HEAVY RAINFALL IN THE R.N. MACEDONIA

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Information on maximum precipitation of a short duration, i.e., knowledge of intensity-duration-probability (i-T-p) curves is highly important for various studies in the field of surface water hydrology, generally in hydrotechnics, water management, traffic, etc. However, such crucial data are often unavailable in different parts of the world due to lack of sufficient measuring stations and also due to unprocessed, raw data.

In R.N. Macedonia, data on heavy rainfall that took place in the period from 1956 to 1988 are still in use in practice. The need for updating these data is more than necessary, given that rainfall is an extremely stochastic phenomenon.

Annual maximum precipitation registered on pluviographic strips in the period from 1989 to 2020 at eight measuring stations has been analyzed in this paper. Maximum precipitation series with a duration of 5, 10, 20, 40, 60, 90, 150, 300,720 and 1440 minutes have been established for the entire period from 1956 to 2020. All these arrays of data have been tested for homogeneity and statistically processed. The probability of occurrence of maximum annual precipitation has been defined according to the adopted mathematical probability function and the i-T-p curves have been constructed. The results of the analysis are presented in a tabular and graphical form.

Key words: maximum precipitation, intensity, time duration, probability of occurrence.

1. INTRODUCTION

Rainfall data are very important for climate study, water resources evaluation, drainage design (Desa and Rakhecha 2004; Wang 1987), environmental studies and many other purposes. To have high quality data on measured precipitation at many measuring stations means a higher degree of quality of conducted hydrological analysis. Unfortunately, it often happens that these data are not available due to lack of a metering network and often due to unprocessed, raw data.

When designing hydraulic facilities, the realistically estimated flood waters are the basic parameter on which depend the necessary investments in construction of these facilities and their maintenance. For the purpose of construction of small reservoirs and sizing of spillway facilities of dams, construction of sewerage systems for drainage of atmospheric waters, regulation of rivers with small catchment areas, regulation of torrents and sizing of anti-erosion protection measures in erosive areas, hydro melioration systems, dimensioning of drainage systems in road construction, dimensioning of bridges and culverts and in many other cases, the competent flood waters are determined by applying methods that enable establishment of a connection between intense rainfall and direct surface runoff.

Defining real quantities of flood waters that can be expected in certain small catchment areas is necessary in order to know the possible occurrences of intense rainfall of a short duration [1]. Data on intense precipitations of maximum intensity and short duration are needed to solve various technical and scientific problems in the field of surface water hydrology, generally in hydrotechnics, water management, traffic and alike.

Intensive precipitation represents a random variable regarding time and space. To explore precipitation as a stochastic process in hydrology, mathematical methods, i.e., methods of statistics and theory of probability are used. These are based on data on this stochastic process of precipitation registered in a certain period. These data are obtained based on an established meteorological network of metering stations for continuous measurement of precipitation and systematic acquisition of data on measured precipitation for the purpose of establishment of a sound database. Based on this database obtained on the basis of a sufficiently long period of measurement, knowledge on occurrence of intensive precipitation in a certain area can be gathered.

In the R.N. Macedonia, data on intensive precipitation obtained by processing precipitation registered in the period from 1956 to 1988 are used for this purpose in practice [16]. Given that precipitation is an extremely stochastic phenomenon, variable in time and space, there is a need to renew the research by extending the data series up to the current period. It is important to note that, for the last thirty years, there has been a change in the precipitation regime in terms of intensity and duration, both globally and regionally as a result of climate change. The importance of the need for re-analysis of the curves of intensity, duration and recurrence of intense rainfall has also been confirmed in the Climate Change Strategy for the City of Skopje (2017) in which it is indicated, within the Action Plan, that there is a need for preparation of a Study on Innovated Curves of Intensity, Duration and Recurrence of Intense Rainfall in the Skopje Region in Conditions of Climate Change [18].

The purpose of the investigations presented in this paper has been to innovate data on intensive precipitation with different recurrence period and short time duration through analysis of data on precipitation obtained at eight measuring stations in the R. N. Macedonia in the period 1959 – 2020 and thus enable definition of the competent real flood waters in proportioning hydrotechnical structures.

2. METHODOLOGY

2.1 OVERVIEW OF METEOROLOGICAL STATIONS FOR MEASURING PRECIPITATION

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), Figure 1.

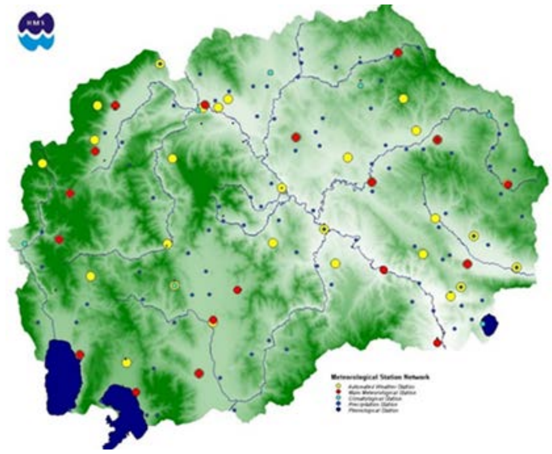

Figure 1. Network of meteorological stations in R.N. Macedonia (Source: UHMR)

Within the network of meteorological stations, short-term precipitation is measured by pluviographs at a number of measuring points. Depending on the possibilities, conditions and the need for information, the number of these measuring stations was decreased or increased in the past period. Permanent monitoring of intense rainfall in the R. N. Macedonia is carried out at the meteorological stations shown in Table 1.

Pluviographic, short-term, rainfall strips registered 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, precipitation is measured at three locations: Skopje - Old airport-(SK-1), Skopje-Petrovec (SK-2) and Skopje-Zajchev rid (SK-3)

Measurement of short-term precipitation is performed mainly by use of three types of instruments: (1) Pluviograph produced by Lambrecht- a German instrument with one-day, weekly and monthly pluviographs. The aperture area of the pluviograph is 200 cm^2, (2) Pluviograph produced by R FRUESS- a German instrument with one-day pluviograph and (3). Pluviograph type P-2- a Russian instrument, one-day pluviograph with forced discharge. The aperture area of this pluviograph is 500 cm^2. Given the technical possibilities for observations of precipitation by pluviogaphs, the measurements were performed only in the warm period of the year (from April to November). In winter, the so-called pluviographs with heaters were used (to prevent freezing under negative temperatures), in which case, not one-day pluviograph tapes were used, but mostly seven-day ones. Such records referring to the period from 1956 to 1988 have not been analysed, while those from the period from 1989 to 2020 have been processed and analysed.

Table 1. Overview of analyzed meteorological stations

station	H [ma.s.l.]	position		pluviograf	measurement period	notes
		latitude	longitude			
SK-1	240	41°59’	20°28’	R FRUESS	1956-66	stopped working
SK-2	239	41°57'42"	021°37'17"	R FRUESS	1967-75	
SK-3	302	42°00’59”	021°12’59”	R FRUESS	1978-1988	with interruption
					1989-2020	
Shtip	336	41°45’13”	022°21’49”	П-2	1963-1988	with interruption
					1988-2020	
Prilep	675	41°20’02”	021°13’14”	П-2	1959-1988	with interruption
					1989-2020	
Bitola	590	41°02’30”	021°12’13”	П-2	1956-1988	with interruption
					1989-2019	with interruption
Ohrid	757	41°06’53”	020°04’50”	Lambrecht	1956-1988	
					1989-2020	with interruption
Kriva Palanka	693	42°12’13”	022°21’52”	П-2	1959-1988	
					1989-2020	
Demir Kapija	112	41°24’34”	022°21’14”	Lambrecht	1957-1979	with interruption
					1987-2020	
Lazaropole	1340	41°32’15”	020°04’45”	П-2	1964-1988	with interruption
					1988-2012	with interruption

2.2 AVAILABLE DATA

For the measuring stations for which there are data on at least 10 years of continuous measurement and registration of amount of precipitation, i.e., for which there is a pluviographic record of precipitation, the intensity of precipitation of a certain duration can be determined. In this paper, precipitation for the period from 1956 to 2020 has been analyzed for the measuring stations: Skopje, Shtip, Prilep, Bitola, Ohrid, Demir Kapija and Lazaropole. An overview of the processed pluviographic diagrams for all analysed stations for the period from 1956 to 1988 is shown in Table 2. For the period from 1989 to 2020, it is shown in Table 3. Pluviographic diagrams for the period from 1989 to 2020 that have been available (source: UHMR) for the meteorological stations are mainly one-day, but there are also weekly and monthly tapes. Based on detailed review of all pluviographic records obtained each year (daily, weekly and monthly) selection of diagrams of all recorded episodes of precipitation and torrents in the course of each month and then in the course of each year has been made. The diagrams with recorded illogical values of precipitation (unreliable diagrams controlled by the UHMR staff) have not been taken into account in the analyses.

Table 2. Overview of available pluviographic diagrams for the period 1956 to 1988

station	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1988	1989
Skopje																																	
Shtip																																	
Prilep																																	
Bitola																																	
Ohrid																																	
Kriva Palanka																																	
Demir Kapija																																	
Lazaropole																																	

Table 3. Overview of available pluviographic diagrams for the period 1989 to 2020

station	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Skopje																																
Shtip																																
Prilep																																
Bitola																																
Ohrid																																
Kriva Palanka																																
Demir Kapija																																
Lazaropole																																

2.3 READING PLUVIOGRAPHIC DIAGRAMS AND FORMING A TABLE WITH BASIC DATA FOR PROCESSING

The procedure of processing pluviographic tapes in order to define the intensity of the maximum precipitation of a certain duration can be done by the method of characteristic (transitional) points or the method of five-minute period of discretization (Δt = 5min). In the investigations presented in this paper, the second method has been used, i.e., the method of five-minute period of discretization (Δt = 5min) for which the period of discrediting is constant (Δt = 5min) and, for the total duration of precipitation, a chronological series of average five-minute intensities of precipitation has been obtained. The maximum values of intensity of precipitation have been obtained by extraction-separation of the largest value in the series of average five-minute precipitation, or the median value of precipitation of a certain duration. An online ***graphreader*** tool has been used to read the values from the pluviographic diagrams. For that purpose, all the tapes have, first of all, been scanned, the diagrams have been digitized and the values of the highest precipitation heights with a duration of 5, 10, 20, 40, 60, 90, 150, 300, 720 and 1440 minutes have been determined.

2.4 DETERMINATION OF ANNUAL MAXIMUM PRECIPITATION WITH A CERTAIN DURATION

For the analysed meteorological stations, all pluviographic diagrams in which precipitation has been registered for all years for the period from 1989 to 2020, have been processed. Based on these data, chronological series of data on annual maximum precipitation with a duration of 5 minutes to 1440 minutes have been established. For each year, a series of maximum daily precipitation measured by an ordinary rain gauge has also been established (source: UHMR).

When establishing the series of annual maximum precipitations, the processed data have been controlled and the following principles have been followed: 1) the height of the annual maximum precipitations of a certain duration must be greater than the annual maximum precipitation of a shorter duration, 2) the annual maximum precipitations with a duration of 1440 minutes must be greater and/or possibly equal to the maximum daily rainfall. In case this condition is not met by processing the pluviographic diagrams, the annual maximum precipitation with a duration of 1440 minutes is equal to the maximum daily precipitation (for these, there is a complete sequence for the analysed period), 3) in case of two or more separate shorter precipitations between which there is a period without precipitation, the maximum precipitation of a certain duration is determined on the basis of precipitation for the entire period, from the beginning of the precipitation to its cessation.

Based on the previously explained procedure, for the analysed meteorological stations (Skopje, Shtip, Prilep, Bitola, Ohrid, Kriva Palanka, Demir Kapija and Lazaropole), unique series of data on annual maximum precipitations with a duration of 5, 10, 20, 40, 60 90, 150, 300, 720 and 1440 minutes have been established for the period from 1989 to 2020.

2.5 ADDING INCOMPLETE ARRAYS

Due to the interruptions of the precipitation measurements at certain measuring stations (Bitola, Lazaropole and Ohrid) and for the purpose of completing the series of annual maximum precipitation of a certain duration, the need to supplement the series has been imposed. The completing of the arrays has been done by establishing correlations between the arrays of annual maximum precipitations of a certain duration and the array of maximum daily precipitations which are complete for all stations. When establishing these correlation links, the strength of the connection has been controlled according to the basic criterion for correlation links, i.e., the correlation coefficient (r) has been calculated and controlled, Table 4.

For the measuring stations Bitola and Ohrid, this coefficient has lower values of precipitation of a shorter duration and higher values of precipitation of a longer duration. For the measuring station Lazaropole, these values have been relatively small, indicating weak connections, wherefore a spatial correlation has been made with the stations: Prilep, Demir Kapija, Ohrid and Bitola. From the comparative analysis of the obtained correlation links, the highest coefficients have been obtained when establishing a correlation relationship of precipitation of a certain duration for m.s. Lazaropole with precipitation of the same duration for m.s. Ohrid.

Table 4. Correlation coefficients

r	**5'**	**10'**	**20'**	**40'**	**60'**	**90'**	**150'**	**300'**	**720'**	**1440'**
Bitola										
24h	**0.297**	**0.356**	**0.417**	**0.435**	**0.467**	**0.490**	**0.498**	**0.502**	**0.590**	**0.560**
Ohrid										
24h	**0.165**	**0.206**	**0.157**	**0.130**	**0.128**	**0.142**	**0.295**	**0.418**	**0.638**	**0.933**
Lazaropole										
24h	0.161	0.106	0.028	-0.003	-0.028	-0.045	-0.057	-0.037	0.029	0.087
Prilep	0.213	0.076	0.052	-0.117	-0.157	-0.122	-0.173	0.049	0.295	0.396
Demir Kapija	0.298	0.244	0.074	0.000	-0.043	-0.095	-0.098	-0.197	-0.037	-0.031
Ohrid	**0.666**	**0.585**	**0.788**	**0.623**	**0.435**	**0.414**	**0.443**	**0.379**	**0.064**	**0.162**
Bitola	0.324	0.429	0.510	0.343	0.222	0.172	0.126	0.025	0.013	0.003

2.7 DEFINING THE FUNCTIONS OF PROBABILITY OF HEAVY RAINFALL

The statistical processing of the established series of data on annual maximum precipitation of a certain duration for all measuring stations consists of determination of the basic statistical parameters: mean arithmetic value (P_{avr}), mean square deviation (σ), coefficient of variation (C_v), coefficient of asymmetry (C_s) [2], Table 5.

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 $\chi 2$-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 and duration of precipitation has been defined by applying the Gumble distribution. The established graphical dependencies between precipitation intensity, duration and probability of occurrence (i-T-p curve) for all measuring stations and short-term precipitation (5, 10, 20, 40, 60, 150, 300, 720, 1440 minutes) are shown graphically, Figure 2-9.

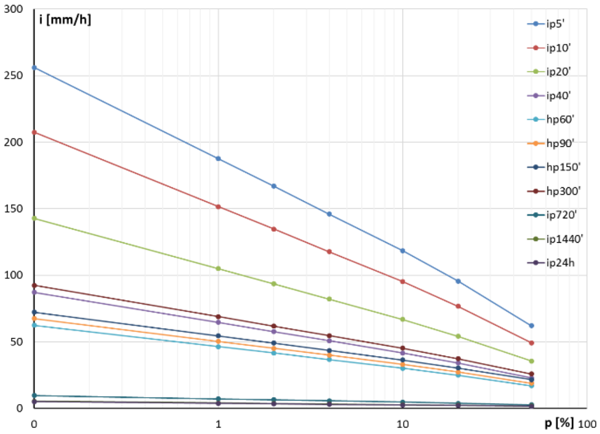

Figure 2. i-T-p curves for Skopje

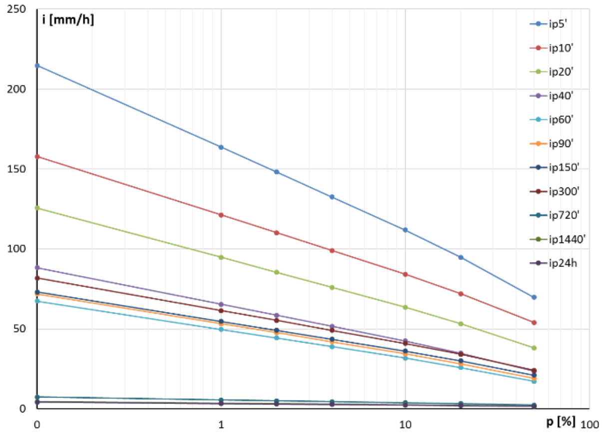

Figure 3. i-T-p curves for Shtip

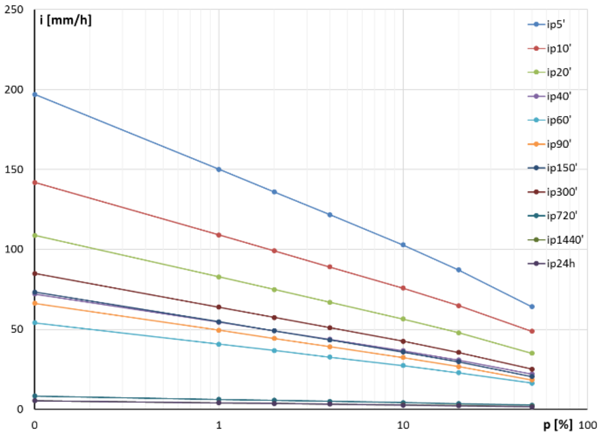

Figure 4. i-T-p curves for Prilep

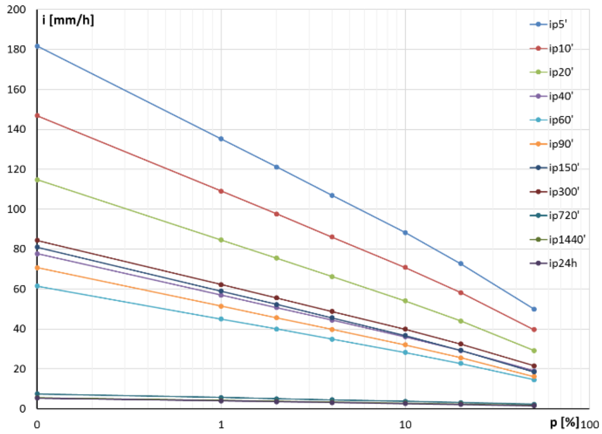

Figure 5. i-T-p curves for Bitola

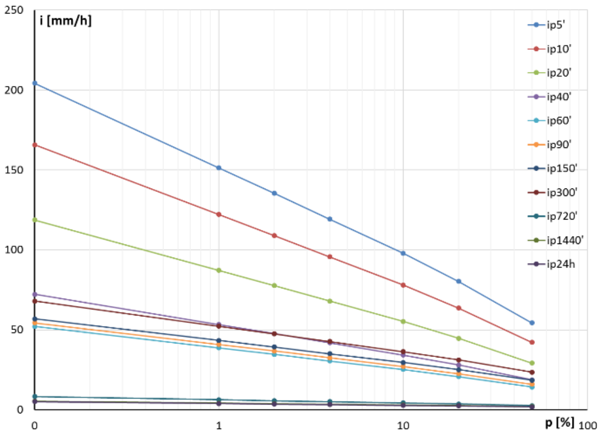

Figure 6. i-T-p curves for Ohrid

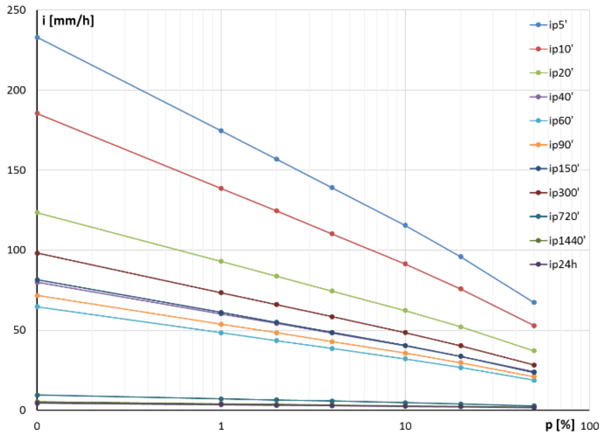

Figure 7. i-T-p curves for Kriva Palanka

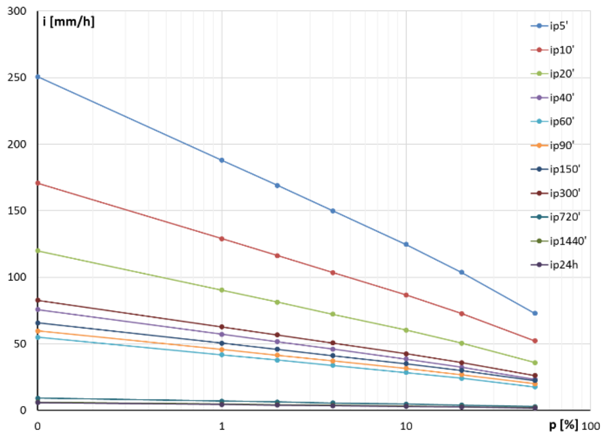

Figure 8. i-T-p curves for Demir Kapija

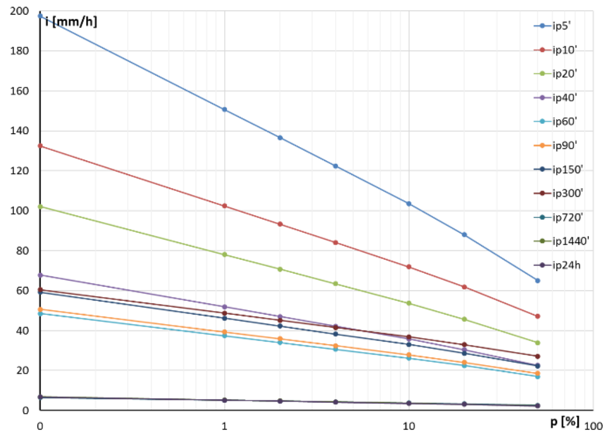

Figure 9. i-T-p curves for Lazaropole

3. ANALYSIS OF RESULTS AND DISCUSSION

In terms of available information on heavy rainfall, the following main advantages or disadvantages can be noted:

- the measuring points where the measurements were performed in the past period may have spatial variability and temporal inconsistency,
- observations of precipitation by means of a pluviogaph were performed only in the warm period of the year (from April to November). In winter, the so-called pluviographs with heaters were used (to prevent freezing under negative temperatures),
- during measurements of precipitation by use of the mentioned "Helman pluviograph", frequent cases of malfunction of the pluviograph (incorrect discharge, lack of ink, defective feather, etc.) were noticed. This often happened on the days with maximum amount of precipitation according to the 24 hour measurements done by an ordinary rain gauge,
- the processing of the pluviographic tapes was done by their digitization, while the reading of the precipitations of a short duration was done with a great accuracy,
- the established series with a total of 65 data on maximum annual precipitation of different duration (5, 10, 20, 40, 60, 150, 300, 720, 1440 minutes) are long enough to define curves with a high degree of reliability.

The established correlations between the series of data on annual maximum precipitations of a certain duration and the series of data on maximum daily precipitations for the measuring stations Bitola and Ohrid, have a correlation coefficient with relatively lower values for the precipitations of a shorter duration and higher values for the precipitations of a longer duration.

The established correlation of precipitation of a certain duration for m.s. Lazaropole with precipitation of the same duration for m.s. Ohrid is characterized by relatively higher values of the correlation coefficient and it can be used to supplement the sequence of maximum precipitation in m.s. Lazaropole.

The calculated statistical parameters show small variability of the variation coefficient (Cv): (0.4 ÷ 0.56) for Skopje, (0.33 ÷ 0.53) for Shtip, (0.35 ÷ 0.47) for Prilep, (0.43 ÷ 0.60) for Bitola, (0.32 ÷ 0.55) for Ohrid, (0.31 ÷ 0.45) for Kriva Palanka, (0.36 ÷ 0.45) for Demir Kapija and (0.23 ÷ 0.37) for Lazaropole. The coefficient of asymmetry (Cs) shows a great variability: (0.69 ÷ 2.02) for Skopje, (0.08 ÷ 2.48) for Shtip, (0.04 ÷ 2.21) for Prilep, (1.00 ÷ 3,40) for Bitola, (0.55 ÷ 2.055) for Ohrid, (0.46 ÷ 2.23) for Kriva Palanka, (0.03 ÷ 1.71) for Demir Kapija and (0.12 ÷ 1.85) for Lazaropole.

The comparative analysis of the graphical dependencies between the intensity of precipitation and the probability of occurrence (i-p) for all measuring stations, for a certain short duration of precipitation of 5, 10, 20, 40, 60, 150, 300, 720, 1440 minutes, is shown in Figure 10-19.

Comparing the maximum values of precipitation intensity for p = 0.1%, it can be noticed that the probability lines for different durations have different positions in relation to the other stations.

Table 5. Statistical parameters for the series of annual maximum precipitation with a certain duration

parameters	5’	10’	20’	40’	60’	90’	150’	300’	720’	1440’	24h
Skopje											
P_{SR}	5.69	9.05	13.00	16.63	18.41	20.40	23.17	27.90	33.80	42.31	38.97
P_{MIN}	0.67	1.33	2.66	4.10	4.10	4.10	5.90	7.30	7.30	14.30	14.20
P_{MAX}	14.00	25.00	33.00	38.00	42.00	45.75	51.02	91.90	92.55	92.55	92.90
σ	3.17	5.17	7.01	8.41	8.91	9.54	9.94	13.06	16.41	16.98	16.26
C_V	0.56	0.57	0.54	0.51	0.48	0.47	0.43	0.47	0.49	0.40	0.42
C_S	0.69	1.10	0.91	0.74	0.78	0.80	0.97	2.02	1.25	0.94	1.28
C_{S2}	1.26	1.34	1.36	1.34	1.25	1.17	1.15	1.27	1.24	1.21	1.31
Shtip											
P_{SR}	6.19	9.55	13.62	17.09	18.70	20.73	22.63	25.92	30.00	40.12	38.44
P_{MIN}	0.50	0.80	1.40	1.90	2.20	2.85	3.50	7.60	15.80	21.00	18.20
P_{MAX}	11.80	20.00	34.82	50.00	67.00	70.17	70.82	71.36	72.20	86.90	86.90
σ	2.37	3.39	5.72	8.45	9.85	10.36	10.20	11.31	11.64	13.39	12.84
C_V	0.38	0.35	0.42	0.49	0.53	0.50	0.45	0.44	0.39	0.33	0.33
C_S	0.08	0.44	1.34	1.94	2.48	2.40	2.30	2.18	1.53	1.21	1.24
C_{S2}	0.83	0.77	0.94	1.11	1.19	1.16	1.07	1.23	1.64	1.40	1.27
Prilep											
P_{SR}	5.70	8.62	12.47	15.78	17.56	19.94	22.21	27.06	32.46	42.40	40.14
P_{MIN}	1.59	2.00	2.60	4.80	4.90	5.00	5.00	7.00	7.00	17.80	17.80
P_{MAX}	10.00	16.31	23.50	29.66	39.88	52.00	58.00	65.83	78.01	120.00	120.20
σ	2.17	3.04	4.82	6.54	7.40	9.39	10.35	11.72	13.46	17.79	17.79
C_V	0.38	0.35	0.39	0.41	0.42	0.47	0.47	0.43	0.41	0.42	0.44
C_S	0.04	0.06	0.32	0.54	0.74	1.27	1.52	1.42	1.38	2.01	2.21
C_{S2}	1.05	0.92	0.98	1.19	1.17	1.26	1.20	1.17	1.06	1.45	1.59
Bitola											
P_{SR}	4.51	7.19	10.66	13.91	16.09	17.83	20.46	23.56	28.98	43.29	39.93
P_{MIN}	0.59	1.19	2.37	4.59	4.96	5.06	6.26	7.70	8.90	2.90	17.80
P_{MAX}	11.95	23.90	39.40	54.70	69.10	78.00	90.80	92.50	93.00	116.00	120.20
σ	2.15	3.50	5.60	7.68	9.21	10.72	12.27	12.34	12.33	18.48	17.71
C_V	0.48	0.49	0.53	0.55	0.57	0.60	0.60	0.52	0.43	0.43	0.44
C_S	1.00	1.66	2.32	2.64	3.29	3.20	3.40	3.06	2.57	1.78	2.27
C_{S2}	1.10	1.17	1.35	1.65	1.65	1.68	1.73	1.56	1.23	0.91	1.60
Ohrid											
P_{SR}	4.93	7.69	10.70	13.62	15.40	17.13	19.69	24.87	33.93	49.42	46.48
P_{MIN}	1.05	2.10	3.00	4.20	5.12	6.11	7.24	8.67	9.53	26.20	25.80
P_{MAX}	15.10	26.20	39.90	45.10	46.20	46.20	48.70	49.50	67.50	95.10	90.40
σ	2.45	4.03	5.85	6.99	7.42	7.54	7.53	8.73	13.23	15.78	15.16
C_V	0.50	0.52	0.55	0.51	0.48	0.44	0.38	0.35	0.39	0.32	0.33
C_S	1.39	2.01	2.38	2.05	1.98	1.88	1.57	0.70	0.55	0.95	1.22
C_{S2}	1.26	1.44	1.52	1.48	1.44	1.37	1.21	1.08	1.08	1.36	1.47
Kriva Palanka											
P_{SR}	6.05	9.52	13.31	17.26	20.21	22.56	25.51	30.47	35.91	45.46	42.30
P_{MIN}	2.25	3.10	4.90	7.81	7.82	9.16	9.40	9.50	9.80	22.10	22.10
P_{MAX}	11.50	20.00	30.10	41.04	50.00	70.00	81.20	91.30	111.20	113.90	97.00
σ	2.71	4.33	5.64	7.29	9.00	9.94	11.35	13.71	15.89	16.20	13.05
C_V	0.45	0.45	0.42	0.42	0.45	0.44	0.44	0.45	0.44	0.36	0.31
C_S	0.46	0.89	0.82	1.38	1.55	2.06	2.31	2.23	2.07	1.49	1.31
C_{S2}	1.42	1.35	1.34	1.54	1.45	1.48	1.41	1.31	1.22	1.39	1.29
Demir Kapija											
P_{SR}	6.55	9.34	12.86	16.68	18.78	21.24	23.76	27.90	35.63	49.49	44.95
P_{MIN}	0.65	1.29	2.55	4.84	6.13	8.75	10.38	10.58	10.58	20.00	13.70
P_{MAX}	15.10	19.70	25.60	34.10	35.10	37.49	41.20	58.90	97.21	122.25	121.90
σ	2.90	3.87	5.49	6.84	7.32	7.78	8.50	11.09	14.98	19.72	18.87
C_V	0.44	0.41	0.43	0.41	0.39	0.37	0.36	0.40	0.42	0.40	0.42
C_S	0.03	0.29	0.34	0.53	0.36	0.29	0.32	0.68	1.47	1.53	1.71
C_{S2}	0.98	0.96	1.07	1.15	1.16	1.25	1.27	1.28	1.20	1.34	1.21
Lazaropole											
P_{SR}	5.78	8.31	12.02	16.05	17.98	19.57	23.45	28.23	32.87	59.75	58.75
P_{MIN}	0.73	1.47	2.93	5.86	6.30	7.90	11.17	16.30	17.00	31.00	31.00
P_{MAX}	12.50	17.00	31.50	34.50	40.20	40.20	42.90	46.20	66.00	154.40	154.40
σ	2.16	2.79	4.46	5.91	6.19	6.29	7.25	6.53	9.07	21.03	20.60
C_V	0.37	0.34	0.37	0.37	0.34	0.32	0.31	0.23	0.28	0.35	0.35
C_S	0.35	0.12	1.29	0.90	1.21	1.16	0.80	0.32	1.47	1.72	1.85
C_{S2}	0.86	0.81	0.98	1.16	1.06	1.08	1.18	1.09	1.14	1.46	1.48

Thus, for the rains with a duration of 5 minutes, the lowest intensity is observed at station Bitola, then Prilep, Ohrid, Lazaropole, Shtip, Kriva Palanka, Demir Kapija, while the highest intensity is observed at m.s. Skopje. As to the precipitation with a duration of 10 minutes, the lowest intensity of precipitation is observed at m.s Lazaropole, then Bitola, Shtip, Prilep, Ohrid; Demir Kapija, Kriva Palanka, while the greatest intensity of precipitations is observed at m.s. Skopje. Regarding the rains with duration of 20 minutes, the intensity is the lowest at Lazaropole station, then Prilep, Bitola, Ohrid, Demir Kapija; Kriva Palanka, Shtip, while the greatest intensity of precipitation is observed at m.s. Skopje.

As to the rains with a duration of 40 minutes, the lowest intensity is observed at m.s Lazaropole, then Ohrid, Prilep, Demir Kapija, Bitola, Kriva Palanka, Skopje, while the highest intensity of rains is observed at m.s. Shtip. For the rains with duration of 60 minutes, the lowest intensity is observed at Lazaropole station, then Ohrid, Prilep, Demir Kapija, Bitola, Skopje, Kriva Palanka, while the highest intensity of rain is observed at m.s. Shtip. Regarding the rains with a duration of 90 minutes, the lowest intensity is observed at Lazaropole station, then Ohrid, Demir Kapija, Prilep, Skopje, Bitola, Shtip, while the highest intensity of rain is observed at m.s. Kriva Palanka.

Concering the rains with a duration of 150 minutes, the lowest intensity is observed at Ohrid station, then Lazaropole, Demir Kapija, Skopje, Shtip, Prilep, Bitola, while the highest intensity of rain is observed at m.s. Kriva Palanka.

As to the rains with a duration of 300 minutes, the lowest intensity is observed at Lazaropole station, then Ohrid, Shtip, Demir Kapija, Bitola, Prilep, Skopje, while the highest intensity of rain is observed atm.s. Kriva Palanka. Regarding the rains with a duration of 720 minutes, the lowest intensity is observed at Lazaropole station, then Shtip, Bitola, Prilep, Ohrid, Demir Kapija, Skopje, while the highest intensity of rain is observed at m.s. Kriva Palanka.

Finally, as to the rains with a duration of 1440 minutes, the lowest intensity is observed at m.s. Shtip, then Skopje, Kriva Palanka, Prilep, Ohrid, Bitola, Demir Kapija, while the highest intensity of rain is observed at m.s. Lazaropole.

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 place, i.e., latitude and longitude as well as altitude.

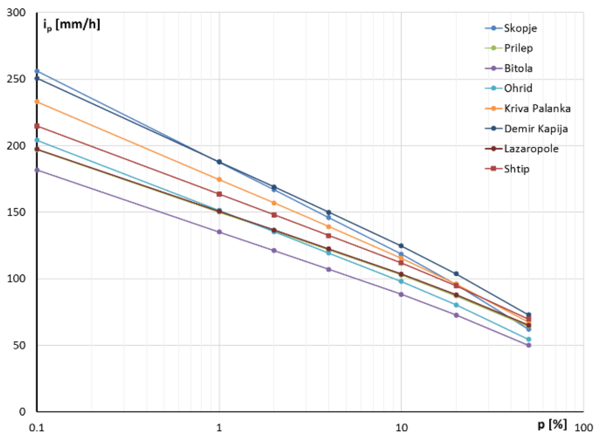

Figure 10. i-p curves for precipitation with duration of 5 minutes

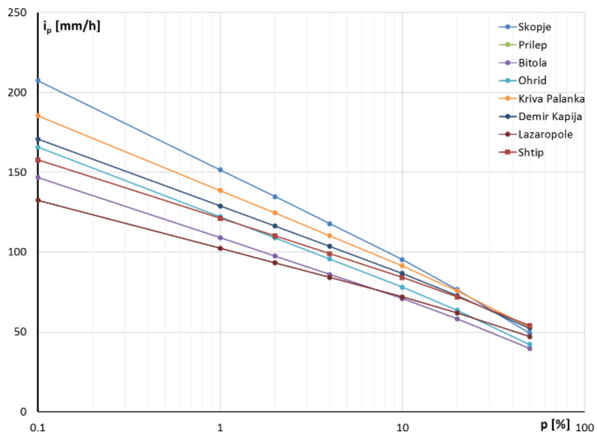

Figure 11. i-p curves for precipitation with duration of 10 minutes

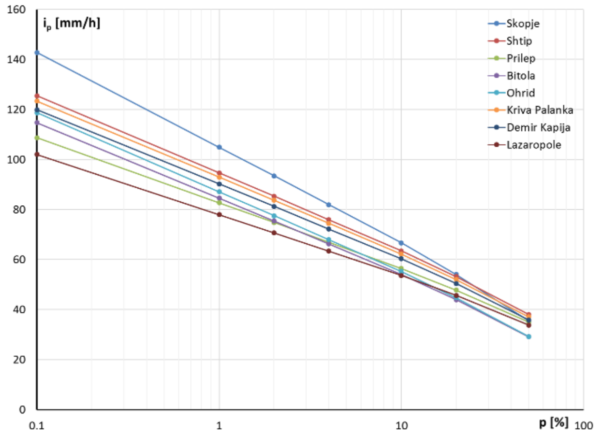

Figure 12. i-p curves for precipitation with duration of 20 minutes

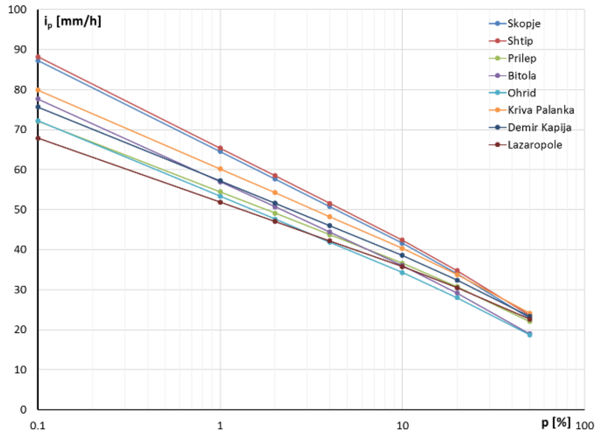

Figure 13. i-p curves for precipitation with duration of 40 minutes'

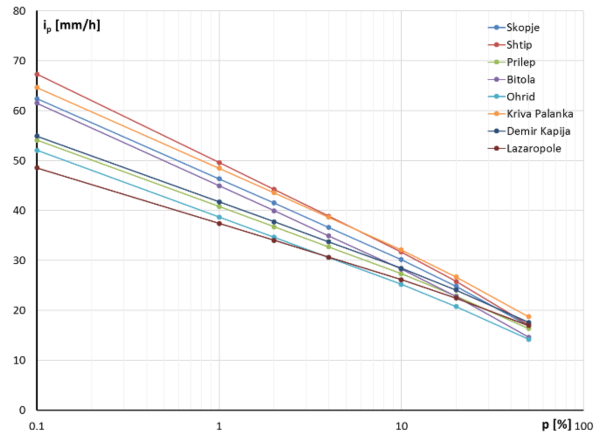

Figure 14. i-p curves for precipitation with duration of 60 minutes'

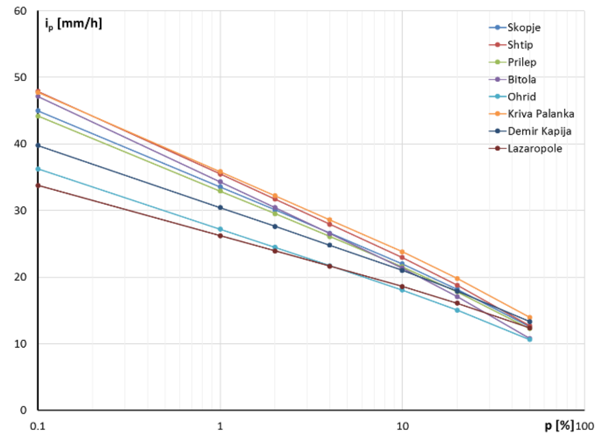

Figure 15. i-p curves for precipitation with duration of 90 minutes

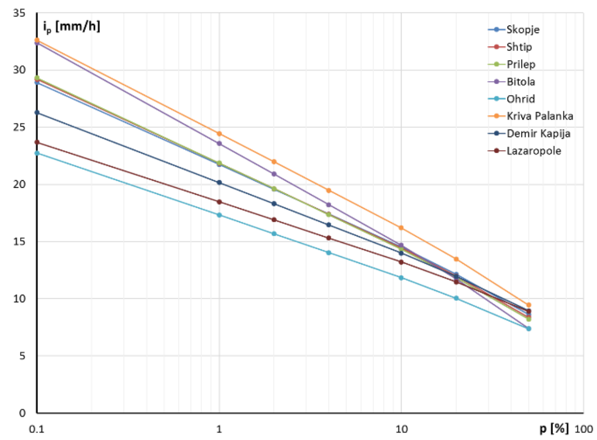

Figure 16. i-p curves for precipitation with duration of 150 minutes

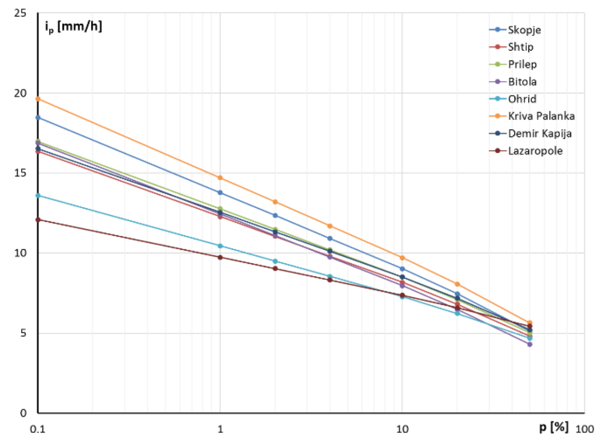

Figure 17. i-p curves for precipitation with duration of 300 minutes

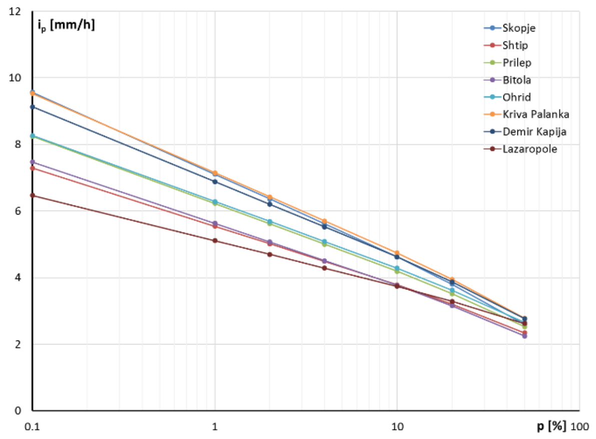

Figure 18. i-p curves for precipitation with duration of 720 minutes

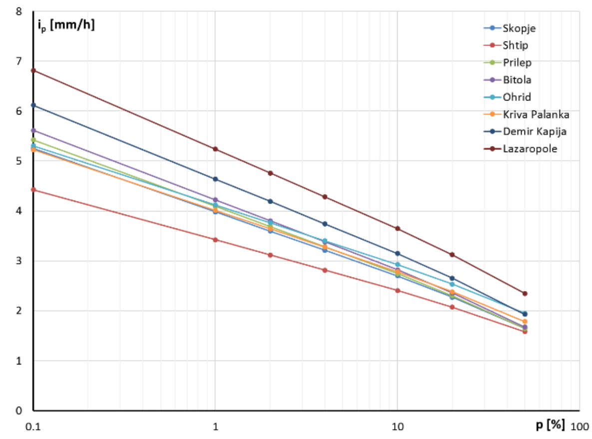

Figure 19. i-p curves for precipitation with duration of 1440 minutes

4. CONCLUSION

Short-term precipitation parameters are extremely important for hydrological analysis of small catchment areas, but also for the urban hydrology. Their application is justified and widely accepted in solving problems in hydrotechnics, water management, agriculture, etc. Recently, due to evident climate changes in all regions worldwide, there has arisen the need for innovation curves of intensity-duration and probability of occurrence i-T-p.

Based on available measured data on precipitation in the form of pluviographic tapes at eight measuring stations in the R.N. Macedonia, there has been established a series of data on maximum annual precipitation of different duration (5, 10, 20, 40, 60, 150, 300, 720, 1440 minutes) with a total of 65 data, for the period from 1956 to 2020. Based on this series of data, the probability of occurrence of maximum intensity of precipitation for all rainfall stations and duration of precipitation has been defined by applying the Gumble distribution.

Graphic dependencies between precipitation intensity, duration and probability of occurrence (i-T-p) for short-term precipitation (5, 10, 20, 40, 60, 150, 300, 720, 1440 minutes) have been established for all measuring stations and can be used for appropriate hydrological analyses to be performed for small catchment areas.

Due to the extremely stochastic nature of the precipitation, it is recommended that these curves are innovated in the next 10 to 15 years.

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