there is a decreasing trend. For the measuring station in Skopje, the differences are in the range of 7.93% to 12.41%, i.e., an average increase of 9.96%. For Shtip, these differences are in the range of 19.11% to 29.60% or an average value of 24.89%. For Prilep, Bitola and Ohrid, the average difference is 22.19%, 7.56% and 5.98%, respectively. For the station in Lazaropole, the minimum difference is 12.36%, while the maximum is 14.49%, or an average value of the increase of precipitation of 13.25%.

Table 6. Differences in extreme rainfall for the period from 1956 to 2020 compared to the calculated extreme rainfall for the period from 1956 to 1988, expressed in [%]

T [year]	p [%]	SK	S	P	B	O	KP	DK	L
2	50	12.41	18.11	15.08	19.82	16.74	12.95	17.49	14.49
5	20	12.60	22.11	19.60	11.21	9.67	5.46	27.47	13.67
10	10	10.28	24.38	21.99	8.55	7.20	2.77	32.48	13.74
25	4	9.16	25.71	23.16	5.51	4.30	-0.29	36.18	13.01
50	2	8.82	26.72	24.09	4.11	2.90	-1.81	38.61	12.83
100	1	8.53	27.57	24.83	3.03	1.78	-3.02	40.61	12.68
1000	0.1	7.93	29.60	26.55	0.70	-0.72	-5.74	45.36	12.36
average		9.96	24.89	22.19	7.56	5.98	1.48	34.03	13.25

4. CONCLUSION

Precipitation as an extremely stochastic phenomenon, variable in time and space, is relevant for analysis in the field of hydrology. These analyses are particularly important given that climate change is evident both globally and regionally. The need for analysis of variations and trend of annual maximum daily precipitation in the R. N. Macedonia is more than necessary, given that such documented analyses were carried out about 30 years ago.

The paper shows analysis of the annual maximum daily rainfall in the R. N. Macedonia based on data measured at eight measuring stations in the period from 1956 to 2020. The analysis of the series of measured data on the annual maximum daily precipitation at all eight measuring stations shows logical variability with an increasing trend of precipitation in the last 30 years. Arrays of 65 data have statistically been processed and tested for sequence homogeneity. Extreme values with different return periods have been defined.

The results obtained from these analyses have been compared with those from the analyses carried out based on data measured at the same eight measuring stations in the period from 1956 to 1988 (published in 1993).

The comparative analysis shows that the extreme values of annual maximum daily precipitation calculated for different return periods, according to the Gumble's probability distribution, are with an increasing trend.

From the aspect of providing relevant parameters for hydrological studies, it is recommended that these analyses are repeated in shorter time periods in future, at least after each 10 to 15-year period.

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