ANALYSIS OF METEOROLOGICAL DATA

THE GRADAŠČICA RIVER BASIN

UL FGG (PP 9)

WORK PACKAGE 4
ACTIVITY 4.3

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Stations locations

Data from rainfall stations Črni vrh nad Polhovim Gradcem, Lučine, Šentjošt were analysed. Besides that data from the climatological station Topol pri Medvodah and series from the main meteorological station Ljubljana-Bežigrad were also considered in analyses. In first step we analysed the daily time scale data, which were measured at 7 am. 13 years of series were used for the analyses (2000-2012). We also used data, with time step ½ hour form the station Dvor pri Polhovem Gradcu for the period 2002-2012. For the main meteorological station Ljubljana-Bežigrad we also used 5-minute rainfall data for the period 2000-2011, for the station Črni vrh nad Polhovim Gradcem we also analysed data with 5-miunte time step for the period 2000-2010. Stations locations are shown in Fig. 1.

Figure 1: Stations location (Scale 1:140000)

Yearly time scale analyses

Main descriptive statistics of used data are shown in table 1. Some descriptive statistics values, like the mean value or the standard deviation, can be used for the presentation of properties of statistical populations (Brilly & Šraj, 2005). 1st order central moment represents the mean value, 2nd order central moment represents the variance, square root of the variance equals the standard deviations, which is a measure of data dispersion (Turk, 2012).

The minimum amount of rainfall was measured at the station Ljubljana-Bežigrad (table 1), the most rainfall was characteristic of the station Šentjošt. This station is the most southern of all

considered stations, while the main meteorological station Ljubljana-Bežigrad is the most eastern station. The largest dispersion (variance and standard deviation) was characteristic of the precipitation (rainfall) station Topol pri Medvodah, but on the other hand the smallest dispersion was measured at the Ljubljana-Bežigrad station (table 1). Maximum value of the daily rainfall sum in observed period was measured at the station Lučine (180,4 mm). The largest skewness was characteristic of the data sample from the station Topol pri Medvodah.

Table 1: Descriptive statistics of used data samples (daily precipitation sum measured at 7 am)

	Črni vrh	Ljubljana	Lučine	Šentjošt	Topol
Mean value [mm]	4,22	3,69	4,51	4,55	4,47
Standard error [mm]	0,15	0,14	0,16	0,16	0,17
Standard deviation [mm]	10,59	9,39	11,25	11,03	11,47
Variance [mm^2]	112,24	88,23	126,61	121,71	131,51
Kurtosis	26,25	25,90	32,48	22,72	31,05
Skewness	4,30	4,25	4,54	4,04	4,55
Maximum value [mm]	137,7	139,6	180,4	130,8	162

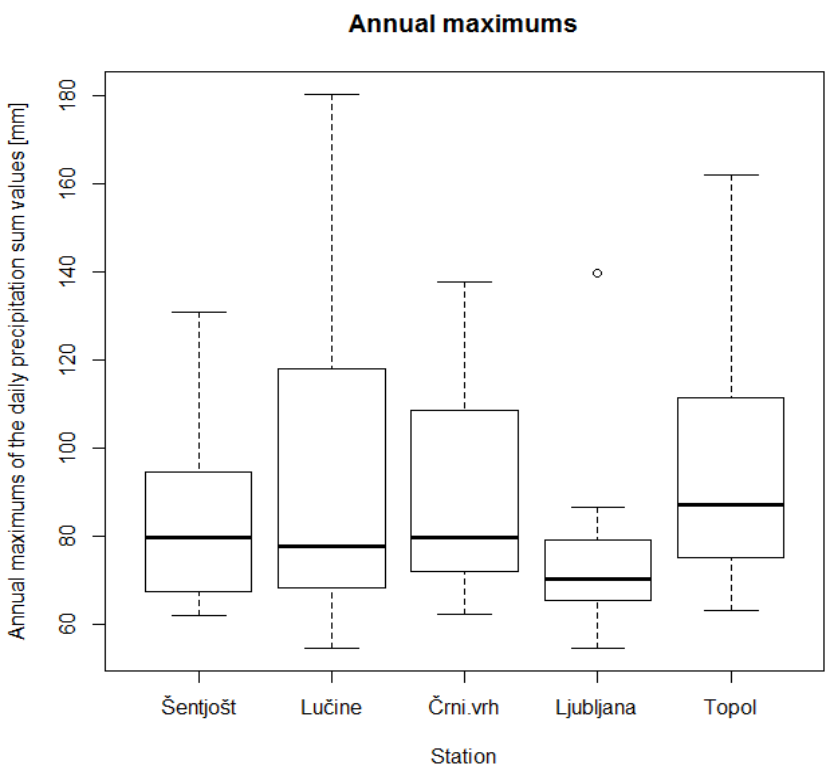

Figure 2: Box-plots of annual maximum of the daily precipitation sum values measured at 7am for the period 2000-2012

Annual maximum values for the daily precipitation sum are shown in Fig. 2. The smallest annual maximums were measured on the main meteorological station Ljubljana-Bežigrad, which also had the smallest dispersion of annual maximums. The largest dispersion was characteristic of the station Lučine, where the largest event also occurred. Similar behaviour as in the case of annual maximums can also be seen in the case of the yearly precipitation sums (Fig. 3). At least rainfall was measured at the station Ljubljana, which geographically differs from other stations. Ljubljana-Bežigrad lies about 10 km east of the station Topol pri Medvodah and approximately 20 km east of the station Črni vrh nad Polhovim Gradcem. In most of the years we can expect between 1200 and 1400 mm in Ljubljana, while for other stations these values are larger and are approximately between 1400 and 1800 mm. Yearly precipitation sums for separate years are shown in Fig. 4. It can be seen that in years 2010, 2008 and 2004 there were more rain as in years 2003, 2006 and 2011. The largest amount of rainfall was measured in year 2010, when for 4 stations yearly precipitation sum exceeded 2000 mm. Again we can see that the station Ljubljana-Bežigrad differs from other stations. Differences between yearly sums are larger in the case of years with larger amount of rainfall (Fig. 4).

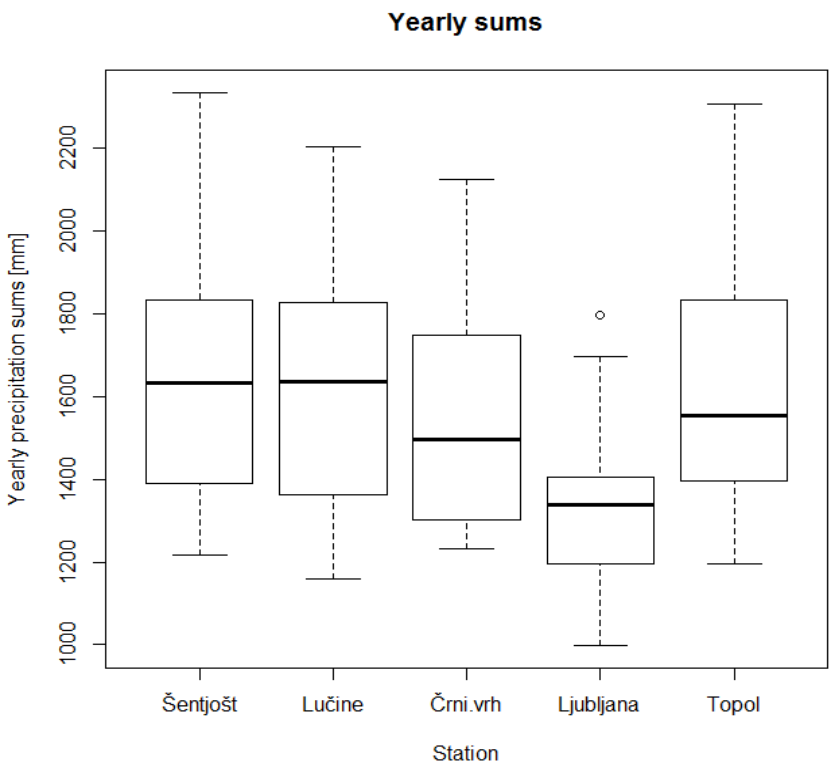

Figure 3: Box plots of yearly precipitation sums for the period 2000-2012

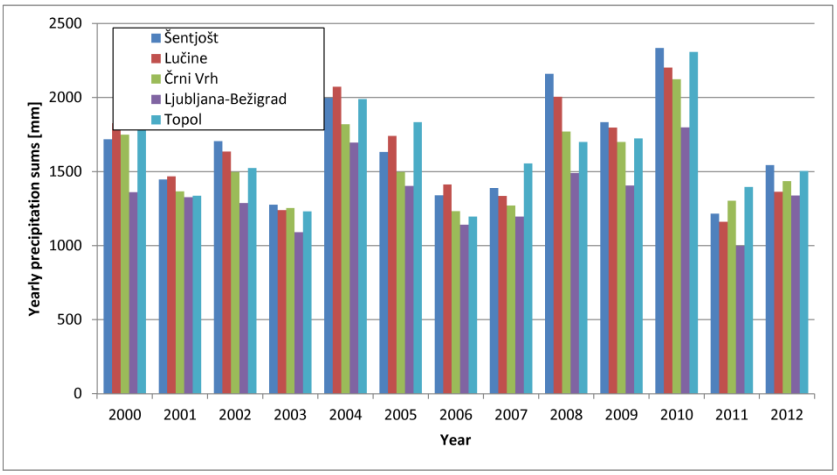

Figure 4: Yearly precipitation sums for analysed stations

Monthly time scale analyses

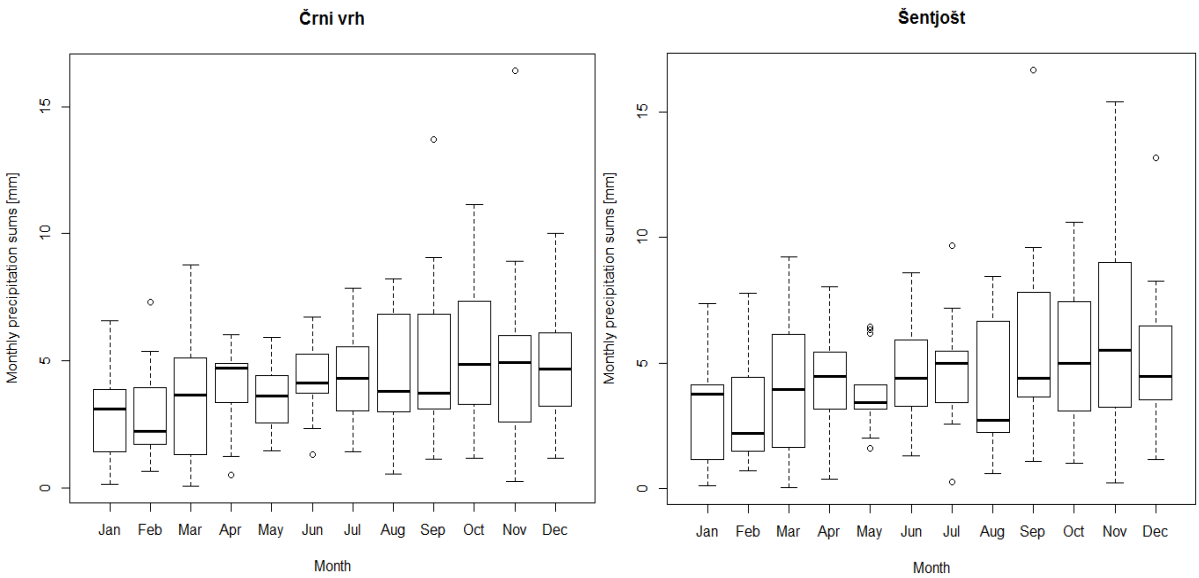

Figure 5: Monthly precipitation sums for stations Črni vrh nad Polhovim Gradcem and Šentjošt

In Fig. 5, 6 and 7 monthly precipitations sums for stations Črni vrh nad Polhovim Gradcem, Šentjošt, Lučine, Topol pri Medvodah and Ljubljana-Bežigrad are shown. It can be seen that all stations have similar seasonal regime, where the largest amount of rainfall is usually measured in the autumn period, from September to December, a little less rainfall usually falls in the summer period. Less rainfall can be expected in winter periods (January, February and March). Srebrnič (2005) wrote that annual maximums of daily precipitation sums, for analysed stations, usually occurred in September and October, but seasonality was not significant. When he analysed monthly precipitation sums he found out that our analysed stations lie between two areas. Frontal and orographic rainfalls, which usually occur in October and November, are

characteristic of the first area, while on the other hand conventional rainfall (usually the summer period) is property of the second area. One can notice that our stations (Fig. 5, 6 and 7) cannot be classified in any of these two areas (median or the second quartile values for the summer and autumn period are equivalent). Perhaps this phenomenon was the most significant for the station Črni vrh nad Polhovim Gradcem, which also has the largest altitude (830 m above sea level).

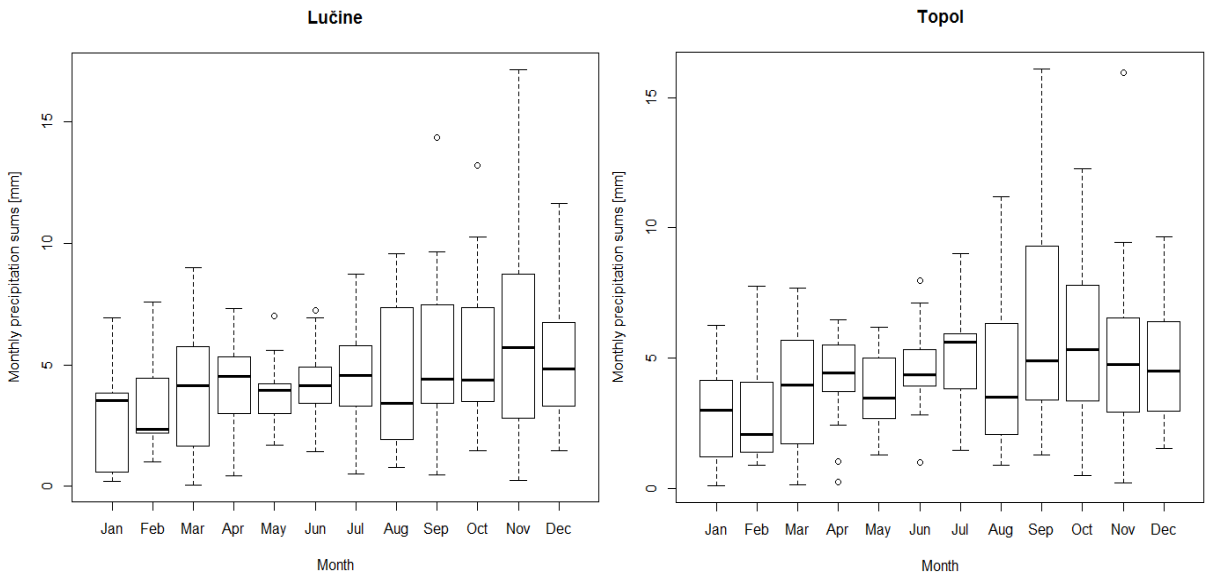

Figure 6: Monthly precipitation sums for stations Lučine and Topol pri Medvodah

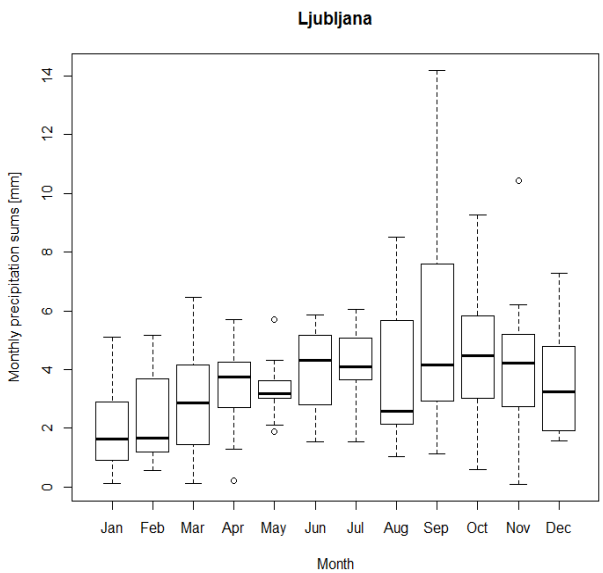

Figure 7: Monthly precipitation sums for the station Ljubljana-Bežigrad

Average of mean monthly precipitation values are shown in Fig. 8. First we calculated monthly average of daily precipitation sums for the whole period and then also the average of these values. One can see that in the case of stations which lie west of the station Ljubljana-Bežigrad

the largest values were characteristic of autumn months (September, October and November). These stations lie at higher altitudes as the main meteorological stations Ljubljana (299 m above sea level). Summer and autumn rainfall were more equivalent in the case of this station (Fig. 8), which means approximately the same influence of the orographic and the conventional rainfall, while for other stations the orographic rainfall had a little bigger impact as the conventional rainfall (Fig. 1).

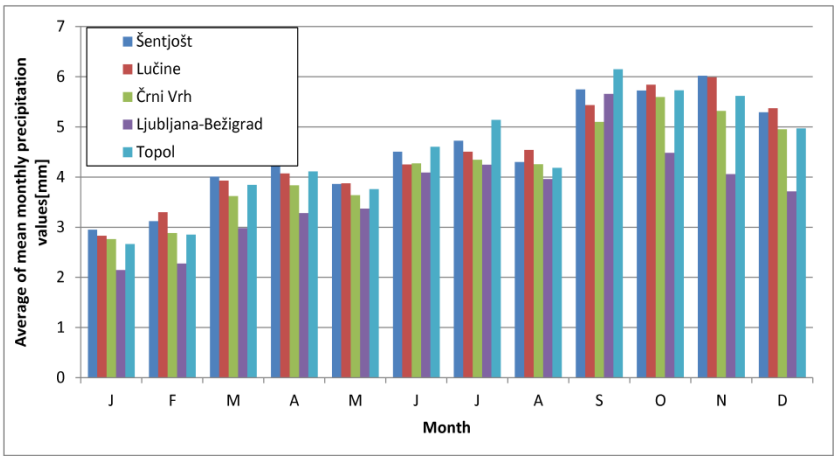

Figure 8: Average of mean monthly precipitation values for analysed stations

Daily time scale analyses

Mean daily precipitations for years 2007 and 2010 are shown in Fig. 9. From Fig. 4 one can notice that the year 2010 was the wettest in the observed period, from Fig. 9 yet also that the most rainfall fall in the September (September floods 2010). Year 2007 was drier as the previously mentioned year 2010, but also in the case of this year the largest amount of rainfall was measured in September (September floods 2007). Mean daily precipitations for the September 2010 were twice as large as those in the September 2007. These years were chosen for the graphical presentation because in both years major floods occurred. Difference between years is that the year 2007 was generally drier as the year 2010.

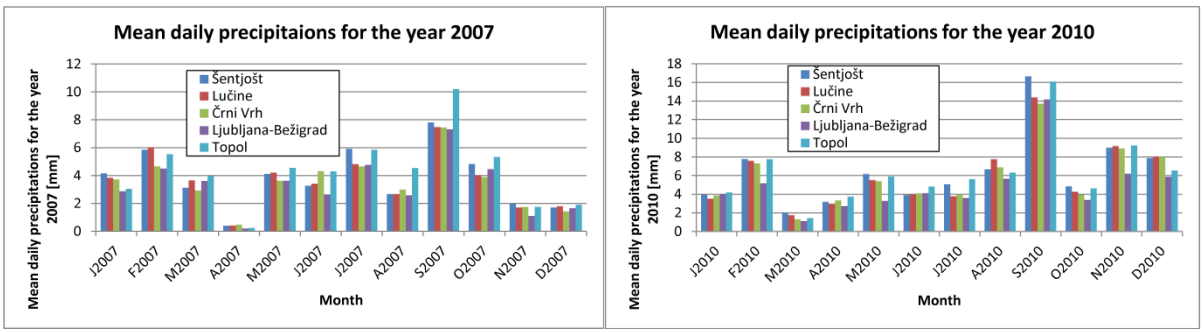

Figure 9: Mean daily precipitation values for years 2007 and 2010

Based on the daily scale data we also calculated correlation coefficients values. Pearson, Kendall and Spearman correlation coefficient were used. Correlation coefficient values are shown in tables 2, 3 and 4.

Table 2: Pearson correlation coefficient values for used stations

	Šentjošt	Lučine	Črni vrh	Ljubljana	Topol
Šentjošt	1	0,958	0,943	0,844	0,913
Lučine	0,958	1	0,943	0,833	0,901
Črni vrh	0,943	0,943	1	0,85	0,925
Ljubljana	0,844	0,833	0,85	1	0,894
Topol	0,913	0,901	0,925	0,894	1

Table 3: Kendall correlation coefficient values for used stations

	Šentjošt	Lučine	Črni vrh	Ljubljana	Topol
Šentjošt	1	0,863	0,845	0,783	0,832
Lučine	0,863	1	0,866	0,775	0,827
Črni vrh	0,845	0,866	1	0,79	0,847
Ljubljana	0,783	0,775	0,79	1	0,83
Topol	0,832	0,827	0,847	0,83	1

Table 4: Spearman correlation coefficient values for used stations

	Šentjošt	Lučine	Črni vrh	Ljubljana	Topol
Šentjošt	1	0,92	0,909	0,869	0,902
Lučine	0,92	1	0,923	0,862	0,897
Črni vrh	0,909	0,923	1	0,875	0,911
Ljubljana	0,869	0,862	0,875	1	0,901
Topol	0,902	0,897	0,911	0,901	1

From tables 2, 3 and 4 we can see that the lowest correlation coefficients were calculated for the station Ljubljana-Bežigrad. Rainfall data from this station has the lowest correlation with other stations (Šentjošt, Lučine, Črni vrh in Topol). These results were expected because the main meteorological station lies east of other stations. Polhov Gradec mountain area has bigger impact on these stations. These properties can be observed in the case of all three correlation coefficients. For Kendall's and Spearman's coefficient, which is based on ranks, the largest correlation was calculated between stations Črni vrh nad Polhovim Gradcem and Lučine. In the case of Pearson's coefficient the largest correlation was calculated between Lučine and Šentjošt stations. These three stations also have similar geographical locations; Lučine and Šentjošt also lie on similar altitude (Lučine 639 m and Šentjošt 627 m above sea level).

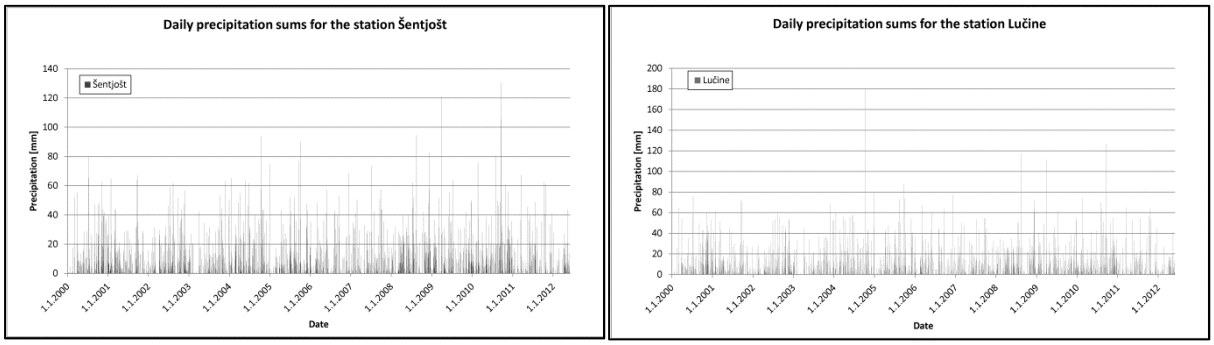

Figure 10: Daily precipitation sums for stations Šentjošt and Lučine (2000-2012)

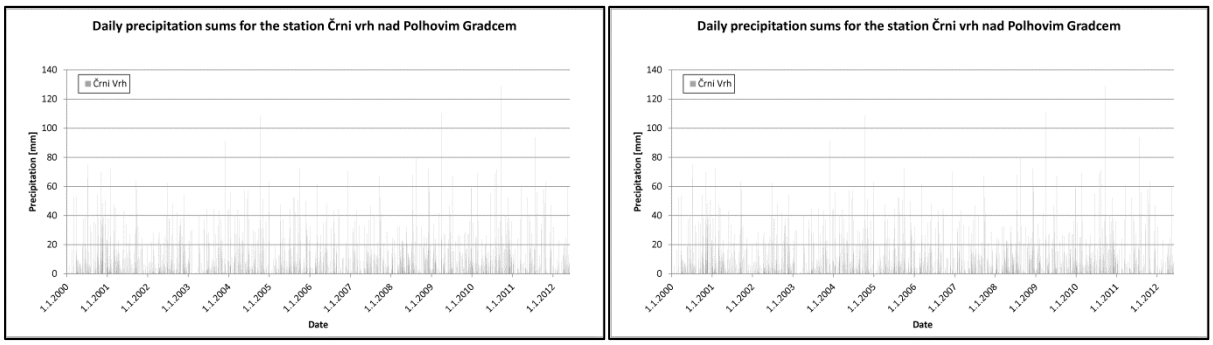

Figure 11: Daily precipitation sums for stations Črni vrh nad Polhovim Gradcem and Ljubljana-Bežigrad (2000-2012)

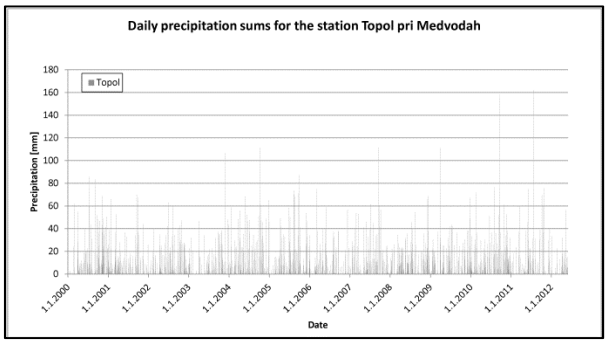

Figure 12: Daily precipitation sums for station Topol pri Medvodah (2000-2012)

Daily precipitation sums are shown in Fig. 10, 11 and 12 for the period 2000-2012. Histograms of daily precipitation sums are shown in Fig. 13 for stations Ljubljana-Bežigrad and Šentjošt. These two stations had the lowest (Ljubljana) and the largest (Šentjošt) amount of rainfall in the observed period (table 1). In histogram plots there is not much difference between the two compared stations, just in the case of the station Šentjošt there were more (few) days with large amount of rainfall. Similar distribution of rainfall events is also characteristic of other stations.

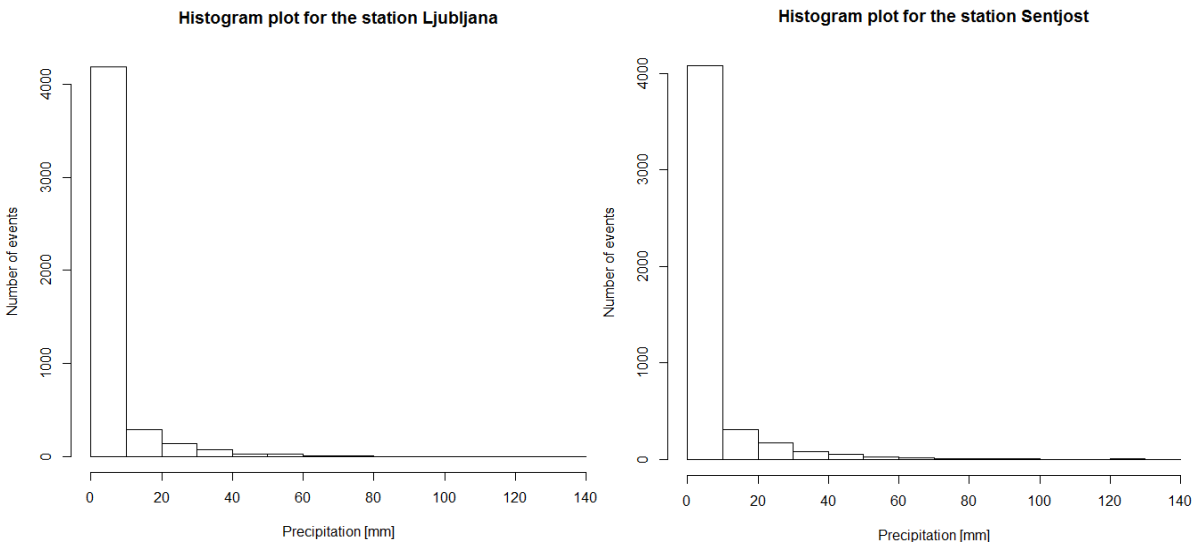

Figure 13: Histogram plot of daily precipitation sums for stations Ljubljana-Bežigrad and Šentjošt

Hourly and 5-minute time scale analyses

For stations Ljubljana-Bežigrad, Črni vrh nad Polhovim Gradcem and Dvor we also analysed data with shorter time step. For the main meteorological station Ljubljana and the station Črni vrh we used 5-minute time scale data and for the station Dvor ½ hour time scale series. In Fig. 14, 15 and 16 one can observe maximum events in the analysed period for these stations.

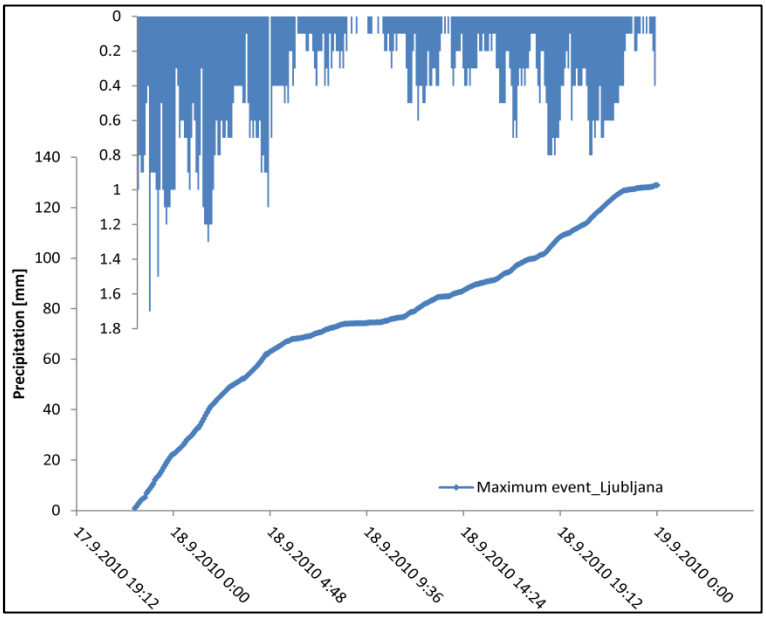

Figure 14: Maximum event from the main meteorological station Ljubljana (September 2010)

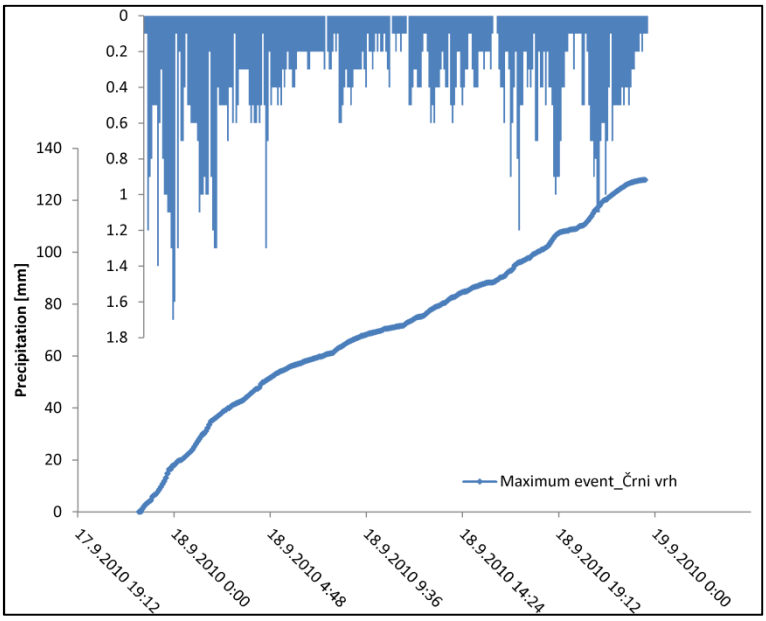

Figure 15: Maximum event from the station Črni vrh nad Polhovim Gradcem (September 2010)

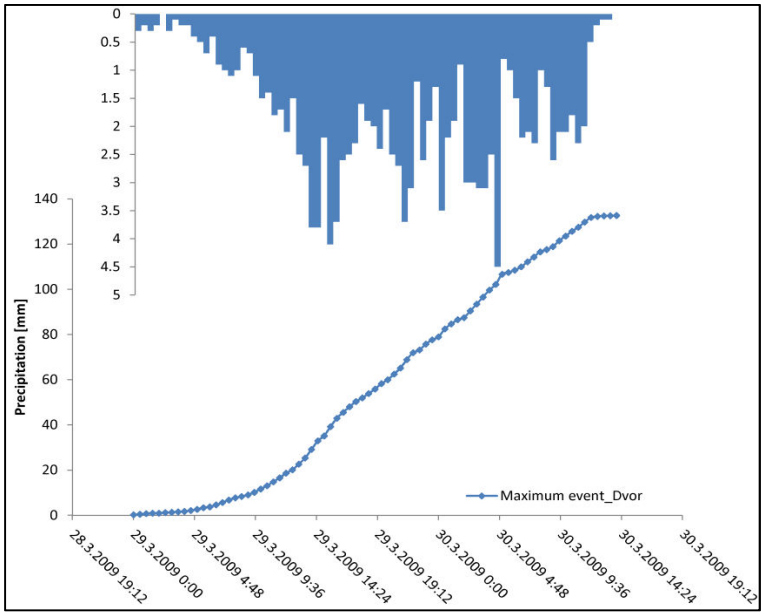

Figure 16: Maximum event from the station Dvor (March 2009)

Cumulative precipitation curves and measured rainfall are shown in Fig. 14, 15 and 16 (5-minute time step for Ljubljana and Črni vrh and ½ hour time step for Dvor). In the case of stations Ljubljana and Črni vrh nad Polhovim Gradcem the largest event occurred in September 2010 and in the case of the station Dvor in March 2009. Cumulative curves for stations Ljubljana and Črni vrh were similar, which was expected, because the same event was observed (Fig. 14 and 15). In the September 2010 event more rainfall fall in the first part of

the event, while for the March 2009 event more rainfall was measured in the second part of the event.

IDF curves

Intensity-duration-frequency curves (IDF) can be used to determine connection between rainfall intensity, rainfall duration and return period of the event. Frequency analyses are needed for construction of IDF curves. Different distribution functions and parameter estimation techniques can be used. Goranc (2012) gathered more information about IDF curves. For construction of IDF curves data with short time step is needed. IDF curves were made for stations Ljubljana-Bežigrad (2000-2011), Črni vrh nad Polhovim Gradcem (2000-2010) and Dvor (2002-2012). Data with 5-minute time step was available for stations Ljubljana and Črni vrh, for the station Dvor we used data with ½ hour time step. First we have to calculate annual maximums for different rainfall durations. Annual maximums were determined for next durations: 5, 10, 15, 20, 30, 45, 60, 90, 120, 180, 240, 300, 360, 540, 720, 900, 1080 and 1440 minutes for stations Ljubljana and Črni vrh and for 30, 60, 90, 120, 180, 240, 300, 360, 540, 720, 900, 1080 and 1440 minutes for the station Dvor. Normal, log-normal, Pearson 3, log-Pearson 3, Gumbel and GEV (generalised extreme value) distributions were used. Parameters were estimated with the method of moments and the method of L-moments. Because the short series were used for the analyses, some distributions like Pearson 3, log-Pearson 3 and GEV were inappropriate for construction of IDF curves. Distribution parameters depend upon skewness of sample, which can distinctly vary with just a little change in the sample (small samples). In the case of smaller skewness values we can also expect smaller estimated precipitation values, for larger skewness values larger estimated events can be expected. This can lead to phenomenon where estimated values do not increase with increasing rainfall duration values (for the same return period). This mean that also IDF curves are not monotonically decreasing like one could expect in the case of the longer time series, where more precise parameter estimations can be made. This phenomenon is more significant in the case of larger return periods.

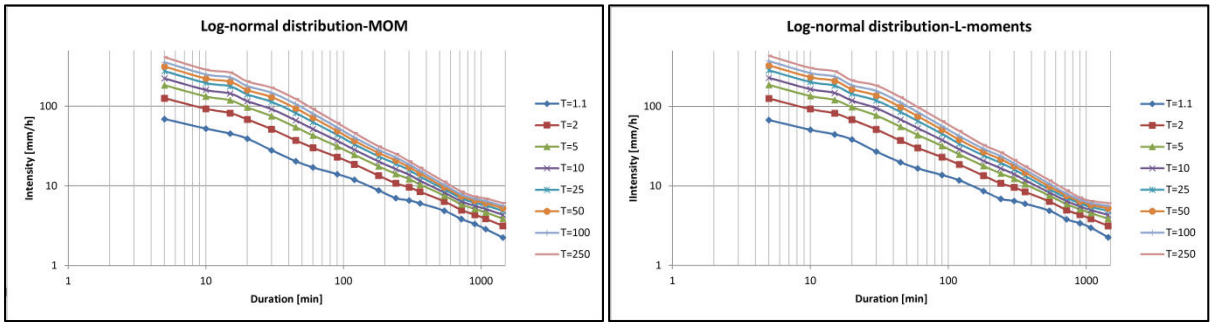

Figure 17: IDF curves for the station Ljubljana-Bežigrad when log-normal distribution is used and parameters are estimated with the method of moments and the method of L-moments (2000-2011)

IDF curves for the main meteorological station Ljubljana-Bežigrad are shown in Fig. 17 and 18. Log-normal and Gumbel distributions were used and parameters were estimated with the method of moments and the method of L-moments.

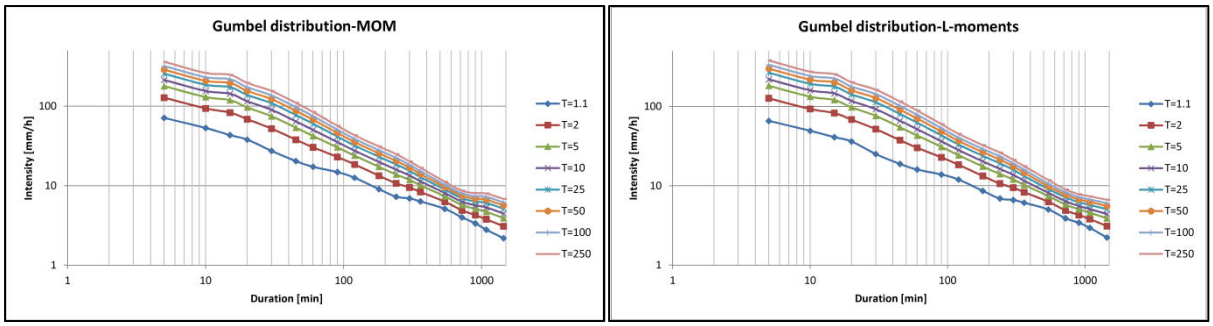

Figure 18: IDF curves for the station Ljubljana-Bežigrad when Gumbel distribution is used and parameters are estimated with the method of moments and the method of L-moments (2000-2011)

IDF curves for the period 1948-2008 for the station Ljubljana-Bežigrad are shown in Fig. 19. Gumbel distribution was used for the construction of IDF curves and parameters of the distribution were estimated with the method of moments (ARSO, 2009). Comparison between our IDF curves for shorter period (2000-2011) and IDF curves from Fig. 19 (1948-2008) are shown on Fig. 20. Results are shown for return period 50 and 100 years. One can notice that curves for the period 2000-2011 had higher intensities at shorter durations, differences for durations longer as 90 minutes were adequately small (Fig. 20).

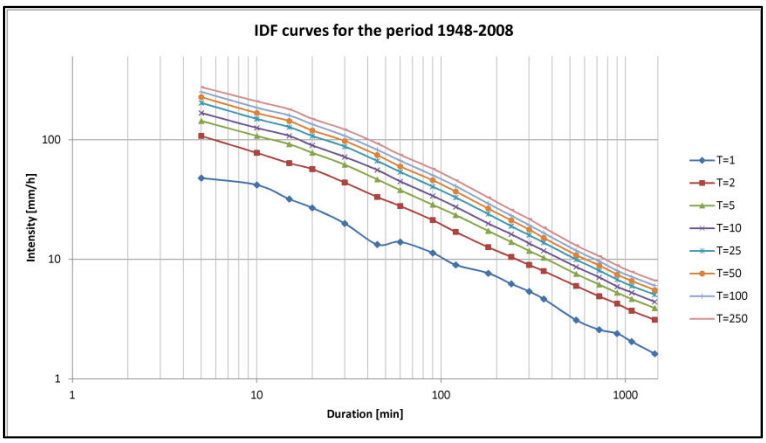

Figure 19: IDF curves for the station Ljubljana-Bežigrad when Gumbel distribution is used and parameters are estimated with the method of moments for the period 1948-2008 (ARSO, 2009)

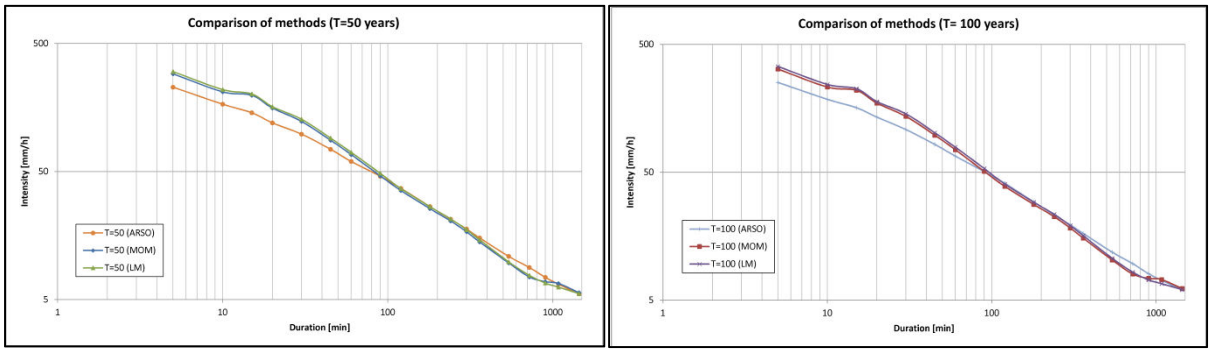

Figure 20: Comparison between IDF curves for the return period 50 and 100 years for the main meteorological station Ljubljana (Gumbel distribution function)

When constructing IDF curves the method of moments and the method of L-moments gave similar results (Fig. 20). Method of moments gives better results in the case of samples with smaller skewness values and especially in the case of small samples; on the other hand the method of L-moments is more efficient in the case of larger skewness values and for all sample sizes (Sankarasubramanian in Srinivasan, 1999).

IDF curves for the station Črni vrh nad Polhovim Gradcem are shown in Fig. 21 and 22 (period 2000-2010). Results are shown for log-normal and Gumbel distributions where parameters were estimated with the method of moments and the method of L-moments.

IDF curves for the station Črni vrh for the period 1976-2008 (ARSO, 2009) are shown in Fig. 23. Parameters of Gumbel distribution function were estimated with the method of moments. Comparison between IDF curves for our data (2000-2010) and longer series (1976-2008) are shown in Fig. 24. Differences between IDF curves are small and there is also not much difference between the method of moments and the method of L-moments. For more precise definition of differences between IDF curves statistical tests, like Kolmogorov-Smirnov or Anderson-Darling, should be used.

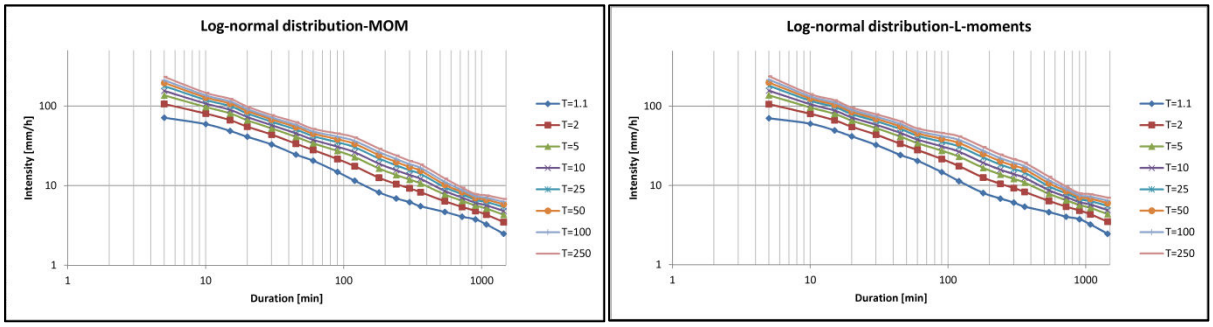

Figure 21: IDF curves for the station Črni vrh nad Polhovim Gradcem when log-normal distribution is used and parameters are estimated with the method of moments and the method of L-moments (2000-2010)

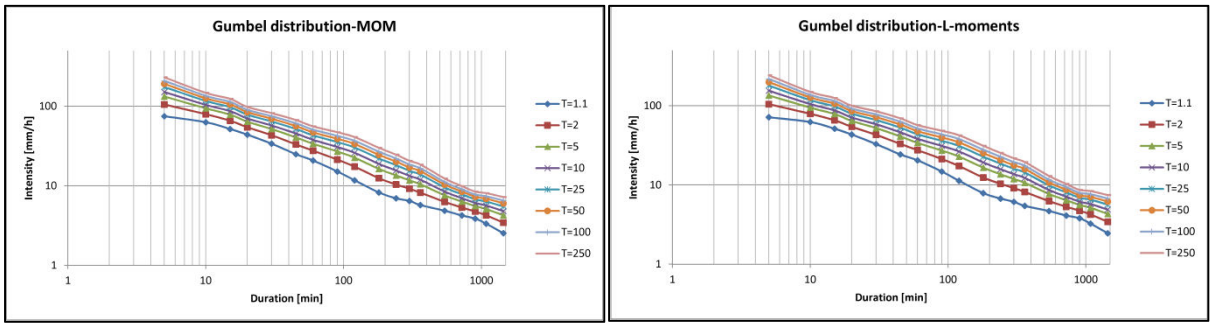

Figure 22: IDF curves for the station Črni vrh nad Polhovim Gradcem when Gumbel distribution is used and parameters are estimated with the method of moments and the method of L-moments (2000-2010)

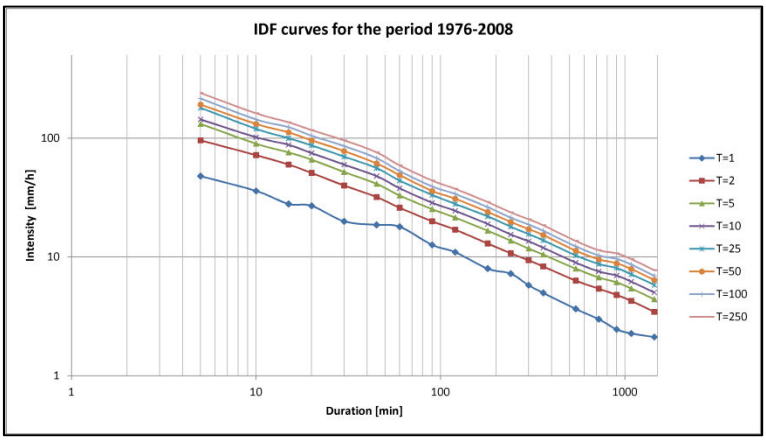

Figure 23: IDF curves for the station Črni vrh nad Polhovim Gradcem when Gumbel distribution is used and parameters are estimated with the method of moments for the period 1976-2008 (ARSO, 2009)

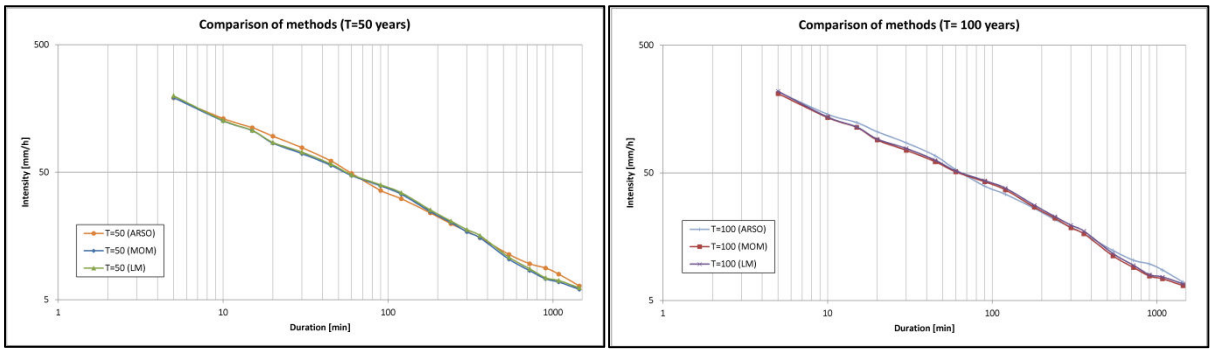

Figure 24: Comparison between IDF curves for the return period 50 and 100 years for the station Črni vrh nad Polhovim Gradcem (Gumbel distribution function)

If IDF curves from stations Ljubljana-Bežigrad and Črni vrh are compared, we can see that for the station Ljubljana higher intensities at shorter rainfall durations were calculated, however in the case of longer rainfall durations the station Črni vrh gave higher intensities (Fig. 18 and

22). These conclusions apply for both parameter estimation techniques (method of moments and method of L-moments) for Gumbel distribution function.

Intensity-duration-frequency curves for the station Dvor are shown in Fig. 25 and 26 (period 2002-2012). Data with ½ hour time step was used for IDF curves construction. In the case of IDF curves from the station Dvor smaller intensities were calculated as in the case of the station Ljubljana for all values of rainfall durations (Gumbel distribution). For shorter durations the station Dvor gave higher intensities as the station Črni vrh, however for longer durations the station Črni vrh gave higher intensities as the Dvor station (Gumbel).

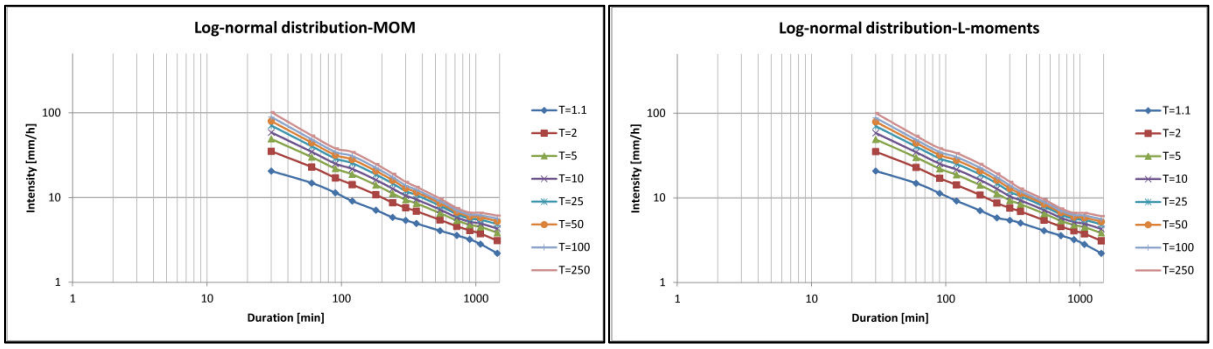

Figure 25: IDF curves for the station Dvor when log-normal distribution is used and parameters are estimated with the method of moments and the method of L-moments (2002-2012)

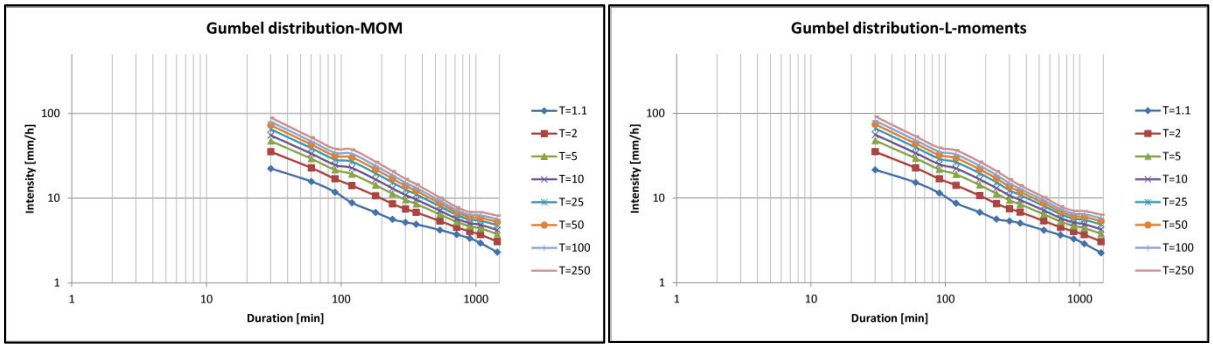

Figure 26: IDF curves for the station Dvor when Gumbel distribution is used and parameters are estimated with the method of moments and the method of L-moments (2002-2012)

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