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Investigation of Trends, Temporal Changes in Intensity-Duration-Frequency (IDF) Curves and Extreme Rainfall Events Clustering at Regional Scale Using 5 min Rainfall Data

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Abstract: High-frequency rainfall data is needed in different practical hydrologic applications, such as the construction of the intensity-duration-frequency curves (IDF). This paper presents an investigation of trends (station-wise and regional) for several rainfall durations that were constructed based on the 5 min rainfall data. Moreover, changes in IDF results for two 22-year sub-samples were also analyzed. Additionally, changes in extreme events clustering at the regional scale were also analyzed. Ten rainfall stations (44 years of data 1975–2018) located in Slovenia (central EU, approx. 20,000 km^2) were used in this study. Results indicate that no clear pattern in the detected trends can be found based on the analyzed stations. However, all the statistically significant trends at the significance level of 0.05 for the 5 min rainfall data were negative. Moreover, regional trends for this duration were also statistically significant. The changes in the design rainfall events between two equal sub-samples (1975–1996, 1997–2018) were between −30% and 60%. The investigation of changes in extreme rainfall event clustering indicated that extreme 5, 30, and 60 min events could more frequently occur a few days earlier in spring or summer compared to the past period. On the other hand, longer duration events (i.e., 360 and 720 min) tend to more frequently occur a few days later in autumn compared to the past. In most cases, changes are not statistically significant.

Keywords: trends; high-frequency data; IDF; clustering; 5 min data; regional scale; extreme events

1. Introduction

Different hydrologic products can be derived based on the high-frequency rainfall data, such as 5 min rainfall data. Intensity-duration-frequency (IDF) curves are an example of such a product that is used as one of the inputs in engineering applications for the design hyetograph definition or rational equation (e.g., [1]). Therefore, knowledge about changes in the rainfall processes related to the high-frequency data is important in order to evaluate the validity of the constructed IDF curves and to test if there are any changes in the IDF analysis results when using some additional years (e.g., the last few years). In other words, to test if IDF curves were constructed using data that have stationary characteristics.

Moreover, climate change is expected to lead to more frequent extreme rainfall events, which means that the nonstationary classical approach used for the IDF curves construction should be updated (e.g., [2–4]). Therefore, many studies have analyzed changes in extreme rainfall events. For example, Madsen et al. [2] reviewed studies that investigated trends in the extreme precipitation in Europe. However, it should be noted that not all studies included in the review [2] used high-frequency rainfall data. Hernebring [5] compared IDF curves (i.e., from 5 min to 24 h) constructed for different periods based on rainfall data from 15 stations in Sweden [2]. Results indicated that no trend could be detected in the IDF curves [2,5]. Moreover, studies that investigated changes in the IDF curves in Denmark found an approx. 10% increase in the IDF curves for the return period of about 10 years and the rainfall duration between 30 min and 3 h [2,6]. Similarly, Pashiardis [7] also found an increase in the extreme rainfall intensities when analyzing rainfall duration between 5 min and 2 h [2]. Furthermore, an increase in the extreme precipitation was also found by [8] when analyzing a more than 100-year rainfall series from a Belgium rainfall station [2]. Ganguli and Coulibaly [3] found that for a smaller return period, differences in values between IDF curves constructed using stationary and nonstationary approaches were up to 7%, while for longer recurrences intervals (50–100 years), these differences were between 2% and 44%. Moreover, also for other continents, no clear pattern in rainfall extreme trends could be detected so far. Soro et al. [9] found no significant positive trend in Côte d'Ivoire based on the analyses of sub-hourly and sub-daily rainfall data. Also, Mekis et al. [10] found no consistent trend in heavy rainfall events when analyzing more than 200 stations in Canada. Similar results were obtained by Shephard et al. [11] when performing a single station analysis; however, trends that are significant were found when performing regional trend tests [11].

In the scope of the presented paper, two main hypotheses were investigated. Firstly, extreme rainfall amounts for short durations, such as 5 min or 30 min, are increasing and thus have an impact on the constructed IDF curves. This hypothesis could be determined based on the climate change impact that is expected to lead to an increased frequency of extreme events (e.g., [2,12]). Secondly, extreme events at the regional scale (approx. 20,000 km^2) tend to be less clustered than they were in the past. Climate change is expected to lead to changed seasonal rainfall-runoff dynamics (e.g., [2]). Thus, the main aim of this study was to investigate station-wise (local) and regional changes in the rainfall patterns that could be observed using available high-frequency rainfall data from 10 stations located in Slovenia for the period from 1975 until 2018.

2. Materials and Methods

Figure 1 shows the locations of the 10 selected rainfall stations that were used in this study. All 10 stations have 5 min rainfall data available from 1975 until 2018 (i.e., in total, 44 years). Rainfall was measured using pluviographs. Stations are relatively uniformly located across Slovenia (Figure 1). Most of the stations are located in temperate continental climate (e.g., [13]), while Rateče and Šmartno pri SG stations are located in mountainous climate although these two stations do not have typical mountain characteristics since they are located at a relatively low altitude for the alpine area (Table 1). Table 1 shows some main characteristics of the selected rainfall stations. Rainfall amounts in Slovenia are generally decreasing from west to east, where the mountainous parts at the western part of the country can have more than 3000 mm of rainfall per year (e.g., [14]). On the other hand, annual rainfall amounts at the most eastern part of the country are below 900 mm (Table 1). Some of these stations were recently used in order to investigate trends in rainfall erosivity [15]. The Slovenian Environment Agency provided the 5 min rainfall data and was also responsible for the maintenance of the equipment.

In order to investigate trends and extreme event clustering, we defined two rainfall-data samples. The first was the annual maximum sample, where we selected one maximum extreme rainfall per year (AM), and the second was the annual maximum sample, where we used five maximum rainfall events of each year (AM5). Both samples were constructed for different rainfall durations: 5 min, 30 min, 60 min, 360 min, and 720 min. For the latter four cases, a rolling sum was used in order to calculate the corresponding rainfall amounts. For the 5 min data, we considered that multiple "events" could occur on the same day. For the 30 min, 60 min, 360 min, and 720 min, we used an additional condition that AM5 occurrences within one year cannot occur on the same day. This means that AM5 events in a specific year were unique days. It should be noted that the AM sample is a sub-sample of the AM5 sample.

In order to investigate the presence of trends in the constructed AM and AM5 samples for 10 rainfall stations, we used the Mann-Kendall test. This test is often used in order to detect changes in hydro-meteorological data (e.g., [16–19]). The null hypothesis is that there is no trend in the investigated sample, and the alternative hypothesis is that there is either a positive or negative trend present in the sample (e.g., [15]). Detailed information about the Mann-Kendall test can be found in [16] or [20]. A significance level of 0.05 was used. Additionally, for the AM sample, we also used the regional Mann-Kendall test in order to test the presence of a trend at the regional level. Detailed information about the regional Mann-Kendall test can be found in [21]. In order to conduct the regional Mann-Kendall test program, the R "rkt" package was used [22].

In order to investigate changes in the results of the intensity-duration-frequency (IDF) analyses, we divided 44 years of rainfall data into 2 sub-samples where each sub-sample contained 22 years of data (first sub-sample: 1975–1996; second sub-sample: 1997–2018). For each sub-sample, a classical approach was used to construct the IDF curves described in hydrological textbooks (e.g., [23]). This means that the maximum event of each year was selected for different rainfall durations (i.e., 5, 30, 60, 360, and 720 min), and the Gumbel distribution was used in order to define the relationship between rainfall amount for different rainfall durations and the return period. Parameters of the Gumbel distribution were estimated using the method of L-moments [24,25]. Additionally, we also constructed the confidence intervals for different cases using the parametric bootstrap approach, as described in [26], where 10,000 random realizations were used for each case. The idea was to compare IDF analyses results for the second sub-sample with the first sub-sample, where 5% and 95% confidence intervals were also considered.

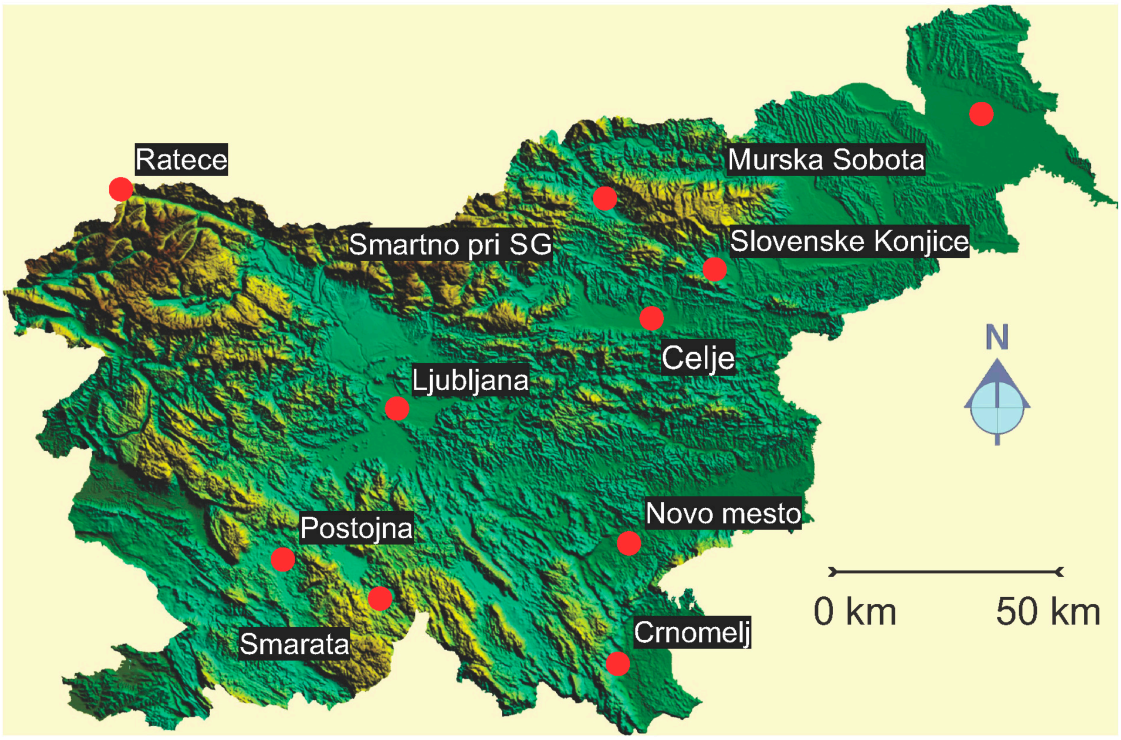

Figure 1. Locations of the rainfall stations used in this study, shown on the topography map of Slovenia.

For the analysis of the extreme events clustering, we used both AM5 and AM samples. For all 10 stations, we counted the number of events that occurred on different Julian dates in the year. The maximum value of such clustering analysis for the 5 min data would be 50 if, for all 10 stations, all 5 values in a year would occur on the same day, which is expected not to be the case (i.e., for the AM5 case). Additionally, the maximum value for the 30 min, 60 min, 360 min, and 720 min rainfall durations was 10 since 10 stations were analyzed and due to the unique day condition that was used when defining the AM5 sample. Based on the constructed AM5 sample, we analyzed changes in the 25%, 50%, and 75% Julian dates. Moreover, the Mann-Whitney test was also used in order to test if there exists a statistically significant difference among the different periods included in the study. For this purpose, we divided 44 years of rainfall data into 4 subsequent sub-samples, each with 11 years of data. This was only done for the AM5 sample. For each sub-sample, we calculated the mean number of occurrences in different Julian dates in these 11 years. In the next step, the Mann-Whitney test was applied for the next combinations: first 11 years–second 11 years; first 11 years–third 11 years; first 11 years–forth 11 years; second 11 years–third 11 years; second 11 years–forth 11 years, and third 11 years–forth 11 years. This procedure was repeated for all five studied rainfall durations. The Mann-Whitney test can be used to test if two sub-samples belong to the same distribution or two sub-samples have different properties, such as mean or variance (e.g., [27]). A null hypothesis, in the case of this test, is that two sub-samples are drawn from the same distribution, and the alternative hypothesis is that two sub-samples do not belong to the same distribution. A significance level of 0.05 was used, and the R software wilcox.test was used for this purpose [28].

Table 1. Main characteristics of the ten analyzed rainfall stations listed based on the longitude coordinate. Mean annual precipitation values are for the period from 1971–2000.

Station	Latitude; Longitude	Altitude (m a.s.l.)	Mean Annual Precipitation (mm)
Rateče	46°29′51″; 13°43′3″	864	1475
Postojna	45°45′59″; 14°11′51″	533	1588
Šmarata	45°41′20″; 14°28′23″	599	1421
Ljubljana	46°3′57″; 14°31′2″	299	1368
Šmartno pri SG	46°29′24″; 15°6′58″	445	1139
Črnomelj	45°33′37″; 15°9′3″	157	1257
Novo mesto	45°48′7″; 15°10′56″	220	1148
Celje	46°14′41″; 15°15′9″	244	1130
Slovenske Konjice	46°20′37″; 15°25′37″	330	1069
Murska Sobota	46°39′9″; 16°11′46″	188	806

3. Results and Discussion

3.1. Trend Detection and Changes in IDF Curves

In the first step of the statistical analyses, the trend detection based on the AM and AM5 samples was carried out using the Mann-Kendall test. Table 2 shows Mann-Kendall test results for the AM sample for different rainfall durations and for 10 analyzed stations, while Table 3 shows results for the AM5 sample. Additionally, Figures 2 and 3 show an example of the AM and AM5 samples for two different stations (i.e., Novo mesto and Celje). Based on the results presented in Table 2, one can notice that only a few detected trends were statistically significant for the AM sample. For the 5 min duration, 7 stations had a negative trend (one statistically significant at the significance level of 0.05) and 3 stations had a positive trend. However, for longer rainfall durations, slightly more trends were positive than negative, while, as already stated, only a few were statistically significant. However, the number of positive trends was only slightly larger. More statistically significant trends were detected for the AM5 sample (Table 3). Similar to the AM sample, all statistically significant trends for the 5 min data were negative. This could indicate that 5 min rainfall amounts are slightly decreasing. Moreover, the same as for the AM sample and AM5 sample, more trends were positive than negative for longer durations, but again, this difference was not large. In general, around 65% and 55% of statistically significant trends were positive for the AM and AM5 samples, respectively. Similar results were also obtained by Petek et al. [15] when analyzing trends in rainfall erosivity, where more trends were positive than negative, but most of the trends were not statistically significant. It can also be seen that the detected trends are very site-specific, and no clear sub-regional pattern in Slovenia could be detected (Tables 2 and 3). Similar results were also obtained by Petek et al. [15], where there was also no clear regional trend in rainfall erosivity in Slovenia. For example, Mekis et al. [10] also could not find a consistent trend in the heavy rainfall events in Canada. Moreover, there are also some differences in the results with respect to the AM and AM5 samples (e.g., more statistically significant trends were observed for the AM5 sample). Similar conclusions were also obtained by Bezak et al. [19], who analyzed trends in different discharge samples using AM and a peaks-over-threshold (POT) approach. Thus, different trend results are obtained for different sample strategies, and hence they have different practical engineering implications, for example, flood risk reduction or stormwater management practices. Moreover, one could argue that 44 years of data is relatively low if one wants to obtain robust trend estimation, and for this purpose, longer data series could be needed [8]. One should bear in mind that such trends, estimated on the basis of a few decadal rainfall data, can be part of multidecadal rainfall oscillations rather than a trend due to climate change [8]. This kind of long series of environmental data are rare (e.g., [29]).

Moreover, a regional Mann-Kendall test was also used in order to detect changes at the regional level. The regional Mann-Kendall test results (i.e., Kendall's tau) were −0.081 (p-value: 0.013), 0.013 (p-value: 0.693), 0.019 (p-value: 0.562), 0.051 (p-value: 0.127), and 0.064 (p-value: 0.052) for the 5, 30, 60, 360, and 720 min durations, respectively. One can notice that only the 5-min duration results were statistically significant, with the selected significance level of 0.05. Trend results for the 5 min duration indicate the presence of a negative trend at the regional level. For longer rainfall durations, the regional Mann-Kendall test results indicate the presence of a positive but not statistically significant (at 0.05 level) trend. Similarly, some climate models also indicate an increase in the maximum 1-day precipitation amounts for various regions around the world [30].

Table 2. Mann-Kendall test results for the AM sample. * and ** indicate statistically significant test result (with the 0.05 significance level) that is negative and positive, respectively.

Station	5 min	30 min	60 min	360 min	720 min
Rateče	0.008	0.064	0.058	0.107	0.190
Postojna	−0.126	−0.132	−0.434	−0.044	−0.028
Šmarata	−0.0735	0.040	0.044	0.005	0.086
Ljubljana	−0.009	0.048	0.022	0.074	0.065
Šmartno pri SG	−0.020	0.072	0.082	0.098	0.052
Črnomelj	−0.147	−0.075	−0.088	−0.124	−0.086
Novo mesto	−0.247 *	−0.168	−0.221 *	−0.085	0.036
Celje	0.106	0.252 **	0.254 **	0.180	0.059
Slovenske Konjice	−0.325	−0.103	−0.086	0.015	−0.012
Murska Sobota	0.012	0.132	0.172	0.290 **	0.292 **

Table 3. Mann-Kendall test results for the AM5 sample. * and ** indicate statistically significant test result (with the 0.05 significance level) that is negative and positive, respectively.

Station	5 min	30 min	60 min	360 min	720 min
Rateče	−0.047	0.051	0.026	0.047	0.146 **
Postojna	−0.227 *	−0.119 *	−0.121 *	0.064	0.106 **
Šmarata	−0.006	0.090	0.075	0.094 **	0.139 **
Ljubljana	−0.096 *	0.021	0.015	−0.001	0.044
Šmartno pri SG	−0.058	0.026	0.020	0.087	0.081
Črnomelj	−0.025	−0.045	−0.037	−0.031	0.035
Novo mesto	−0.192 *	−0.078 *	−0.104 *	−0.033	0.030
Celje	0.071	0.141 **	0.154 **	0.143 **	0.109 **
Slovenske Konjice	−0.212 *	−0.113 *	−0.085	−0.022	−0.042
Murska Sobota	0.027	0.164 **	0.147 **	0.194 **	0.263 **

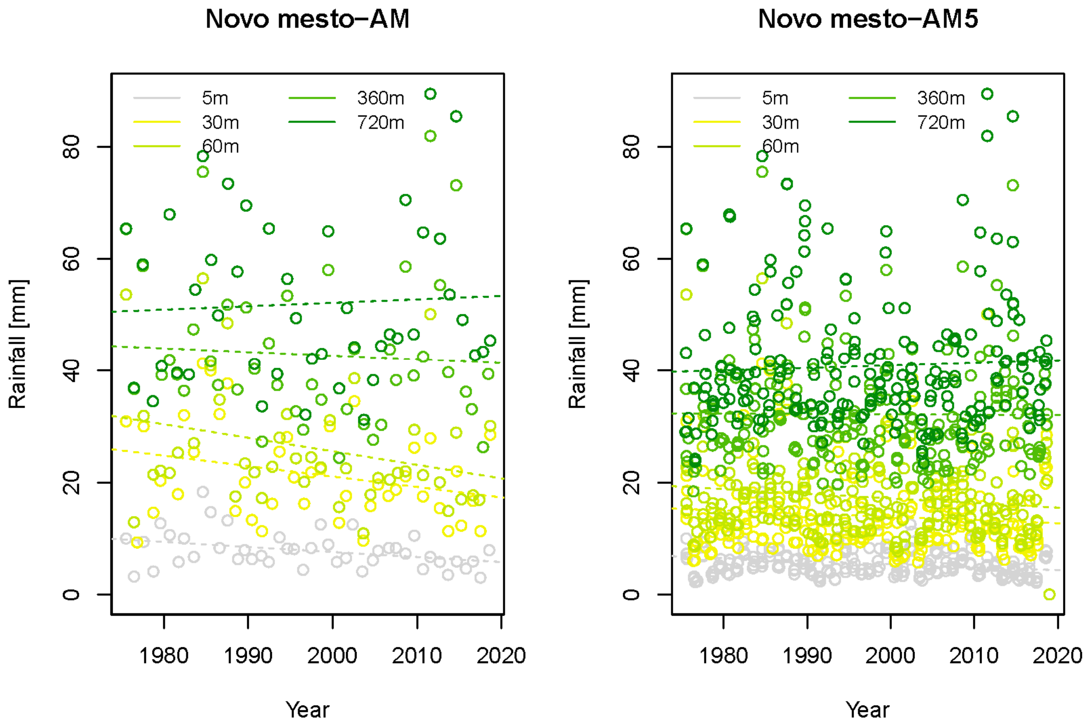

Figure 2. AM and AM5 samples for different rainfall durations (i.e., 5, 30, 60, 360, and 720 min) for the Novo mesto station. Linear trend lines are also added to the plot.

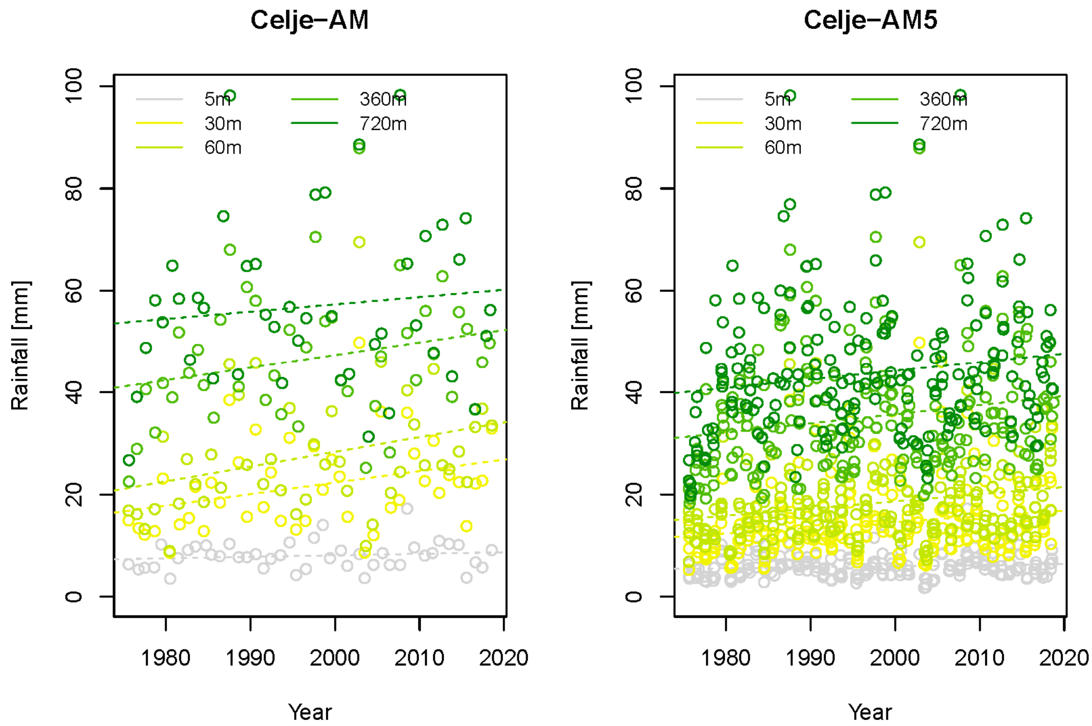

Figure 3. AM and AM5 samples for different rainfall durations (i.e., 5, 30, 60, 360, and 720 min) for the Celje station. Linear trend lines are also added to the plot.

In the next step of the study, we also investigated changes in the results of the IDF analyses using two sub-samples (i.e., first and second 22 years of the data from 1975 until 2018). Figure 4 shows the relative change of the IDF analyses results for different durations and 10 and 100 years return period for the 1997–2018 period compared to the 1975–1996 period. The presented results are relatively consistent with the trend results, where for 5 min durations, there are more rainfall stations, with a decrease in the design rainfall amounts for this duration both for 10 and 100 years return period than for other rainfall durations (Figure 4). For longer rainfall durations than 5 min, there are less stations that have a negative change in the design rainfall amounts. The most extreme negative change does not exceed −30% for the 1997–2018 period compared to the 1975–1996 period. On the other hand, the increase in the design rainfall values is much higher and, in some cases, reaches up to 60%. This kind of large increase in the IDF curves, as shown in Figure 4, would also have a potentially significant impact on the cost of the engineering design [6]. However, no consistent pattern could be detected at the regional level when looking at Figure 4. Similar results were obtained by Hernebring [5] when analyzing IDF curves in Sweden [2]. Moreover, the Gumbel distribution was selected for the IDF analysis because it is also used by the Slovenian Environment Agency in order to derive IDF curves for Slovenia. It should be noted that the distribution and parameter estimation method selection has an impact on the results, and the results would not be the same if other methods were used. For example, [31] found that differences in the design discharge with the 100-years return period using different distribution and parameter estimation methods were up to 25%.

3.2. Clustering of Events

In the second part of the study, we analyzed the clustering of the events for different rainfall durations using the methodology described in Section 2. Figures 5–7 show the clustering analysis results for the 5 min, 60 min, and 720 min rainfall duration. Additionally, Tables 4 and 5 present an overview of the clustering analysis for all five rainfall durations that were considered in this study for the AM and AM5 samples. One can notice that for the 5 min duration, the median occurrence date is approx. the end of July, while the 25% and 75% dates are approx. at the start of July and the end of August both for the AM5 and AM samples. Furthermore, it can be seen that in 44 years, the median timing for the 5 min duration has shifted for 8.1 and 5.3 days towards spring for the AM5 and AM samples, respectively (Table 4). Similar results were also obtained for the 30 min and 60 min rainfall durations, where the shifts towards spring were even smaller than for the 5 min duration (Tables 4 and 5). Moreover, longer duration extremes are slightly shifted towards the autumn period for AM5 and AM samples and have generally larger changes in the median Julian date occurrence than shorter duration extremes, especially for the AM5 case. We also calculated Kendall's correlation coefficients between stations for the AM5 sample. Results indicate that for longer rainfall durations, the mean correlation among stations is generally higher than for the shorter rainfall durations (e.g., mean correlation for the 5 min and 720 min durations were 0.26 and 0.32, respectively). This could be somehow expected because extreme 5 min rainfall amounts in Slovenia are most often caused by summer thunderstorms (Figure 5) that are often very localized, while rainfall extremes of longer duration could also be a consequence of the longer duration frontal precipitation that can occur practically in any part of the year (Figure 7). Based on the presented results, one could argue that longer duration events could now more frequently occur also in winter and spring, which leads to the spread in the 25% and 75% levels shown in Figure 7. We additionally tested the significance of changes in the 25%, 75%, and 75% − 25% (i.e., spread) cases for the AM and AM5 for all rainfall durations. Using the Mann-Kendall test, we tested if there was a significant trend present in this data. Statistically significant results with the significance level of 0.05 were obtained for the 75% and 75% − 25% data for the 720 min for the AM5 case. For all other cases, the results were not statistically significant with the selected significance level. This means that for the longer rainfall durations (i.e., 720 min), the spread in the clustering is significantly larger compared to the past, especially due to more frequent occurrence of events in (late) autumn (Figure 7). For other rainfall durations and all AM cases, there is no significant difference between the present and past periods.

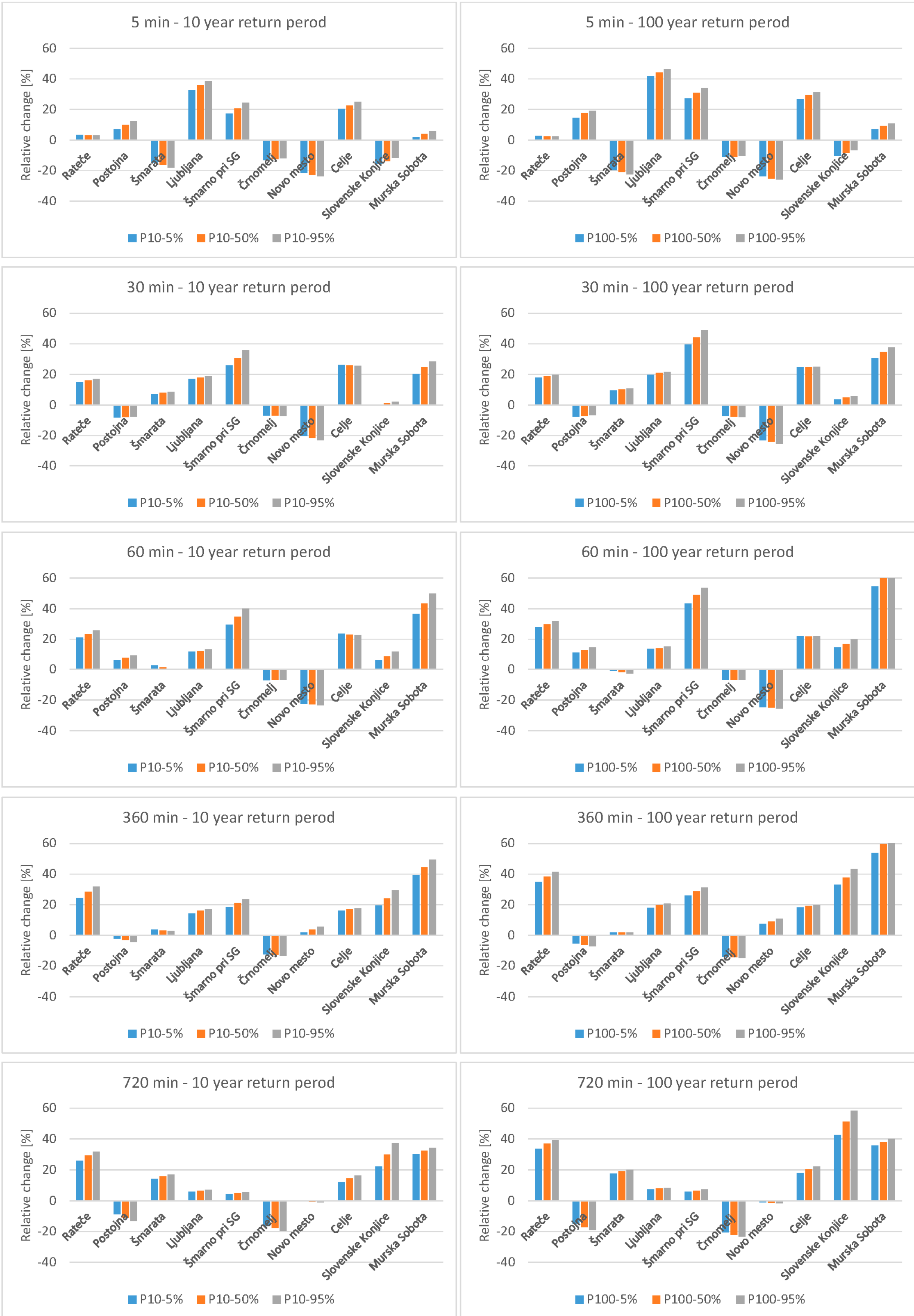

Figure 4. Relative changes in the intensity-duration-frequency (IDF) analysis results for the period from 1997–2018 (second 22 years) compared to 1975–1996 (first 22 years) for different rainfall durations and for the 10 and 100-years return period. The 5%, 50% (median), and 95% values are shown.

Additionally, we compared different 11-year periods using the Mann-Whitney test, and we were not able to detect any statistically significant test result based on the selected significance level of 0.05. The different combinations listed in Section 2 were tested. This means that according to the selected test, there is no statistically significant difference in the distribution of the extreme rainfall events clustering through the year. This applies to all tested rainfall durations. Comparing the AM and AM5 samples, one can notice that the 25% and 75% interval for shorter durations is a bit smaller for the AM sample compared to the AM5 sample (Table 5). Moreover, for longer rainfall durations, median AM values are slightly larger than the median AM5 values (Table 5). Additionally, shifts for the AM for longer rainfall durations are smaller compared to the AM5 sample. Changes in rainfall timing also affect flood timing. For example, Blöschl et al. [32] found a clear pattern in European flood timing.

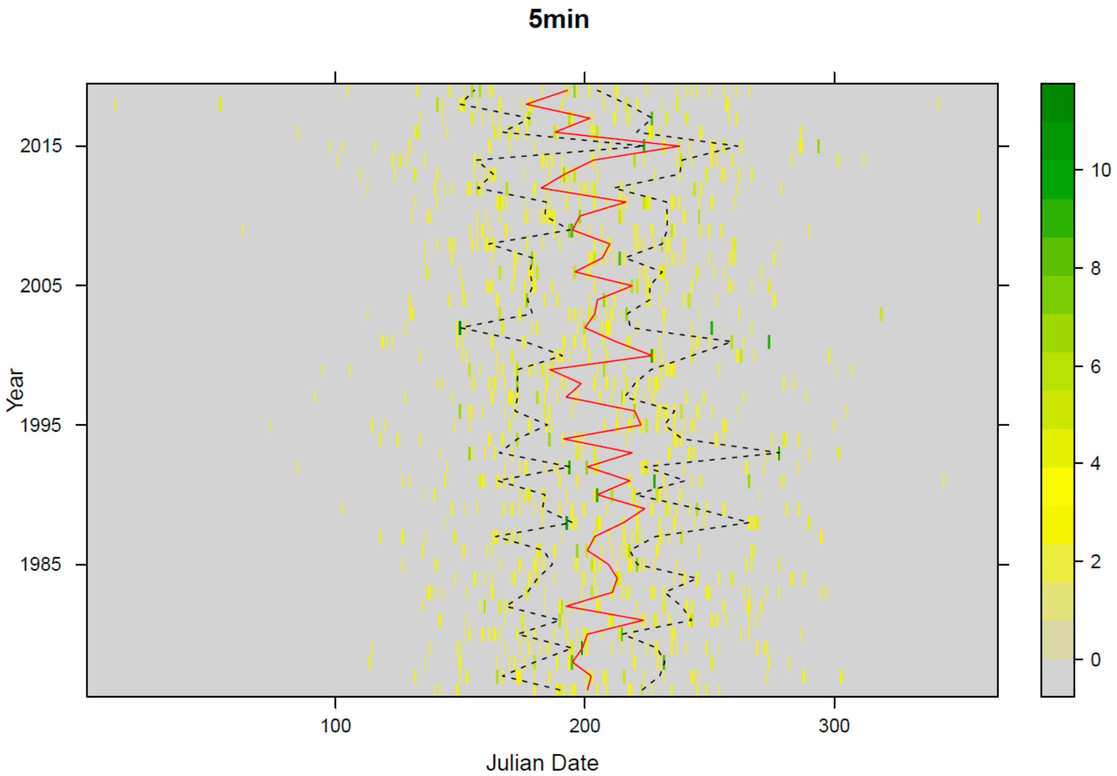

Figure 5. Clustering of the AM5 events for the 5 min rainfall duration. Red line shows the median Julian date and dotted black lines show 25% and 75% Julian date.

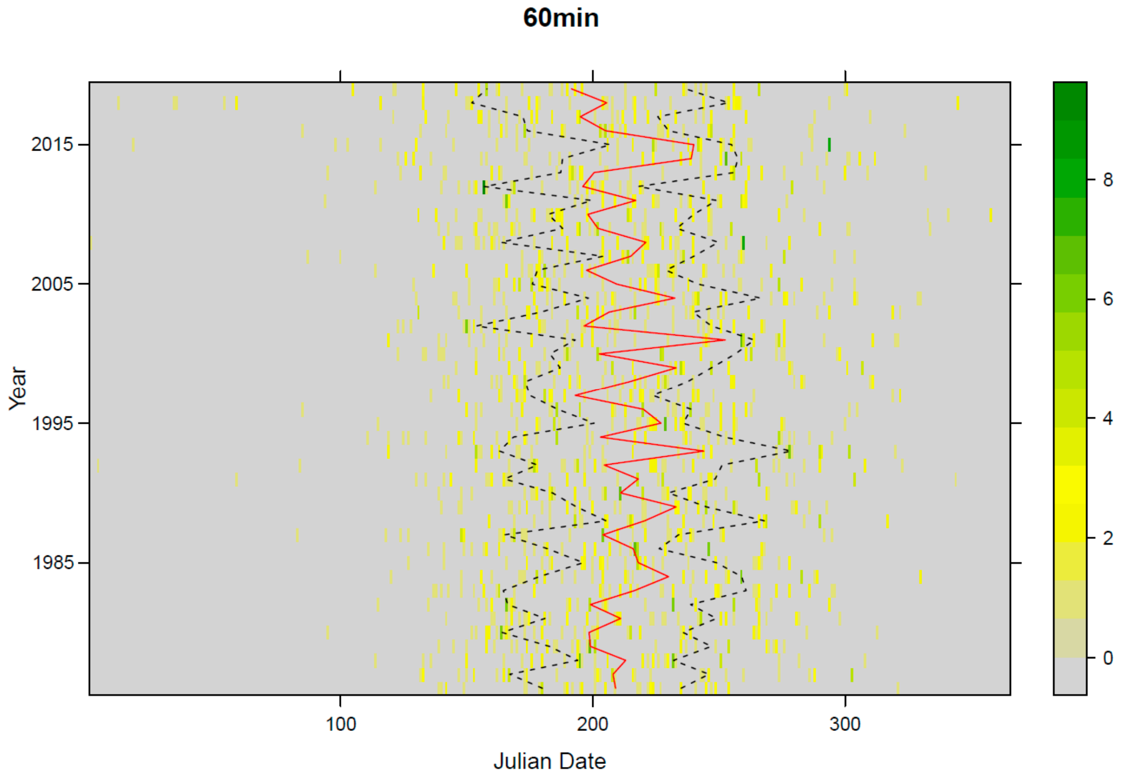

Figure 6. Clustering of the AM5 events for the 60 min rainfall duration. Red line shows the median Julian date and dotted black lines show 25% and 75% Julian date.

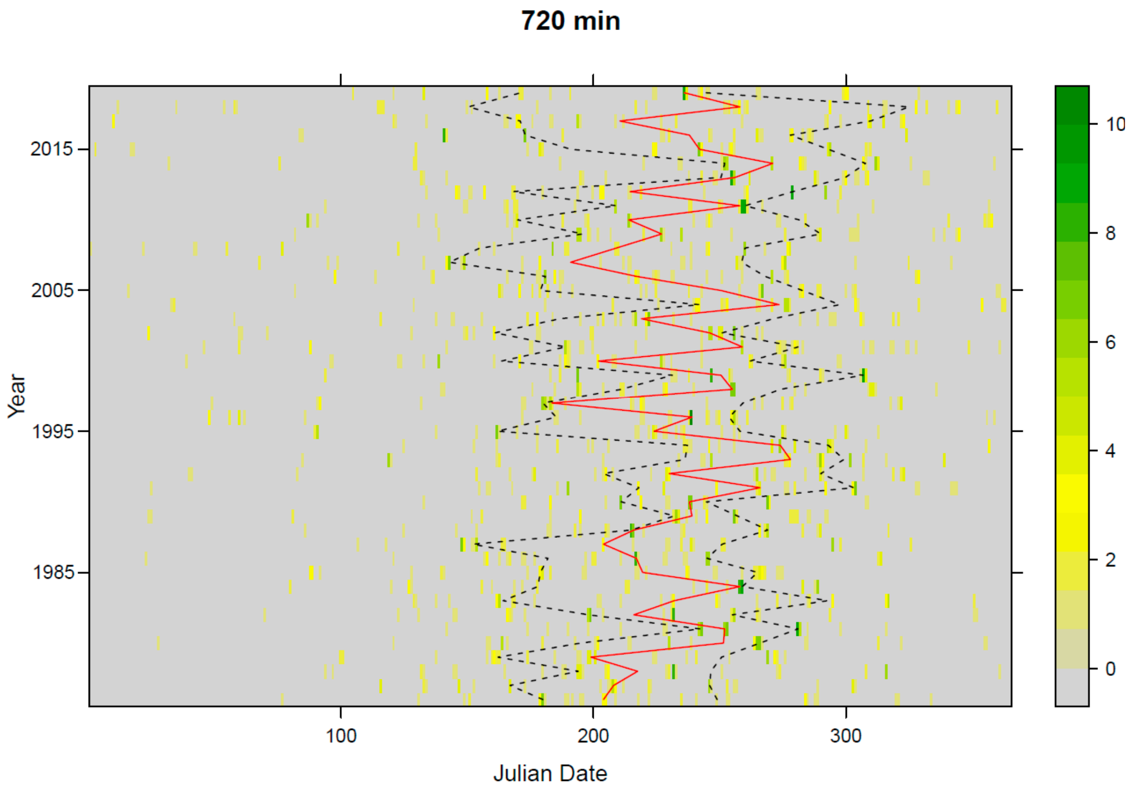

Figure 7. Clustering of the AM5 events for the 720 min rainfall duration. Red line shows the median Julian date and dotted black lines show 25% and 75% Julian date.

Table 4. Slope of the linear trend lines fitted to the 25%, 50%, and 75% data samples multiplied with the number of years in the sample. Thus, results indicate the change in the number of Julian days for the entire 44 years.

	AM5 (n = 220 Events)			AM (n = 44 Events)		
Rainfall Duration	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**
5 min	−11.4	−8.1	−7.1	−11.7	−5.3	−6.3
30 min	−6.9	−4.7	−4.5	−7.0	0.6	0.9
60 min	−0.6	−3.1	−2.5	−9.1	−0.3	12.7
360 min	6.4	14.2	21.8	−13.6	3.3	8.9
720 min	−6.4	14.7	40.4	−9.6	2.9	4.6

Table 5. Intercept of the linear trend lines fitted to the 25%, 50%, and 75% data. Thus, results indicate the Julian date at the start of the investigation period (i.e., year 1975).

	AM5 (n = 220 Events)			AM (n = 44 Events)		
Rainfall Duration	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**
5 min	182	209	236	186	206	231
30 min	180	211	240	186	206	230
60 min	180	214	246	191	214	231
360 min	186	226	255	214	233	257
720 min	195	226	256	213	238	264

4. Conclusions

This study presents the results of the trend analysis (station-wise and regional), IDF analyses results, and clustering of the extreme rainfall events investigation based on the 5 min rainfall data for 10 rainfall stations in Slovenia that have data available from 1975 until 2018. Based on the 5 min rainfall data, 30 min, 60 min, 360 min, and 720 min rainfall was also calculated. AM and AM5 samples were considered. Based on the presented results, the following conclusions can be made:

- All the statistically significant trends for the 5 min rainfall data are negative for the AM and AM5 samples. Among all statistically significant trends at the 5% level for all rainfall durations, around 65% and 55% of the trends are positive for the AM and AM5 samples, respectively. However, only a few detected trends were statistically significant. This means that according to the analyzed data, extreme rainfall events are not significantly more intense than they were in the past decades.
- For the AM and AM5 samples, there is no clear pattern in the calculated trends for all five rainfall durations, which means that no uniform trend could be determined. Moreover, calculated trends are also very site-specific, and no clear regional trend could be identified for all analyzed rainfall durations.
- The regional Mann-Kendall test results indicate that for the 5 min rainfall duration, the detected trend at the regional level is negative and statistically significant with the selected significance level of 0.05. For longer rainfall durations, trend results are positive, but not statistically significant with the selected significance level.
- The comparison of the results of the IDF analyses for two subsequent sub-samples (first and second 22 years) indicate that changes in the results are relatively consistent with the trend analysis. However, for more stations, we have detected an increase in the design rainfall values for the 1997–2018 period compared to the 1975–1996 period. The maximum change was up to 60%. The largest negative change did not exceed 30%.
- The median Julian date occurrence of the AM5 events for the 5 min data is mid-July, while for longer rainfall durations, it is mid-August.
- Longer rainfall duration extremes are shifting toward the (late) autumn period, while shorter rainfall durations are occurring a few days earlier compared to the past decades.

- The spread in the occurrence of the longer duration events is larger than it was in the past decades, which means that extreme longer duration events can now more frequently occur also in winter and spring periods compared to the past decades. However, the spread was only statistically significant for the 720 min duration for the AM5 case. For other cases, there are no significant differences between the past and present. Furthermore, similar analyses could also be carried out for longer duration events.
- Moreover, Mann-Whitney test results indicate that there is no statistically significant difference among four 11-year periods (i.e., mean number of occurrences for different Julian dates).

Moreover, based on the above points, we can conclude that extreme rainfall amounts for short durations, such as 5 min or 30 min, are not purely increasing, and that extreme events at the selected regional scale are, especially for longer rainfall durations, slightly less clustered than they were in the past. However, test results indicate no statistically significant differences among different periods.

The presented results are valid for Slovenia, but, nevertheless, the methods and statistical analyses presented in this study can be used for other regions and similar hypotheses to be tested. The choice of rainfall data used in such hydrologic statistical analyses is to be carefully made in order to fulfill specific engineering applications and their needs. A general impression about a clear positive trend in the number and severity of extreme rainfall events due to climate change should be rigorously tested and also put into a larger regional context.

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