Heavy rains in Brno Region (The Czech Republic)

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ABSTRACT

This study evaluates occurrence of the heavy rains at urban areas on the example of Brno agglomeration. Extreme precipitation events are studied with the help of 1-minute records from three urban sites in the Brno and one site in the rural region. Additionally data from nine Hellmann rain gauges from Brno and surroundings were used. The event of torrential rains was evaluated according to Wussow's method. The study found that torrential rains occurred in Brno in the season from April to November. The fifteen-year long observation of the phenomenon at Brno-Žabovřesky station shows varying frequency of torrential rainfall – from none in 2007 to four in 2004 and 2010. The most extremal was catastrophic downpour on July 15, 2009 when precipitation sum reached total up to 42.7 mm in 52 minutes and the maximal rainfall intensity was 4.1 mm/min. This phenomenon occurs only one day after downpour on July 14, 2009. The overall number of torrential episodes is not very high, but it is compensated by the fact that they can repeat in a relatively short period of time, due to specific synoptic conditions. Maximum rainfall intensity during torrential rains reaches values of about 3 mm / min and the average proportion of torrential rain in the daily precipitation sum is around 70%. The phenomenon of heavy rains represents a significant problem for densely populated urban areas because such extreme rainfall has a large impact on the hydrological system of cities.

KEY WORDS: precipitation, downpour, urban climate, rainfall intensity, extreme weather

1. Introduction

The evaluation of precipitation occurrences is one of the significant issues in urban climatology. Extreme weather events have especially big impact in densely populated urban areas, as downpour can cause local flooding. Downpours, defined as rain of high intensity and short duration, though very local, they can have very dramatic and costly consequences. As an recent example we can use the event from July 31st 2014, when an extremely intense rain occurred in Brno, Czech Republic. This particular situation was analyzed in a paper published by KNOZOVÁ (in print). This particular rain event blocked the city sewage system, flooded a major road in the city center (http://video.idnes.cz/?idvideo=V140731_151725_tv-zpravy_sha) and caused damages in many buildings, such as the building of the Faculty of Philosophy of the Masaryk University, where a newly built archive was flooded as a result of backward water flow from the city sewage system. Rehabilitation of

these damages took several months and was further complicated by frequent rains in very humid August and exceptionally humid September. Czech Hydrometeorological Institute produced several expert opinions, which were requested by clients of insurance companies claiming compensation for damage. As a result of repeated intense rain events in the summer of 2014, also the tram rails in Brno-Žabovřesky were undermined.

In the context of anticipated climatic changes an increase in total precipitation and change in the seasonal distribution of precipitation is stated (BRÁZDIL ET AL., 2007). According to the results of RUBEL & KOTTEK (2010), the summer may become warmer but not dryer in Central Europe. Such a climate subjected to a hot summer without dry period could be perhaps favourable to heavy rains. On the other hand ZÁHRADNÍČEK ET AL. (2015) showed that, the end of the 20th and the beginning of the 21st century in the Czech Republic were characterized by frequent extreme water cycle fluctuations, i.e. floods in 1997, 2002, 2006, 2009,

2010 and 2013 and droughts in 2000, 2003, 2007, 2009 and 2012. It should in fact be noted that while evaluating the rainfall extremity in most climatological works, indexes based on daily rainfall totals are used (e.g. DOLEŽELOVÁ & KNOZOVÁ, 2013). Researching the rainfall occurrence requires a more detailed study material containing the hour and minute totals depending on the methodology used.

The downpour evaluation criteria differ. For example, according to Hellmann downpour is a rain with precipitation between 10 mm and 80 mm in period shorter than 180 minutes (SOBIŠEK ET AL., 1993). According to Chomicz scale a downpour is when the rainfall total reaches at least 12.8 mm in 10 minutes (NIEDŹWIEDŹ ET AL., 2003). The most common methodology used in the Czech Republic is the Wussow's method, according to which a torrential rain is when rainfall over a specific time, expressed in minutes, exceeds a critical value, determined on the basis of empirical formula; for example, for a period of 10 min rainfall amount reaches at least 7.1 mm (WUSSOW, 1922; ČHMÚ, 1988).

Torrential rainfall usually affects an area spanning from a few to several tens of square kilometres and occasionally hundreds of square kilometres. With a varying intensity they may take from several minutes to several hours. In Central Europe they occur in the warm season from April through October (DIMITROVA ET AL., 2009; TWARDOSZ ET AL., 2011; KNOZOVÁ, 2014a). Occurrence of heavy rain is caused by the convection phenomena. In storms and during the transition of atmospheric fronts rainfall reaches the highest intensity. According to ŘEZÁČOVÁ ET AL. (2007) the potential for torrential rainfall grows when the convective storm moves slowly and thus allows many cells reach a mature stage. The adverse effects of heavy rainfall mainly depends on three factors: the amount of water fallen during the rain, the duration and the intensity of precipitation. The intensity of torrential rain and its frequency is related to the local and remote terrain configuration allowing frequent thunderstorms formation or regulating the frontal storms pathways (TRUPL, 1958). Forecasting of torrential rains is very limited due to the rapid dynamics of convective cloud. Although the weather conditions for the strong rainstorms occurrence can be quite successfully predicted, precise localization, duration and intensity of heavy rainfall and hence the area of eventual occurrence of flash floods cannot be substantially predicted (DAŇHELKA ET AL., 2015).

The subject of the study is the scheme of heavy rainfall in Brno and its surroundings. Brno is a city of moderate size with four hundred thousand inhabitants and covers an area of 230.22 square kilometres (<https://www.brno.cz>). The geographic environment in the area is quite varied as the city lies where three geomorphological units meet. The northern edge of the city lies on Dražanská Highlands, the western part on the Bobrava highlands and the eastern part is in Dyjsko-svratecký Valley. The altitude of urban areas is in the interval from 190 m up to 479 meters affecting the climatic conditions of Brno (DOBROVOLNÝ ET AL., 2009).

The aim of the study is to analyse the occurrence of torrential rains in Brno in the context of the precipitation scheme in Brno agglomeration in the period between the years 2010 and 2014. A great attention is devoted to case studies regarding the events of July 31, 2014. The conclusion is formulated in the context of how urbanization affects on precipitation conditions on a regional scale.

2. Data and the method

Rainfall totals measured at six meteorological stations of the Czech Hydrometeorological Institute (ČHMÚ) are used as a basic study source. Three stations represent the urban environment: Brno-Žabovřesky, Brno-Jundrov and Brno-Židenice, and two other stations: Brno-Tuřany and Troubsko, represent the suburban climate, while Bukovinka station is located outside the urban area in Dražanská Highlands. Furthermore, for the purpose of spatial analysis data from seven remote locations are used (Fig. 1).

To evaluate the intensity of precipitation the data measured with rain gauge with tipping bucket type MR3H500 at four ČHMÚ stations are used. Additionally, for the analysis of selected cases images of radar reflectivity network CZRAD and records of the occurrence of atmospheric phenomena are used. It should be noted that the materials used are not quite complete, mostly due to technical problems. Intense rainfall is often accompanied by extreme atmospheric phenomena, such as lightning or strong winds, which can cause disruption in the measuring device or clogging the rain gauge with mechanical impurities in the form of leaves, twigs, etc. All cases of torrential episodes are therefore carefully verified.

Fig. 1. Meteorological stations used in the study

To evaluate the intensity of the precipitation the Wussow method is applied (1922). Wussow's empirical relationship establishes the critical value of total precipitation fallen over time beyond which rain can be classified torrential. When applied to precipitation with duration up to two hours with inequality $h \leq \sqrt{5t}$, where h is the rainfall total in mm and t is the time of the duration in minutes, it indicates the rain as normal. For $\sqrt{5t} < h \leq 1.5\sqrt{5t}$ rain is considered downpour, for $1.5\sqrt{5t} < h \leq 2\sqrt{5t}$ a strong downpour, and $h > 2\sqrt{5t}$ are the definition of catastrophic downpour. For sum calculations of different precipitation durations climatological applications ProClimDB (<http://www.climahom.eu>) are used.

3. Analysis of downpours on July 14th and 15th 2009

The precipitation event that occurred on July 15th 2009 is the most extreme precipitation events in the Brno region in the analyzed period. Very intense rain caused damages in the city center. Upon requests from insurance company clients claiming compensation for damage, the Czech Hydrometeorological Institute confirmed several

occurrences of downpour in the city of Brno and surrounding areas. This situation will now be analyzed in detail and used as an example of downpours in urban conditions.

On July 14th 2009, warm air from Southwest was entering the Moravian region as a result of anticyclone with a central region above Southern Europe. Cold front was slowly moving east across Germany. In the evening, a belt of intense thunderstorms with heavy rains formed in the Brno region. Based on Wussow classification, the rain observed at stations in Brno-Tuřany and Bukovinka can be classified as a downpour. The 13 stations analyzed reported daily cumulative rainfall amount from 0.0 mm in Moravské Bránice to 35.2 mm. The next day on July 15th 2009, cold front above central Europe was still affecting the weather conditions. In front of it, warm air from Southwest was entering Moravia. In the evening, rains and thunderstorms began to appear and were eventually observed in most areas. Based on radar images, a very intense thunderstorm occurred in Brno at 7:10 PM. The large thunderstorm system was accompanied by frequent lightening and downpours. Maximum rain intensity was observed at the station in Brno-Žabovřesky, reaching a value of

4.1 mm/min (Fig. 2). This, based on the Wussow classification, is categorized as a catastrophic downpour. After 8.10 PM the rain became less intense, but it was still raining until 11.40 PM. Maximum daily rainfall amount in Brno on this day was observed at a station in Brno-Jundrov, reaching a value of 57.9 mm. Rainfall amounts in the areas surrounding the city were slightly lower, but in some places exceeded a value of 50.0 mm (Fig. 3). This extreme precipitation event and intense rains also affected Silesia (Fig. 4).

The above described event is an example of a downpour occurring on two consecutive days. The extreme rainfall on July 15th 2009 was generated by synoptic factor but certain effect had an intense evapotranspiration resulting from the downpours that occurred the day before. Humid air from the afforested region of Dražanská Highlands probably contributed to

the development of convection processes and downpours in the Brno region repeated. Similar situation was observed during several other occasions later, for example during the already mentioned event on July 31st 2014 and two days later on August 3rd 2014. A study by PICKETT ET AL. (2011) on the base of comparisons of soil moisture between urban and rural forest patches or between urban forest soils and distributed soils found that differences in soil moisture occur between land-use and cover types in urban landscapes. These differences then lead to transport of moisture in the boundary layer of the atmosphere between various types of landscape. Precipitation regime of Brno, city situated between afforested hills on the North and West and agricultural areas on the South and East, is affected by spatial distribution of precipitation of the entire region.

Fig. 2. The course of precipitation in Brno region on July 15, 2009 at minute intervals

Fig. 3. Daily precipitation totals on 15 July 2009 in Brno region

Fig. 4. The radar reflectivity on July 15, 2009 in the Czech Republic

4. Characteristics of torrential rainfall in Brno in 2000 – 2014

Continuous measurement of precipitation in 1-minute intervals in the Hydrometeorological Institute network has been conducted from 2000 to the present. The assessed period is thus limited to the start of automatic measurement at the individual stations. The long-term analyse was based on measurement records taken between 2000 and 2014 at Brno-Žabovřesky meteorological station. The comparison of based statistics from four meteorological stations was carried out using data over the period 2010-2014.

In Brno-Žabovřesky there is the longest series of data concerning the intensity of rainfall in Brno. The fifteen-year long observation of the phenomenon at this station shows varying frequency of torrential rainfall – from none in 2007 to four in 2004 and 2010 (Fig. 5). The most extremal was catastrophic downpour on July 15, 2009 (precipitation reached a total 42.7 mm in 52 minutes), the second was strong downpour on July 31, 2014 (precipitation reached a total 44.4 mm in 1 hour and 48 minutes), and the third was strong downpour on June 12, 2010 (precipitation reached a total 31.7 mm in 60 minutes).

The results of the continuous measurements between 2010 and 2014 are from four meteorological stations. Torrential rains in those years occurred in the studied area in the largest number in 2011 – two to five episodes were reported at the individual stations (Tab. 1). This year was the driest in the fifteen-year period. The annual totals were from 351.9 mm in Troubsko up to 448.9 mm in Brno-Židenice.

The time of occurrence of specific storm events was monitored in a five-year period in Brno and its surroundings. Its analysis shows that the season in which the heavy rains occur usually lasts from May through September. The season begins the earliest in April and the last torrential rain can occur in October and November as also documented in other Moravian regions (KNOZOVÁ, 2014a). Torrential rains predominantly repeated in number of months, but in some seasons the events recurred over several days, as in the case describing the events of July 2009 above. There are serious consequences to such recurrences in the form of flash floods and soil erosion. The report evaluating floods in the Czech Republic in 2013 concludes saturation of soil profile occurs during the first torrential rain and can have disastrous consequences even when the rainfall is slightly less intense (DAŇHELKA ET AL., 2014).

The torrential rainfalls occur predominately in the morning and around noon midday depending on the development of convective processes in the atmospheric boundary layer. However exceptional cases of torrential rainfall during the atmospheric fronts change can affect the monitored areas during the evening or night hours. Hail occurs during rainstorms in many cases (KNOZOVÁ, 2014b). The duration of torrential rains spans from few to tens of minutes.

The intensity maximum in the torrential rains reaches around 3 mm/min. The precipitation

totals in torrential rains depend on the intensity and duration. The most intense rainfalls occur in storms residing in the given territory for an extended period of time, moving slowly, or those creating more convective cells during their development (ŘEZÁČOVÁ ET AL., 2007). In the observed period torrential rains reached totals ranging from 7.3 mm to 50.9 mm (Tab. 2). Note that these amounts were calculated only from the episodes evaluated as torrential. The torrential rain share in the daily rain total varies from 40% to 100% (Tab. 3).

Fig. 5. The number of torrential rains at Brno-Žabovřesky meteorological station (2000 – 2014)

Table 1. Number of torrential rains in Brno (2010 – 2014)

Year	Troubsko	Brno-Žabovřesky	Brno-Tuřany	Bukovinka
2010	2	4	1	3
2011	3	2	2	5
2012	2	3	2	3
2013	2	2	4	1
2014	2	2	2	3

Table 2. Maximum torrential rain totals in Brno (2010 – 2014) [mm]

Year	Troubsko	Brno-Žabovřesky	Brno-Tuřany	Bukovinka
2010	47.0	31.6	50.9	44.0
2011	19.0	17.2	16.3	21.7
2012	20.1	21.3	16.2	30.2
2013	13.6	18.0	27.6	16.5
2014	25.2	44.4	32.6	29.1

Table 3. Torrential rain precipitation share in daily rain totals in Brno (2010 – 2014) [%]

Year	Troubsko	Brno-Žabovřesky	Brno-Tuřany	Bukovinka
Min	33.9	37.1	40.1	58.5
Max	96.9	100.0	97.0	99.5

5. The occurrence of torrential rains in the urban climate context

Urban areas have, due to a variety of geographic features, characteristics different to the countryside protected from the intense human intervention. In the case of precipitation regime it is quite difficult to clearly assess the impact of human activities on the rainfall intensity and its character. Processes taking place around the city, as stated in chapter 3, influence the intensely changed geographical environment of Brno adjacent to the protected area of Moravian Karst. However, there is a significant influence of urban phenomena, e.g. urban heat islands (UHI).

Air temperature in urban areas is formed and influenced by a number of factors. Among the most important are the specific characteristics of active surfaces, including its vertical segmentation and spatial organization. The build-up area geometry is one of the main mechanisms that contribute to urban heat island shaping (FORTUNIAK ET AL., 2006). In the detailed analysis of Brno temperature conditions has been found the heat island peak in Brno is reached at night due to the limited long wave radiation heat loss and the slower release of the stored heat (DOBROVOLNÝ ET AL., 2012). Another significant factor largely affecting the thermal regime of a particular area is the relative topography and slope of relief. The Brno basin is open to the south and the southwest. Although plains and plateaus of the slope of 3 degrees dominate the Brno relief there is a relatively large area formed by a gentle and steep slopes. The orientation of slopes to the south and southwest exposes the surface to sunlight and the maximum air temperature in the city is higher than in its surroundings. The above-mentioned geometry of urban development is an additional contributor. Intensive air warming occurs in the urban area in the afternoon and thus causes a secondary maximum of UHI. In the summer, the maximum temperature in the city can be about 1.5°C to 2.0°C higher than in its surrounding areas (DOBROVOLNÝ ET AL., 2012).

The thermal phenomena of urban climate affect the precipitation regime. The thermal effect is considered a major cause of isolated rainfall over the city in summer. PATHIRANA ET AL. (2014) noted that is a significant increase of local extreme rainfall when the urban area is increased. In this context, storms are more frequent. They are initiated by the convective processes over the city and move in the area depending on the structure of buildings (BORNSTEIN & LIN, 2000). It has also been found the presence of urban surfaces causes

noticeable change to the physical properties of rainfall, including accumulated rainfall, intensity, frequency, dynamic properties of storm evolutions (eg. structures, tracks, timings) (YANG ET AL., 2013).

The impact of evapotranspiration of urban vegetation on the flow of latent heat is taken into consideration in the latest models of urban climate (DE RIDDER ET AL., 2015). Evapotranspiration also contributes to the development of convective processes and convective precipitation.

ŠÁLEK ET AL., (2012) works dedicated to the short-term precipitation analysis using the information from the weather radar has brought interesting results. It deals with 5, 10, 20, 30 and 60 min precipitation episodes recorded in a dense network of 20 stations. Based on the spatial analysis it has been found the highest totals of 10 and 20-minute rain occur in the south-western part of Brno, which means the sheltered side of the city. It should be noted the work used data from the period 2003 – 2009 and included all the episodes not only torrential rain.

This work focuses mainly on the characteristics of the torrential rains occurrence in Brno. Processed material includes a relatively short period of 5 years, and therefore the conclusion should be cautiously formulated. The analysis of the 33 days of torrential rain in the years 2010 to 2014 showed rainfall is highly variable in space. In some situations, a greater total precipitation fell in areas of the city (for example, July 31, 2014), in other, in its surroundings. The decisive factor was the specific direction of the storm current. For example, on 1 June 2011 torrential rain occurred 5 kilometres north of Brno in a thunderstorm tied with waving cold front and continuing from east to west. The daily total precipitation was 25 mm. The storm hit only the edge of the city and the daily precipitation reached up about 9 mm.

The influence of urban areas on the rainfall intensity is not entirely clear, but it is possible to observe relatively more substantial rainfall in the central part of the city. The total annual precipitation at 13 monitored stations in the Brno region is dependent mainly on the altitude of individual sites (Tab. 4). Somewhat exceptional in this context is the Brno-Židenice station with the highest total precipitation of all in the urban area. The station is located near the Svitava River at an altitude of 203 m above sea level and is one of the lowest stations. It is strongly influenced by local conditions – located in a built-up area near an industrial zone. For these reasons, it can be assumed that more rainfall totals herein may be tied to the occurrence of UHI and increased air pollution.

The comparison of the average daily precipitation in the days of torrential rain comes to the same conclusion (Fig. 6). The analysis shows that the highest rainfall in those days fell again in Brno-Židenice. Differences in the precipitation totals between the localities were not too significant. Somewhat more substantial rainfall was recorded in the central part of the city (Brno-Jundrov and Brno-Židenice) and in the northeast suburbs (Babice nad Svitavou and Bukovinka). The lowest values occurred at Židlochovice and Těšany stations lying to the south of Brno in the lowest altitude in the Dyje-Svratka ravine. These facts suggest the morphology of the terrain directs the movements of storms bringing heavy rains.

Based on the results described it can be stated the circular factor plays the dominant role during

intensive rainfall in Brno. A factor determining the occurrence of heavy precipitation - atmospheric circulation was described in other studies (eg. [LUPIKASZA, 2010](#)). The morphology and the character of the landscape of the wider region play an important role ([KNOZOVÁ, in press](#)). The city's influence on the modification of precipitation regime is most evident in the central part and is probably tied to the presence of UHI ([DOBROVOLNÝ ET AL., 2012](#)). To evaluate the city's significance in the intensification of rainfall totals and its eventual ceasing a much longer series of data needs to be used. Linking of automatic rain gauges and earlier ombrographic data would be necessary. Data recorded using weather radar are also an important source of spatial information ([CUP ET AL., 2012](#); [ZOCCATELLI ET AL., 2010](#)).

Table 4. Annual rainfall totals average in Brno (2010-2014)

Station	Altitude [m a.s.l.]	Precipitation [mm]
Bukovinka	524	647.5
Babice nad Svitavou	470	625.5
Zastávka	345	557.1
Kuřim	291	579.9
Troubsko	278	507.5
Brno-Jundrov	260	550.5
Brno-Tuřany	241	526.5
Brno-Žabovřesky	236	540.1
Slavkov u Brna	211	565.7
Moravské Bránice	210	546.8
Těšany	209	523.3
Brno-Židenice	203	562.9
Židlochovice	183	516.9

Fig. 6. Daily rainfall totals average in the days of torrential rain in Brno (2010-2014)

6. Conclusion

The precipitation regime in urban areas is very important with regards to surface runoff. Runoff from impermeable surfaces in the cities differs from the surface runoff in a natural environment. Impervious surfaces mainly affect the speed and height of the drain. The main problem of the torrential rains of July 31, 2014, discussed in Chapter 3, arose during water runoff. Correct assessment of surface runoff during and after an extreme rainfall is very important when sizing the city sewer system. PRAX ET AL., 2010 conducted a research study regarding the subject for Brno.

How to deal with rainwater at construction sites is covered by legislation of the Czech Republic. Great emphasis is on seepage or draining of rainwater from paved areas regarding its potential to mixed with harmful substances. Another significant hydrological issue in urban areas is the overall deficit of water and thus the need for rainwater retention and the reuse of wastewater for e.g. irrigation of urban green spaces (KRÁTKÝ, 2014).

Extreme rainfall plays an important role in the hydrological system of cities (PICKETT ET AL., 2011). The aim of the analysis was to characterize the frequency and intensity of rainstorms in Brno and its surroundings. Extreme rainfalls, as classified according to the Wussow's method, occur in Brno in the season from May through September. Only a few torrential episodes occur in the season, however, can repeat in a relatively short period of time, a series of several days, in specific synoptic conditions. The precipitation intensity in torrential rains reaches 3 mm / min and torrential rainfall totals contribute to the daily precipitation sum around 70%. The existing results can be considered as the basis for future studies focused on the specific characteristics of precipitation regime in urban areas.

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