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DOES IT REALLY RAIN MORE OFTEN ON WEEKENDS THAN ON WEEKDAYS? A CASE STUDY FOR SLOVENIA

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Climate conditions in Slovenia are changing as indicated by an increasing number of extreme events.

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Does it really rain more often on weekends than on weekdays? A case study for Slovenia

ABSTRACT: The article presents the results of precipitation and aerosol (PM_{10}) data analyses in Slovenia. Analyses of rainfall data for some areas of Slovenia, such as the Ljubljana Basin, Zasavje, Šalek Valley, Celje Basin, and the coastal area, suggest that rain on the weekend is more frequent than on weekdays; nevertheless, these deviations are not statistically significant. A comparison of three separate decades showed that the pattern of weekly rainfall in the 21st century is different than that in the last period of the 20th century. The weekly cycle of PM_{10} for the considered stations is quite similar to that of some of the more contaminated regions of the world. Furthermore, the connection between PM_{10} and precipitation in most of the analyzed cases was statistically significant.

KEY WORDS: precipitation, air pollution, weekly precipitation cycle, PM_{10}, statistical tests, Slovenia

Ali res pogosteje dežuje ob koncih tedna kot med tednom? Analiza za Slovenijo

POVZETEK: Prispevek prikazuje analizo podatkov o padavinah in delcih v zraku (PM_{10}). Za nekatera območja v Sloveniji, kot so Ljubljanska kotlina, Zasavje, Šaleška dolina, Celjska kotlina ter obalno območje, je glede na analizirane podatke o padavinah značilno, da večkrat dežuje ob koncih tedna kot med tednom, vendar odstopanja niso statistično značilna. Primerjava treh desetletnih obdobij pokaže, da je vzorec tedenske razporeditve padavin v 21. stoletju drugačen kot v zadnjem obdobju 20. stoletja. Tedenski cikel delcev PM_{10} na obravnavanih merilnih mestih je precej podoben kot v nekaterih bolj onesnaženih regijah sveta. Poleg tega je povezava med delci PM_{10} in količinami padavin v večini analiziranih primerov statistično značilna.

KLJUČNE BESEDE: padavine, onesnaženje zraka, tedenska razporeditev padavin, PM_{10}, statistični testi, Slovenija

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1 Introduction

We often have the feeling that it rains more frequently during weekends when the majority of people are not working. Since the beginning of the 20th century, the modern society has mostly adopted a 5-day work week cycle, and Saturday and Sunday are considered as non-working days (Arts 2008; Cerveny and Balling 1998). On these days sunny weather is usually preferred. The theory about the impact of human weekly cycle on the rainfall pattern has a logical explanation and was the topic of many studies (e.g., Gong et al. 2007; Shultz et al. 2007; Bell et al. 2008; DeLisi et al. 2011; Stjern 2011). The theory is related to anthropogenic influence that became more pronounced over the last century with daily commuting and development of heavy industry (Gong et al. 2007; Arts 2008; Bell et al. 2008; DeLisi et al. 2011; Stjern 2011). Higher air pollution may increase the amount of aerosols in the air, which influences the probability of rainfall occurrence (Bell et al. 2008). This means that the accumulation of small solid particles (PM_{10}) in the air, which may increase during the weekends, could trigger the changes in the atmospheric circulations that can result in non-uniform weekly rainfall patterns (Gong et al. 2007).

Several studies dealing with this phenomenon have been carried out in recent years (Bell et al. 2008; DeLisi et al. 2011; Gong et al. 2007; Seibert et al. 2013; Shultz et al. 2007). In most of these studies, data on rainfall and PM_{10} particles (particles with a diameter up to 10 μm) were used, and their conclusions depended on the location of the study and the selected data. Shultz et al. (2007) analyzed precipitation records from 219 stations in the United States with more than 40 years of measurements. They found that neither the amount nor the occurrence of rainfall differs statistically significantly from the uniform distribution as a function of the day of the week. Similar conclusions were drawn also by DeLisi et al. (2011) who analyzed data from seven stations along the east coast of the United States. Furthermore, Seibert et al. (2013) analyzed data from 376 stations in Switzerland and the main conclusion was that in some areas and on particular days of the week there was 10 to 20% more rainfall than on other days. Moreover, Gong et al. (2007) found that the significant weekly cycle of PM_{10} and, consequently, rainfall is characteristic of urban regions in China, one of the most polluted areas in the world. In Slovenia, no study about weekly rainfall patterns has been conducted so far. However, some analyzes of seasonal characteristics of rainfall and discharge series were performed (Srebernič 2005; Bezak et al. 2015a, 2015b).

The main aim of this study was to test if it really rains more often on weekends than on weekdays in Slovenia, and to find out which parts of Slovenia are those where rainfall distribution during the week is significantly non-uniform. Other aims of the study were as follows: (i) to analyze the weekly rainfall distribution in Slovenia and the differences among seasons, (ii) to compare weekly rainfall patterns among various 10-year periods (1980–2014), and (iii) to analyze the concentration of PM_{10} particles in the air and how this relates to the weekly rainfall pattern.

2 Data and methods

Daily rainfall data from 13 rainfall stations in Slovenia (Table 1) from 1980 onwards were used to analyze the weekly rainfall pattern (ARSO 2015). Any day with at least 0.1 mm of recorded rainfall was defined as a rainy day. The complete daily rainfall series was divided into 4 periods, i.e., 1980–1989, 1990–1999, 2000–2009, and 2010–2014, which were compared in the study. Furthermore, the differences in the seasonal pattern of the weekly rainfall distribution were analyzed. December, January, and February were assumed as winter months; March, April, and May as spring months; June, July, and August as summer months; and September, October, and November as autumn months. Moreover, PM_{10} particles were analyzed in this study (the data were provided by the Slovenian Environment Agency; Table 2). Figure 1 shows the location of the considered stations where rainfall and PM_{10} particles were recorded.

Various parametric and nonparametric tests can be used to detect the changes in the time series (e.g., Kendall 1975; Maidment 1993; Esterby 1996; Rao and Hamed 2001; Kundzewicz and Robson 2004; Khaliq et al. 2009; Bezak et al. 2015a). The nonparametric χ^2 test (Haan 2002) was used in the study to test the hypothesis about a non-uniform rainfall pattern. The main advantage of the χ^2 test is that it can be applied to both continuous and discrete variables (Haan 2002) and is mostly used for hypothesis testing about distribution of samples (Turk 2012). In our study the following null hypothesis was used (H_0): rainfall distribution during the week is uniform, while the alternative hypothesis was (H_A): rainfall distribution

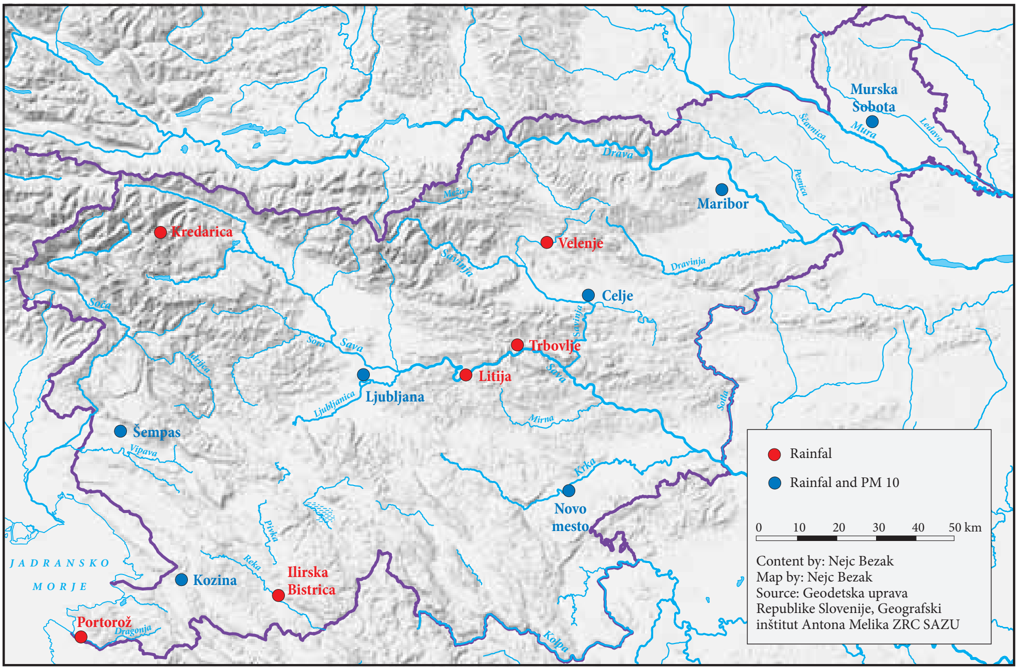

Figure 1: Location of the selected stations.

Table 1: Considered rainfall stations.

Station name	Station type	Study period
Ljubljana–Bežigrad	meteorological	1980–2014
Kredarica	meteorological	1980–2014
Maribor–letališče	meteorological	1980–2014
Murska Sobota–Rakičan	meteorological	1980–2014
Celje–Medlog	meteorological	1980–2014
Portorož–letališče	meteorological	1980–2014
Novo mesto	meteorological	1980–2014
Velenje	climatological	1980–2005
Ilirska Bistrica	climatological	1980–1999
Kozina	rainfall	1980–2014
Šempas	rainfall	1980–2014
Litija–Grbin	rainfall	1980–2004
Trbovlje	rainfall	1980–1992

Table 2: Stations with recorded PM_{10} concentrations.

Station name	Station type	Study period
Ljubljana	Urban	2012–2014
Maribor–center	Urban (traffic)	2009–2014
Murska Sobota–Rakičan	Rural	2010–2014
Celje	Urban	2011–2014
Novo mesto	Urban	2010–2014
Koper	Urban	2009–2014
Nova Gorica	Urban	2011–2014

during the week is non-uniform. Data about the number of days with rainfall were normalized against the total number of days. The χ^2 distribution with 6 degrees of freedom was used according to the number of days in the week (7). Furthermore, graphical presentations were used for analyzing the weekly rainfall distribution, where normalized data were shown together with the value of 3 standard deviations. The non-parametric Mann-Whitney test was selected for comparing the various periods. The null hypothesis (H_0) was: the tested samples are drawn from the same distribution, and the alternative hypothesis (H_A) was: the tested samples are not drawn from the same distribution. A significance level of 0.05 was selected. Moreover, critical value U_{krit} was equal to 8 since both samples have 7 elements (H_0 can be rejected if test statistic U is smaller than U_{krit}). Pearson and Spearman correlation coefficients were used to analyze the connection between rainfall and PM_{10} values.

3 Results and discussion

3.1 Weekly rainfall pattern

For 13 rainfall stations in Slovenia (Table 1), the number of rainy days on each day was determined for different periods. Table 3 shows an example of weekly rainfall distribution for station Ljubljana-Bežigrad. Days with the maximum number of rainy days in each period are shown in bold text. Furthermore, the calculated values were normalized and also presented graphically. Figure 2 shows weekly rainfall distribution for different seasons for the Ljubljana-Bežigrad station together with the values of 3 standard deviations. As shown in Figure 2, for the period 1980–1989 Sunday was the day with the maximum number of rainy days for spring, summer, and autumn. Similar results were obtained for both the last period and the entire study period.

Table 3: Weekly distribution of rainy days for different periods for the Ljubljana-Bežigrad station.

Period	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
1980–1989	212	216	211	211	216	215	**238**	1519
1990–1999	220	225	209	**234**	218	216	224	1546
2000–2009	206	**221**	202	198	194	205	210	1436
2010–2014	118	123	114	110	107	119	**128**	819
1980–2014	756	785	736	753	735	755	**800**	5320

The summary of the results of the basic statistical analyses (standard deviation) and the χ^2 test for all analyzed stations are given in Table 4. The days on the weekends with the maximum number of occurrences are indicated in bold text. Table 4 also shows the deviations of the results regarding the (2 and 3 times) standard deviation values. For 10 of 13 analyzed stations, there was at least 1 time period when the maximum number of rainy days was on weekends, particularly at Ljubljana-Bežigrad, Portorož, Velenje, and Trbolje stations. For the Ljubljana-Bežigrad station for 2 of 4 periods the weekends were found as the rainiest. In the first period (1980–1989), the rain on Sundays was 9.7% more frequent than on other days. Sunday was also the rainiest day for the entire period (1980–2014) and the number of rainy days was 5.3% more frequent. For the Portorož station, for 3 of 4 time periods the deviation exceeded the value of 2 standard deviations and, in the last study period, even the value of 3 standard deviations. The rainfall in the first, second and fourth study periods was 6.7%, 6.9%, and 11.2%, respectively, more frequent on Sundays than on other days of the week. Similar results were obtained for the entire study period where the percentage was 4.8. Sunday was the day with the maximum number of rainy days also for the Velenje station for the period 1980–1989 where the deviation exceeded the value of 3 standard deviations. In this period, the rain on Sunday was 9.0% more frequent that on other days. For the Trbovlje station, the rain on Sunday was by 4.6% and 4.1% more frequent than that during other days for the periods 1980–1989 and 1980–1992, respectively. These results are in accordance with other studies that concluded that non-uniform weekly rainfall distribution is more explicit for more polluted areas (Gong et al. 2007; Stjern 2011). The Šalek Valley and Zasavje are regarded as areas with relatively high pollution, Ljubljana Basin is the largest urban area in Slovenia, and the pollution at the Portorož station can be attributed to the influence of Trieste, Italy.

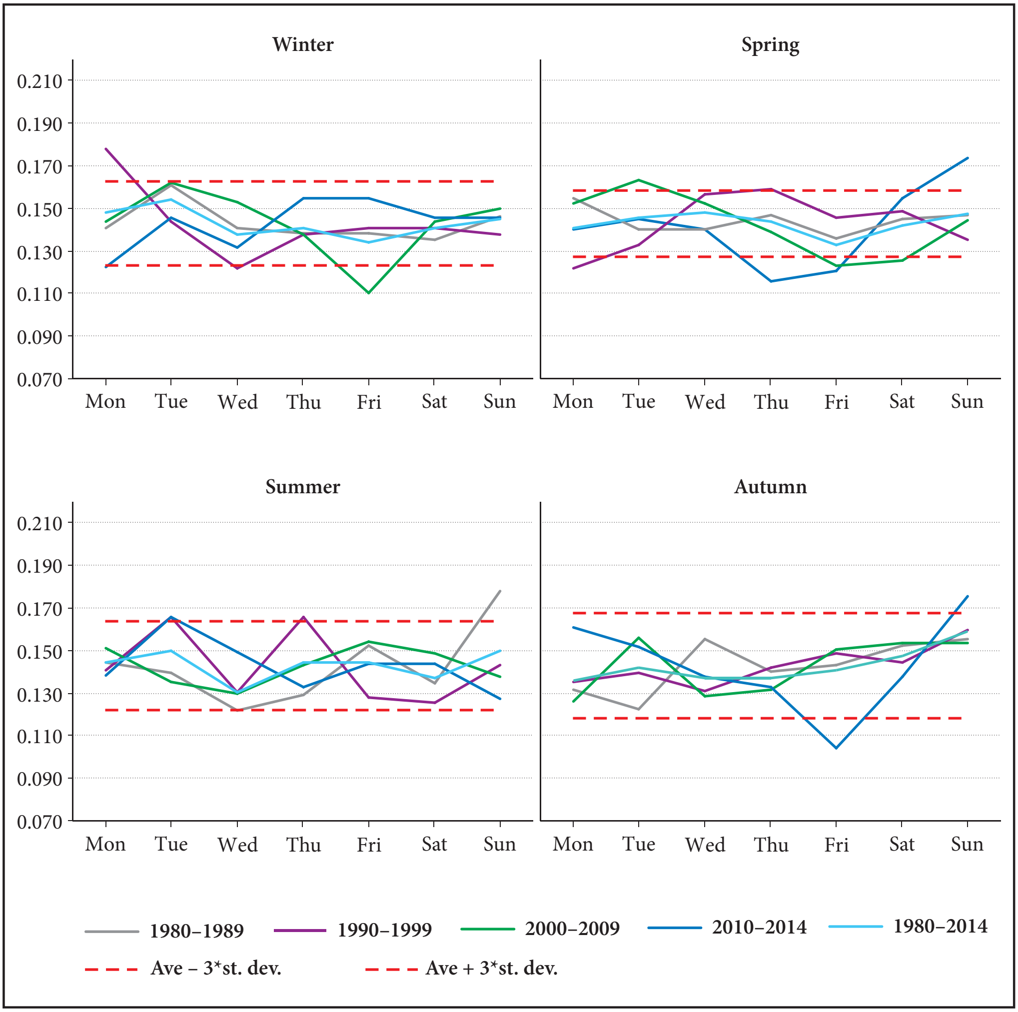

Figure 2: Normalized values of rainy days for different seasons for the Ljubljana-Bežigrad meteorological station.

These results are, to some extent, similar to those derived for Switzerland where in some cases the deviations were up to 20% (Seibert et al. 2013). Furthermore, the χ^2 test was applied to test whether the null hypothesis could be rejected with a significance level of 0.05. The null hypothesis could not be rejected for any of the 13 analyzed stations and for any of the study periods. Moreover, the same test was applied to compare the distribution of rainy days on weekends and on weekdays (H_0: on weekends and on weekdays the frequency of rainy days is the same; H_A: on weekends and on weekdays the frequency of rainy days is not the same), but, for all the considered stations and periods, the null hypothesis could not be rejected with the selected significance level (Plečko 2015).

3.2 Changes in the rainfall pattern among different periods

In the next step, we tested if the weekly rainfall pattern changed from 1980 to 2009. The Mann-Whitney test was applied and the following 10-year periods were tested: 1980–1989 and 1990–1999; 1990–1999 and 2000–2009; and 1980–1989 and 2000–2009. We compared the weekly rainfall pattern for the total period

Table 4: Summary of the results for the weekly rainfall pattern for the analyzed stations in Slovenia and the calculated p-values of the χ^2 test.

Station	Period	Day with max. number of occurrences	Deviation (2 times the standard deviation)	Deviation (3 times the standard deviation)	p-value
Ljubljana	1980–1989	**Sunday**	YES	NO	0.87
	1990–1999	Thursday	NO	NO	0.95
	2000–2009	Tuesday	YES	NO	0.90
	2010–2014	**Sunday**	YES	NO	0.84
	1980–2014	**Sunday**	NO	NO	0.59
Maribor	1980–1989	**Sunday**	NO	NO	0.91
	1990–1999	Tuesday	NO	NO	0.83
	2000–2009	Tuesday	YES	NO	0.66
	2010–2014	Tuesday	YES	NO	0.91
	1980–2014	Tuesday	NO	NO	0.29
Murska Sobota	1980–1989	**Sunday**	NO	NO	0.94
	1990–1999	Tuesday	NO	NO	0.79
	2000–2009	Tuesday	NO	NO	0.88
	2010–2014	Tuesday	YES	NO	0.98
	1980–2014	Tuesday	NO	NO	0.68
Celje	1980–1989	**Saturday**	YES	NO	0.96
	1990–1999	Thursday	NO	NO	0.75
	2000–2009	Monday	YES	NO	0.92
	2010–2014	**Sunday**, Monday	YES	NO	0.81
	1980–2014	**Saturday**	NO	NO	0.74
Novo mesto	1980–1989	Tuesday	YES	YES	0.84
	1990–1999	Friday	YES	NO	0.79
	2000–2009	Tuesday	YES	NO	0.95
	2010–2014	Monday	YES	YES	0.89
	1980–2014	Tuesday	NO	NO	0.92
Kozina	1980–1989	Tuesday	NO	NO	0.99
	1990–1999	Thursday	YES	NO	0.98
	2000–2009	Tuesday	YES	YES	0.80
	2010–2014	**Sunday**	YES	YES	0.88
	1980–2014	Tuesday	NO	NO	0.91
Šempas	1980–1989	Tuesday	YES	NO	0.89
	1990–1999	Thursday	YES	YES	0.74
	2000–2009	Monday	YES	NO	0.82
	2010–2014	**Sunday**	YES	YES	0.57
	1980–2014	**Sunday**	NO	NO	0.89
Kredarica	1980–1989	Monday	YES	NO	0.52
	1990–1999	Friday	NO	NO	0.99
	2000–2009	Thursday	NO	NO	0.99
	2010–2014	**Sunday**	YES	NO	0.87
	1980–2014	Tuesday	NO	NO	0.67
Portorož	1980–1989	**Sunday**	YES	NO	0.97
	1990–1999	**Sunday**	YES	NO	0.92
	2000–2009	Monday	YES	NO	0.98
	2010–2014	**Sunday**	YES	YES	0.61
	1980–2014	**Sunday**	NO	NO	0.83
Velenje	1980–1989	**Sunday**	YES	YES	0.90
	1990–1999	Monday	YES	NO	0.88
	1980–2005	**Sunday**, Monday	NO	NO	0.89
Ilirska Bistrica	1980–1989	Friday	YES	NO	0.90
	1990–1999	Thursday	YES	NO	0.86
	1980–1999	Friday	NO	NO	0.93
Litija	1980–1989	Thursday	NO	NO	0.99
	1990–1999	Thursday	YES	NO	0.74
	1980–2004	Thursday	NO	NO	0.95
Trbovlje	1980–1989	**Sunday**	NO	NO	0.99
	1980–1992	**Sunday**	NO	NO	0.96

and the individual seasons. Table 5 shows the results for the complete period, while Plečko (2015) presented the results for different seasons. It can be seen that for 7 stations the changes in the weekly rainfall pattern between 1990–1990 and 2000–2009 periods were statistically significant and for 4 stations the same conclusions were made for the 1980–1989 and 2000–2009 periods. The presented results indicate notable differences among the study periods, among which the last decade, i.e. the beginning of the 21th century, stands out, which indicates changes in Slovenia's climate characteristics.

Table 5: Summary of the Mann-Whitney test results used to detect changes between different time periods.

Station	Period	Test results	Test statistic U
Ljubljana	1980–1989 and 1990–1999	H_0 could not be rejected	14
	1990–1999 and 2000–2009	**H_0 was rejected**	5
	1980–1989 and 2000–2009	**H_0 was rejected**	6
Maribor	1980–1989 and 1990–1999	H_0 could not be rejected	10
	1990–1999 and 2000–2009	H_0 could not be rejected	16
	1980–1989 and 2000–2009	H_0 could not be rejected	15,5
Murska Sobota	1980–1989 and 1990–1999	H_0 could not be rejected	19,5
	1990–1999 and 2000–2009	H_0 could not be rejected	12
	1980–1989 and 2000–2009	**H_0 was rejected**	3
Celje	1980–1989 and 1990–1999	H_0 could not be rejected	14,5
	1990–1999 and 2000–2009	**H_0 was rejected**	7
	1980–1989 and 2000–2009	H_0 could not be rejected	8
Novo mesto	1980–1989 and 1990–1999	H_0 could not be rejected	24
	1990–1999 and 2000–2009	**H_0 was rejected**	6
	1980–1989 and 2000–2009	**H_0 was rejected**	4,5
Kozina	1980–1989 and 1990–1999	H_0 could not be rejected	17,5
	1990–1999 and 2000–2009	**H_0 was rejected**	7
	1980–1989 and 2000–2009	H_0 could not be rejected	11,5
Šempas	1980–1989 and 1990–1999	**H_0 was rejected**	6
	1990–1999 and 2000–2009	H_0 could not be rejected	15
	1980–1989 and 2000–2009	H_0 could not be rejected	16
Kredarica	1980–1989 and 1990–1999	H_0 could not be rejected	18,5
	1990–1999 and 2000–2009	**H_0 was rejected**	7
	1980–1989 and 2000–2009	H_0 could not be rejected	12
Portorož	1980–1989 and 1990–1999	**H_0 was rejected**	0
	1990–1999 and 2000–2009	H_0 could not be rejected	10
	1980–1989 and 2000–2009	**H_0 was rejected**	0
Velenje	1980–1989 and 1990–1999	H_0 could not be rejected	17,5
Ilirska Bistrica	1980–1989 and 1990–1999	H_0 could not be rejected	14
Litija	1980–1989 and 1990–1999	H_0 could not be rejected	16

3.3 Connection between PM_{10} particles and rainfall

In the last step of the study, the connection between the measured values of PM_{10} particles in the air and rainfall was analyzed. Comparisons were made only for the time periods when PM_{10} measurements are available (Table 2). Weekly distribution of PM_{10} particles is shown in Table 6 and for the selected stations in Figure 3. It can be seen that Sunday was the day with the minimum PM_{10} values for all stations. However, the day with the maximum PM_{10} values was always in the second part of the week. A similar pattern in PM_{10} particles distribution is also characteristic of much more polluted areas such as major urban regions in east China (Gong et al. 2007). Gong et al. (2007) noted that the characteristic pattern in PM_{10} particles (i.e., gradual increase until the middle or the end of the working week, and minimum values on weekends) is accompanied by some other meteorological parameters such as wind speed in the troposphere, which is on average higher when PM_{10} concentrations are smaller. Further, increased PM_{10} concentrations could influence solar radiation, higher maximum temperatures, and the number of rainfall events (Gong et al. 2007).

Table 6: Days with maximum and minimum PM_{10} concentrations for the selected stations in Slovenia.

Station	Period	Day with maximum PM_{10}	Day with minimum PM_{10}
Ljubljana-Bežigrad	2011–2014	Friday	Sunday
Maribor-letališče	2009–2014	Thursday	Sunday
Murska Sobota-Rakičan	2010–2014	Thursday	Sunday
Celje-Medlog	2011–2014	Wednesday	Sunday
Novo mesto	2010–2014	Wednesday, Thursday, Friday	Sunday
Kozina	2009–2014	Friday	Sunday
Šempas	2011–2014	Friday	Sunday

Pearson (r) and Spearman (r) correlation coefficients were used to detect the relationship between the daily PM_{10} values and the daily rainfall values in the selected seasons (Table 7). The calculated Pearson's

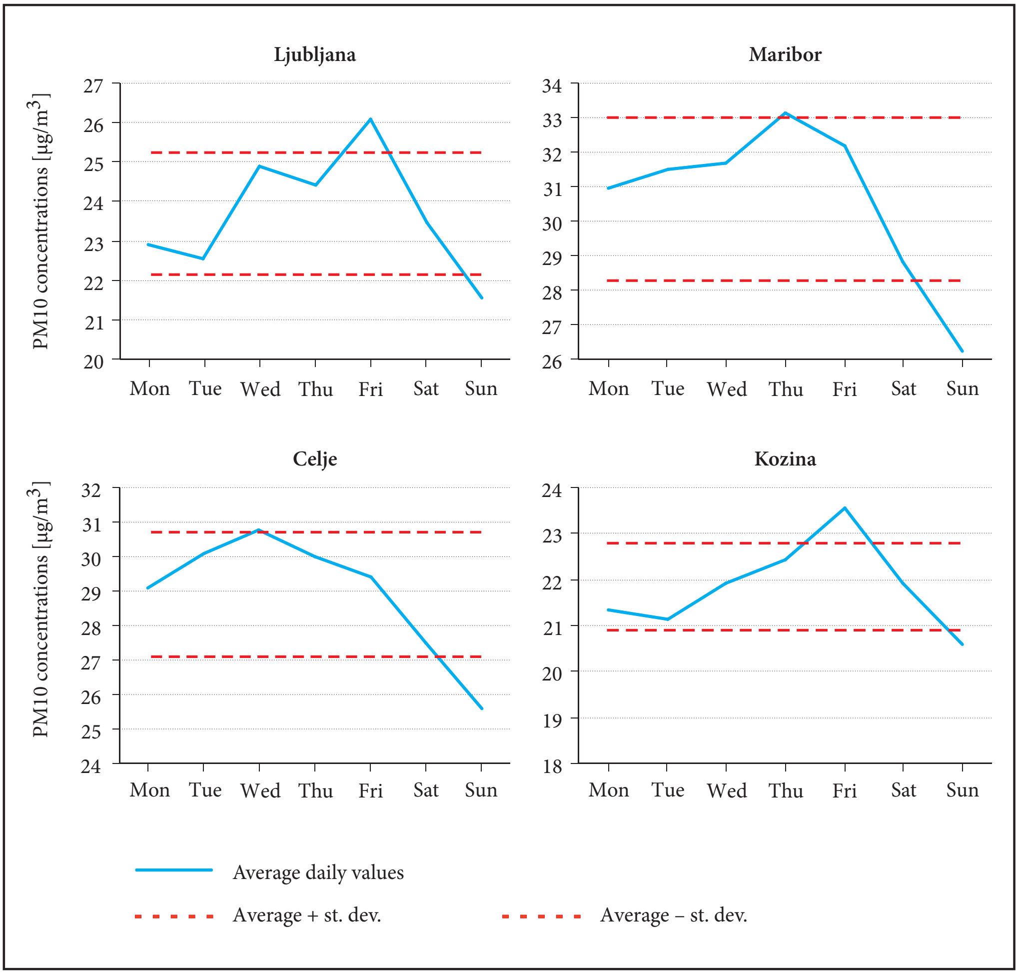

Figure 3: Weekly distribution of PM_{10} concentrations at Ljubljana, Maribor, Celje, and Kozina stations.

correlation coefficients indicate a negative and relatively weak linear correlation between the analyzed variables, however the calculated p-values demonstrate that the correlation is statistically significant (significance level 0.05) for all tested stations and all seasons with the exception of the Celje station where the relationship was not statistically significant for autumn, and the Novo mesto station where the relationship was not statistically significant for spring and autumn. Moreover, similar results were obtained with the use of the Spearman's correlation coefficient where the relationship was statistically significant (significance level 0.05) for all tested stations and all seasons. We can conclude that in Slovenia PM_{10} directly and indirectly impact the rainfall occurrence and that rain events wash out large amounts of PM_{10} particles from the air. However, hourly data would be needed to identify the relationship between PM_{10} and rainfall more accurate, but such data on PM_{10} are currently not available.

Table 7: Calculated Pearson (r) and Spearman (r) correlation coefficient values between rainfall and PM_{10} particles for various seasons and the corresponding p-values.

Station	Season	r	p-value	r	p-value
Ljubljana	winter	–0.30	~0	–0.48	~0
	spring	–0.22	~0	–0.38	~0
	summer	–0.37	~0	–0.55	~0
	autumn	–0.35	~0	–0.48	~0
Maribor	winter	–0.22	~0	–0.33	~0
	spring	–0.25	~0	–0.29	~0
	summer	–0.32	~0	–0.47	~0
	autumn	–0.34	~0	–0.43	~0
Murska Sobota	winter	–0.26	~0	–0.31	~0
	spring	–0.19	~0	–0.26	~0
	summer	–0.25	~0	–0.48	~0
	autumn	–0.28	~0	–0.44	~0
Celje	winter	–0.26	~0	–0.28	~0
	spring	–0.11	0.04	–0.13	0.02
	summer	–0.13	0.01	–0.24	~0
	autumn	**–0.05**	**0.33**	–0.15	0.003
Novo mesto	winter	–0.26	~0	–0.26	~0
	spring	**–0.09**	**0.06**	–0.15	0.001
	summer	–0.12	0.01	–0.28	~0
	autumn	**–0.06**	**0.21**	–0.15	0.01
Kozina	winter	–0.22	~0	–0.29	~0
	spring	–0.24	~0	–0.38	~0
	summer	–0.24	~0	–0.39	~0
	autumn	–0.31	~0	–0.47	~0
Šempas	winter	–0.28	~0	–0.35	~0
	spring	–0.26	~0	–0.55	~0
	summer	–0.31	~0	–0.49	~0
	autumn	–0.33	~0	–0.39	~0

4 Conclusion

The weekly rainfall pattern in Slovenia depends on the region and the analyzed time period as well as on the season and the pollution of individual regions. For the Trbovlje, Velenje, Portorož, and Ljubljana stations the differences between weekends and weekdays were larger than those for other analyzed stations. In some cases, the number of occurrences of rainfall exceeds the value of 3 standard deviations. However, using the χ^2 test, a statistically significant non-uniform rainfall pattern was found neither for the tested stations nor for seasons. The comparison between different time periods shows that the weekly rainfall pattern at the beginning of the 21st century differs from that in the last decade of the 20th century. A possible reason could be the decreasing air pollution values as a consequence of abandonment of heavy industry and wood heating, and the passing of adequate laws (Gosak 2014). However, the exceeding values of PM_{10} are still relatively frequent (Gosak 2014). The weekly pattern of PM_{10} particles in Slovenia is similar to that in some other more or less polluted areas in the world. Consequently, some level of connection between the rainfall values and PM_{10} concentrations was detected for the tested stations, which was in most cases statistically significant.

To sum up, the answer to the title question is as follows: For some areas in Slovenia such as the Ljubljana Basin, Celje Basin, coastal area, Zasavje and Šalek Valley, the possibility of rain on weekends is, indeed, larger than on weekdays, but the detected deviations are not statistically significant.

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