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VII Climate Change and Flood Risk Management

# ANALYSIS OF THE CHANGE OF PRECIPITATION WITH SHORT DURATION IN MACEDONIA

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## Abstract

The change in precipitation has a direct impact on people's lives at different levels. For example, an increase rainfall can cause floods and / or landslides that affect individual homes, cities, and even entire countries. Floods cannot be prevented or accurately predicted, but effective mitigation measures based on their occurrence estimates can significantly reduce their impact. All models for estimating floods are based on precipitation analysis, with special emphasis on short-term precipitation, which is often the cause of catastrophically large floods. Knowing the changes in rainfall over a long period of time guarantees a better prognosis of floods and timely taking appropriate measures to mitigate or to some extent prevent them. Hence, access to up-to-date / new and accurate short-term precipitation data is essential. However, such key data are often unavailable in different parts of the world due to the lack of sufficient measuring stations, but also in the case of raw data. In R.N. Macedonia in practice is still used data on heavy rainfall for the period from 1956 to 1988. The need to update this information with more recent data is more than necessary, given that rainfall is an extremely stochastic phenomenon.

The subject of this paper is updating the precipitation data in Macedonia for the period from 1956 to 2020. The changes of precipitation in the last 30 years in eight measuring stations have been analysed. Existing series for annual maximum precipitation with short duration for the period from 1956-1988, are supplemented with data for precipitation from 1989 to 2020. The procedure of processing pluviographic tapes in order to define the annual maximum precipitation of a certain duration have been done by the method of characteristic (transitional) points or the method of five-minute period of discretization ($\Delta t$ = 5min). The obtained series are statistically analysed, a homogeneity test is performed and the i-D-P (intensity-duration-probability of occurrence) curves are defined. The results are presented in tabular and graphical form.

**Keywords:** floods, annual maximum precipitation, short duration, i-D-P (intensity-duration- probability of occurrence) curves.

## 1. Introduction

Precipitation with short duration directly affect the occurrence of floods that can cause serious consequences on people's lives at different levels. Precipitation with short duration and hence floods can not be prevented, but effective mitigation measures based on assessment of their occurrence can significantly reduce the negative effects. All models for estimation of occurrence of floods are based on analysis of precipitation, with special emphasis on short-term precipitation, which is often the cause of catastrophically large floods. Knowing the changes in precipitation over a long period of time guarantees a better prognosis of the occurrence of floods and timely taking appropriate measures to mitigate or prevent them to some extent. Hence, access to up-to-date / new and accurate short-term precipitation data is essential. However, such key data are often unavailable in different parts of the world due to the lack of sufficient measuring stations, but also in the case of raw data.

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. 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. 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, (P. Willems, et al., 2012), (J.R. Porto de Carvalho, et al., 2014). 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 (A. Longobardi and P. Villani, 2010), (P.T. Nastos, 2011) accompanied by an increase of exceptional events such as severe droughts and devastating floods, (P. Alpert, T. Ben-Gai, A. Baharad et al., 2002). 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, (M.J.M. Römkens, K. Helming, and S.N. Prasad, 2002). 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, (Alexander, L.V., et al., 2006). 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.

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, (Ž. Shkoklevski, B. Todorovski, 1993). 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 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. 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 precipitation with a certain return period.

### 1.1. Study area and available data

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). 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.

**Table 1.** Overview of analyzed meteorological stations

| Station | H [ma.s.l.] | Position | | Measurement Period | Notes |
|---|---|---|---|---|---|
| | | latitude | longitude | | |
| SK-1 | 240 | 41°59’ | 20°28’ | 1956–1966 | stopped working |
| SK-2 | 239 | 41°57’42” | 021°37’17” | 1967–1975 | |
| SK-3 | 302 | 42°00’59” | 021°12’59” | 1978–1988 | with interruption |
| | | | | 1989–2020 | |
| Shtip | 336 | 41°45’13” | 022°21’49” | 1963–1988 | with interruption |
| | | | | 1988–2020 | |
| Prilep | 675 | 41°20’02” | 021°13’14” | 1959–1988 | with interruption |
| | | | | 1989–2020 | |
| Bitola | 590 | 41°02’30” | 021°12’13” | 1956–1988 | with interruption |
| | | | | 1989–2019 | with interruption |
| Ohrid | 757 | 41°06’53” | 020°04’50” | 1956–1988<br>1989–2020 | |
| | | | | | with interruption |
| Kriva Palanka | 693 | 42°12’13” | 022°21’52” | 1959–1988 | |
| | | | | 1989–2020 | |

| | | | | | |
|---|---|---|---|---|---|
| Demir Kapija | 112 | 41°24'34" | 022°21'14" | 1957–1979 | with interruption |
| | | | | 1987–2020 | |
| Lazaropole | 1340 | 41°32'15" | 020°04'45" | 1964–1988 | with interruption |
| | | | | 1988–2012 | with interruption |

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). 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. 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. 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 ($\Delta t = 5min$). In the investigations presented in this paper, the second method has been used, i.e., the method of five-minute period of discretization ($\Delta t = 5min$) for which the period of discrediting is constant ($\Delta t = 5min$) 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. 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.

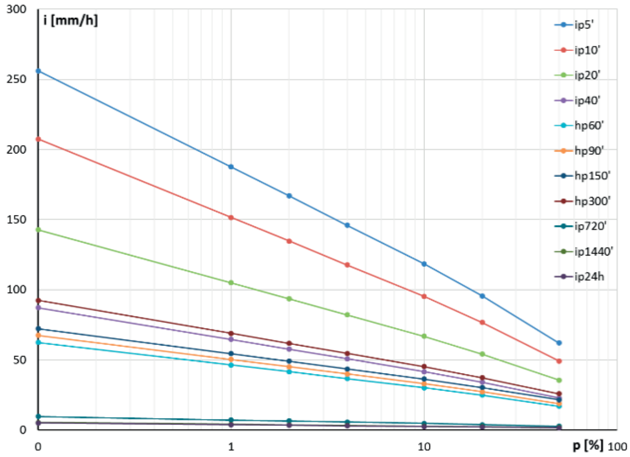
For the measuring stations Bitola and Ohrid, this coefficient has lower values of precipitation of a shorter duration and higher values of precipitation of a longer duration. For the measuring station Lazaropole, these values have been relatively small, indicating weak connections, wherefore a spatial 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.

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, 1440 minutes and 24h have been established for the period from 1989 to 2020.

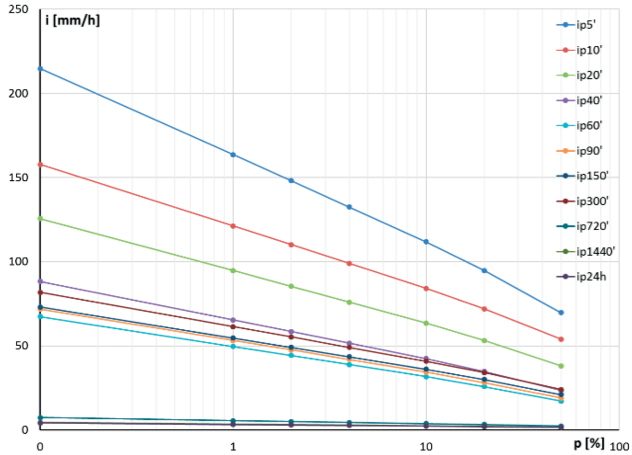
### 1.2. Defining the functions of probability of heavy rainfall

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 (Pavr), mean square deviation ($\sigma$), coefficient of variation (Cv), coefficient of asymmetry (Cs). 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 ($n=\infty$), 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 $\alpha = 5\%$, 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.

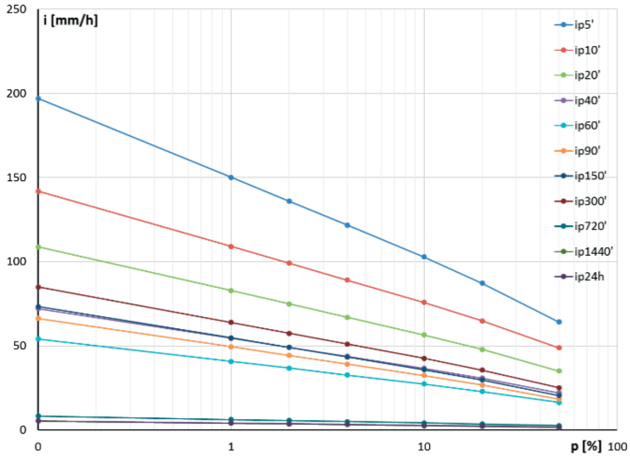
The established graphical dependencies between precipitation intensity, duration and probability of occurrence (i-T-p curve) for all measuring stations and short-term precipitation (5, 10, 20, 40, 60, 90, 150, 300, 720, 1440 minutes) are shown graphically, Figure 1.



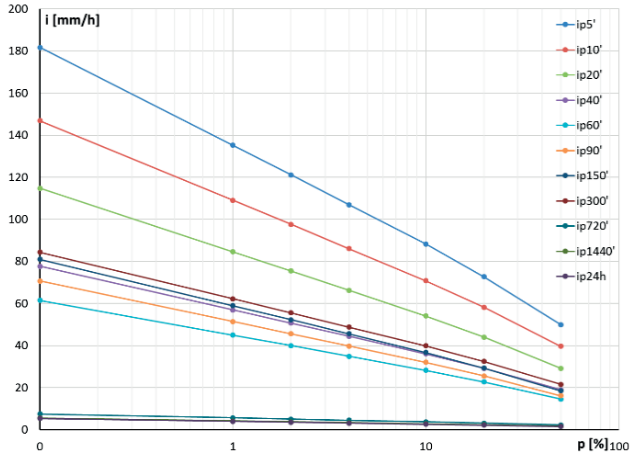

i-T-p curves for Skopje



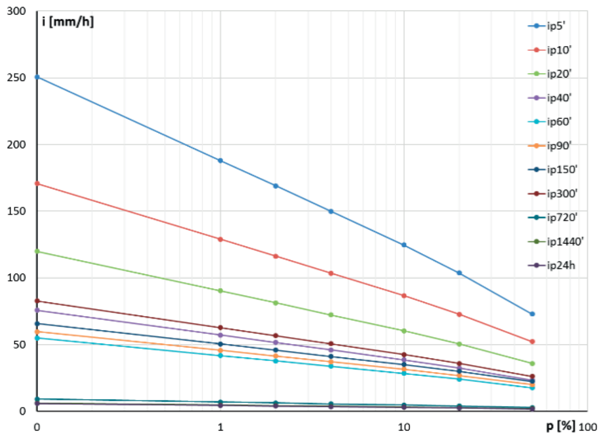

i-T-p curves for Shtip



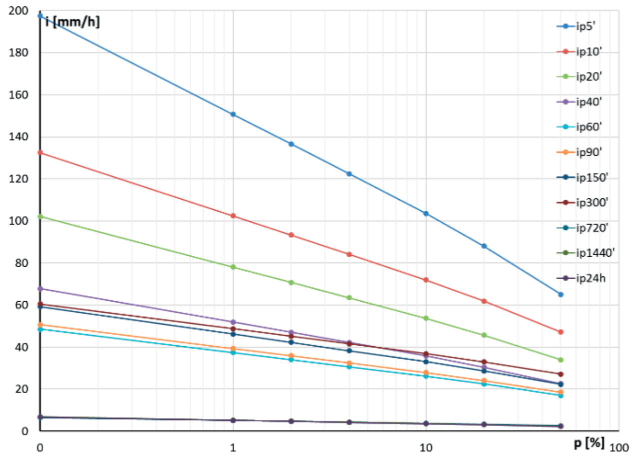

i-T-p curves for Prilep




i-T-p curves for Bitola




i-T-p curves for Demir Kapija




i-T-p curves for Lazaropole

**Figure 1**. i-T-p curves

## 2. Results and discussion

If we analyze the calculated values for the intensity of precipitation with a short duration (5, 10, 20, 40, 60, 90, 150, 300, 720, 1440 minutes) for a return period of 10 years for the period 1956 to 2020 with the same data for the period from 1956 to 1988, Figure 2, it can be noted that in Skopje the intensity of rainfall, rainfall with a duration of 5, 10, 20, 40, 60, 90, 150 recorded a decrease, while rainfall with a longer duration of 300, 720, 1440 minutes and 24 hours have increase over the last 30 years. In Shtip, the increase in intensity was observed for precipitation white duration longer than 20 minutes. For the measuring station in Prilep, an increase in the intensity of precipitation with a duration shorter than 1440 minutes was observed, while a decrease in intensity was observed for precipitation lasting 1440 min and 24h. In Bitola and Ohrid, for all periods of duration of precipitation, a decrease in intensity can be observed in the last 30 years. In Kriva Palanka, there is an increase in the intensity of precipitation with a duration of 40, 60, 90, 150 minutes. In Demir Kapia, there is an increase in precipitation with a duration of more than 300 minutes, while in Lazaropole only for precipitation with a duration of 720 minutes.

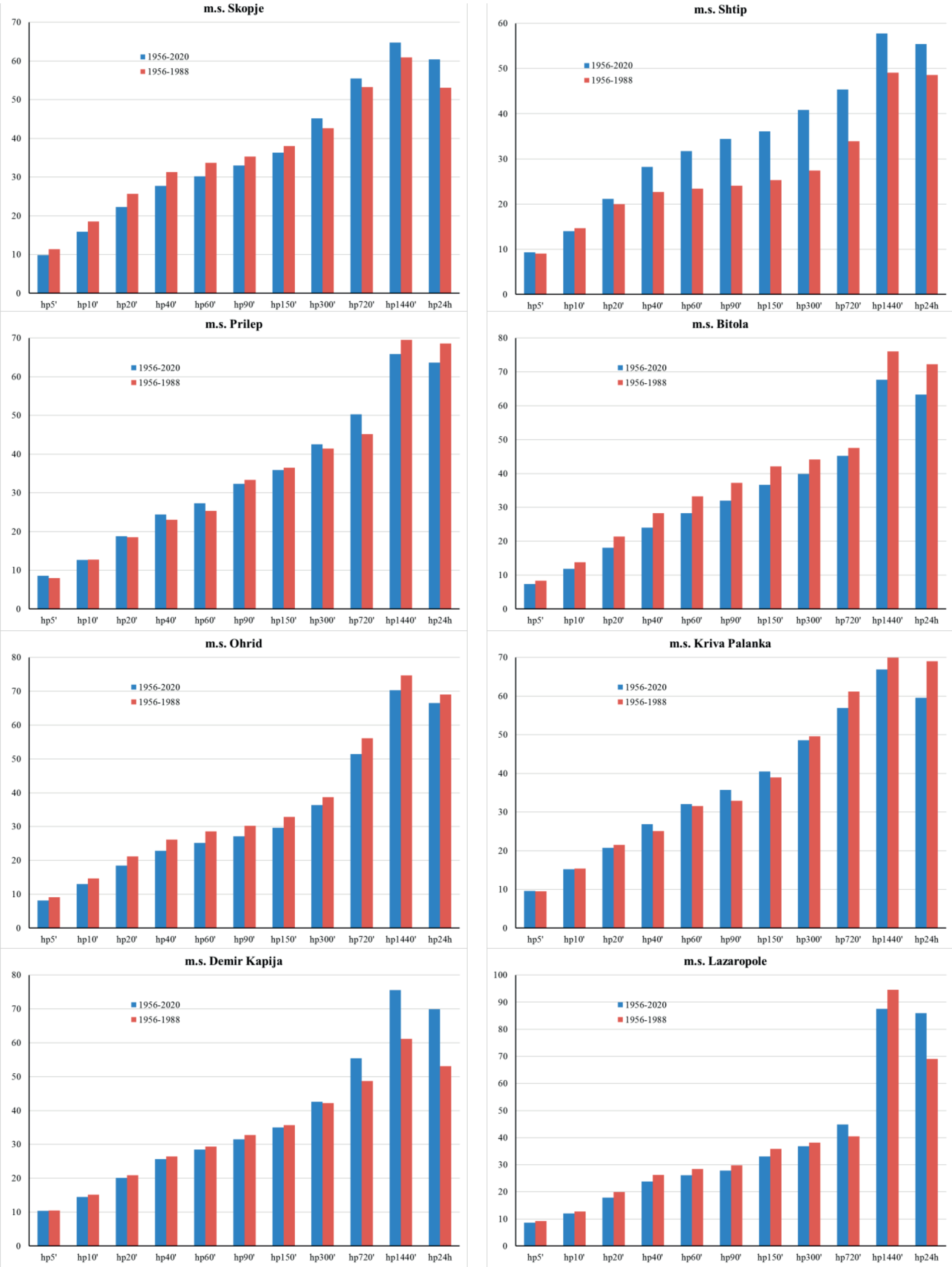



**Figure 2**. Intensity of short-term precipitation for a return period of 10 years (period 1956–2020 compared to period 1956–1988)

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 for period 1981–2010, Fig. 3, (HMS).

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 years, Fig. 4, the situation is similar. Maximum rainfalls take place in Lazaropole, while the least rainfall is characteristic for Shtip.

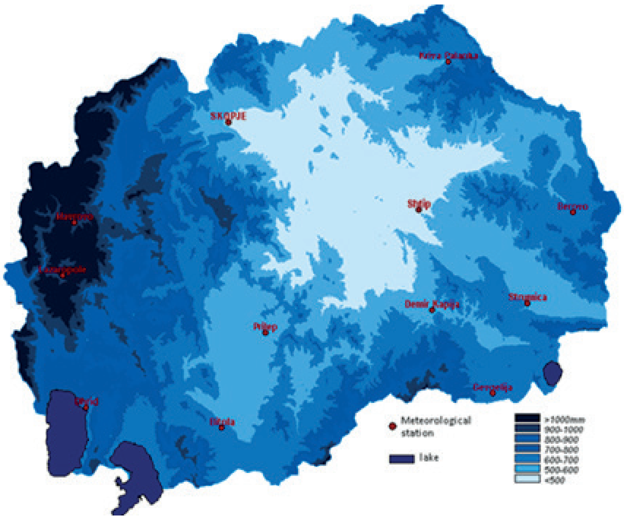



**Figure. 3**. Spatial distribution of average annual rainfall for the period 1981–2010. (Source: HMS)

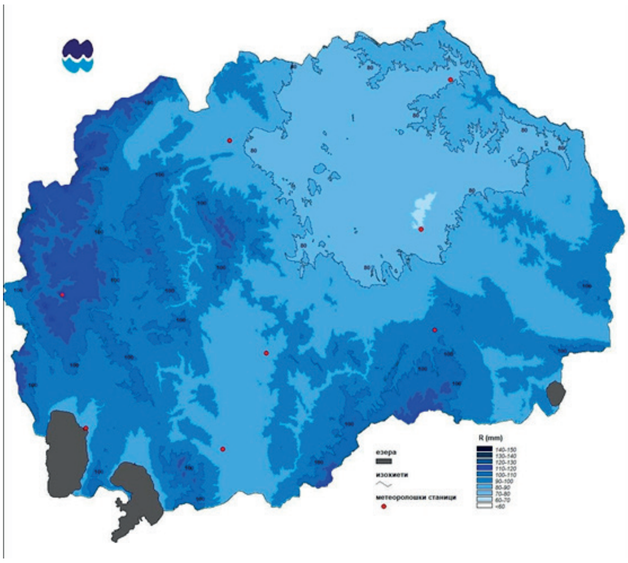


**Figure. 4.** Spatial distribution of maximum precipitation with a return period of 50 years

## 3. 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 precipitation with short duration 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 precipitation with short duration 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 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 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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