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AN ANALYSIS OF SHORT DURATION HIGH-INTENSITY RAINFALL EVENTS IN CRACOW AREA

Elżbieta Jarosińska
Cracow University of Technology

Abstract

The study involves a preliminary analysis of short-duration high-intensity rainfall events in the area of Cracow. The events were selected from a 2-year data record from the MPWiK (*Miejskie Przedsiębiorstwo Wodociągów i Kanalizacji* [Municipal Water and Sewage Company]) in Cracow. A spatial analysis was carried out by comparing rainfall events with highest single totals which occurred at the same time at all observed precipitation stations. Extracted were nine cases from the data record of 2013 and ten from the data record of 2014. Each of the analysed events was classified according to the Chomicz scale for rainfall intensity in order to distinguish maximum rainfalls, in particular of the following types: heavy rainfalls, rainstorms and torrential rains. Additionally, observed were cases of the most unfavourable rainfall events, i.e. ones with the highest totals in the observed year. In both 2013 and 2014, certain areas in Cracow were observed to be characterised by a pattern of repeating rainfall types. Also, a change in the rainfall category was observed from lower into higher and reverse in certain areas represented by the same gauging stations. At the stations located in varying distances within one urban area of Cracow, the intensity of rainfall varied from rainstorm A_1 to torrential rain B_1.

Keywords: urban catchment, flooding, rainfall intensity, Chomicz scale

INTRODUCTION

Extreme phenomena occurring in urban catchments have become part of reality. Nowadays it has to be accepted that the climate change has brought a change in the character of precipitation (Moberg *et al*. 2006). If it does occur at all, is usually very intense and short in duration. It has to be accepted that the character of precipitation has been considerably affected by the climate change (Moberg *et al*. 2006). More specifically, rainfall has generally become scarce, and when it occurs, it is usually very intense and short in duration. According to Jania and Zwoliński (2011), based on their own meteorological and climatological research, storms over Cracow will occur much more often than before. Moreover, the increasing trend of urban catchment sealing contributes to faster rainfall runoff from sewage systems to the receiver (Walsh *et al*. 2005, Fox *et al*. 2012, Dams *et al*. 2013). According to Kotowski *et al*. (2010), intense (maximum) rainfalls are responsible for the highest discharge in rain water drainage or combined sewage systems. Repeatedly, they cause local floods which damage houses or public roads and bring about considerable economic losses. The situation calls for changes in the approach to setting up measuring guidelines for both drainage and sewage systems by the responsible authorities. It is also becoming more important to perform continuous observations and quantitative research on rainfall which inform on the so-called design rainfall intensity, a fundamental measurement when designing rain water or combined sewage systems. Knowledge on the character of precipitation as well as the extent of its impact can provide basis for designing a system of rain water management in cities, which relies on storing the water from periods of excess and using it in dry periods (Chocat *et al*. 2007, Stahre 2006). This, in turn, calls upon the authorities to take precaution while planning further developments in the catchment area as well as retain rain water as and when it occurs in previously sealed area.

While analysing the applicability of the rainfall models as proposed by Błaszczyk, Chomicz and Lambor, or Bogdanowicz and Stachy (Kotowski *et al.* 2010) and designing new projects, such as PANDA (www.retencja.pl), it is important to pay special attention to intense rainfall, especially heavy rainfalls, rainstorms and torrential rains, which occur in urban catchments (Kotowski 2011) and are characterised by varied intensity in different parts of a city. Studies regarding maximum rainfalls have been popular in the existing body of literature, however they are often based on observations of daily or hourly precipitation totals (Szalińska and Otop 2012, Ziernicka-Wojtaszek and Kaczor 2013). Their analysis (Ziernicka-Wojtaszek and Kaczor 2013) may reveal, however, the application of the method which requires extracting single rainfalls (rainfall events) called ‘individual’ as described by Wit-Jóźwik (1977). As opposed to the traditional methods based on determining various parameters, e.g. the count and frequency of the occurring rainfall in even time frames, the design event method is based on determining for each event the actual duration, sum and intensity of rainfall.

The article presents a preliminary analysis of short-duration high-intensity rainfall events in the Cracow area selected from a 2-year data record from the MPWiK in Cracow.

PRECIPITATION DATA

Measurement data of precipitation formed observation sequences recorded in 2013 and 2014 at precipitation stations located in Cracow (Figure 1), south of Poland.

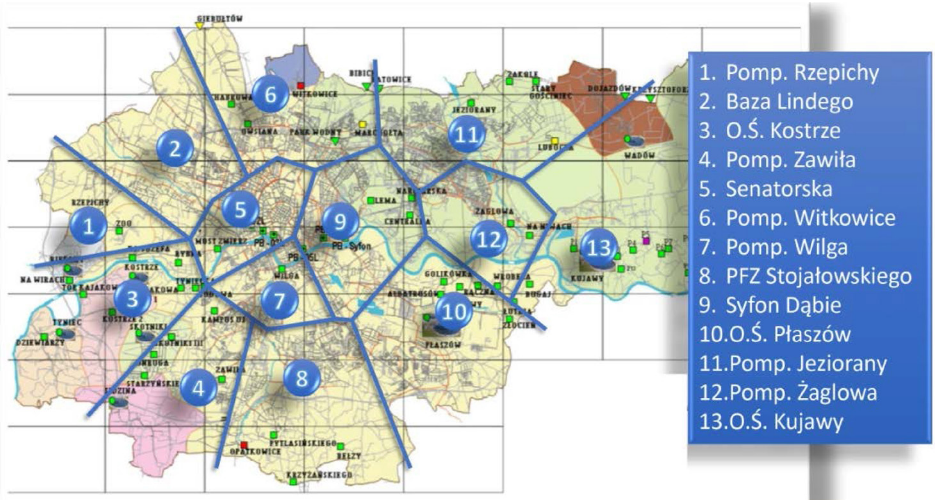


Figure 1. Locations of the MPWiK precipitation stations in Cracow (source: MPWiK)

Raw measurement data of precipitation was recorded by a system of 13 rain gauges provided by the MPWiK (Table 1) as impulses with the accumulated rate of 0.2 mm of rainfall total. Each impulse was assigned a date and time of occurrence with accuracy of 1 sec. During data preparation, it became necessary to discretize the values into equal widths to match the values of time steps of 10, 20, 30, and 60 min as well as 2, 6, and 24 h. Data discretization was performed with the use of a macro created in Microsoft Excel. In order to obtain 10-minute rainfall values, the 24-hour period was broken down into 10-minute steps and for each of those steps the rainfall values in millimeters were summed up. Subsequently, longer time steps were created by merging 10-minute rainfall values.

Table 1. Locations of the MPWiK precipitation stations in Cracow (DMS – degree-minute-second and temporal range of obtained data (source: MPWiK)

NO.	PRECIPITATION STATION	TEMPORAL DATA RANGE	EAST LONGITUDE (λE) DMS	NORTH LATITUDE (φN) DMS	HEIGHT (H) m
1	Pomp. Rzepichy	07.05-31.12.2013, 06.04.-27.11.2014	19° 49’	50° 04’	257.7
2	Baza Lindego	08.03.-31.12.2013, 24.03.-28.11.2014	19° 52’	50° 04’	212.2
3	O.Ś. Kostrze	19.04.-31.12.2013, 27.05.-27.11.2014	19° 51’	50° 02’	204.3
4	Pomp. Zawiła	23.05.-31.12.2013, 06.04.-27.11.2014	19° 56’	49° 59’	233.7
5	Senatorska	17.04.-31.12.2013, 06.04.-27.11.2014	19° 55’	50° 03’	203.3
6	Pomp. Witkowice	09.08.-31.12.2013, 09.04.-27.11.2014	19° 57’	50° 06’	227.9
7	Pomp. Wilga	17.04.-31.12.2013, 06.04.-27.11.2014	19° 56’	50° 02’	205.9
8	PFZ Stojałowskiego	23.05.-31.12.2013, 04.04.-27.11.2014	19° 57’	50° 00’	218.6
9	Syfon Dąbie	15.04.-16.12.2013, 24.03.-25.11.2014	19° 58’	50° 03’	203.6
10	O.Ś. Płaszów	11.07.-31.12.2013, 04.04.-27.11.2014	20° 01’	50° 02’	198.4
11	Pomp. Jeziorany	16.04.-31.12.2013, 09.04.-27.11.2014	20° 02’	50° 06’	215.8
12	Pomp. Żaglowa	23.05.-31.12.2013, 08.04.-25.11.2014	20° 03’	50° 03’	195.3
13	O.Ś. Kujawy	30.08.-18.12.2013, 07.04.-27.11.2014	20° 06’	50° 03’	196.3

Despite discretizing the precipitation data into a time step of over 10 min, further analysis was performed utilising data with the time step equal to 10 min. It was assumed that 10-minute values provide best and most reliable description of the rainfall course over time, while each subsequent data aggregation into a time step over 10 min generates distortion.

RAINFALL EVENTS

A spatial analysis of precipitation data included a comparison of precipitation totals of rainfall events, which occurred at the same time (or within a few minutes time difference) at all observed precipitation stations. The precipitation total was assumed as defined by Chomicz (1951) and Bogdanowicz and Stachy (1998) as a total in particular time *t*, regardless of whether it came from a single rainfall or several separate rainfalls occurring in a sequence and separated by shorter or longer dry periods. While the available body of literature proposes various methods of determining the minimum interval between single rainfalls (Wit-Jóźwik 1977, Mazurkiewicz and Sowiński 2014), it was assumed that an undivided rainfall is one with an interval until subsequent single rainfall lasting less than 2 h. This rule applies only in case of short-duration rainfalls which last from several minutes up to 1.5 h (Kupczyk and Suligowski 1997). According to Wit-Jóźwik (1977), a two-hour break in rainfall is not long enough to allow for drying up the top layer of soil or, in some cases, to even let the surface runoff drain. The analysis adopted a principle stipulating that isolated rainfall events would be those characterised by the highest rainfall total at least at one of the precipitation stations. Next, it was analysed how the totals of a rainfall observed at the same time at the other stations were distributed in 2013 and 2014.

In the course of data analysis, selected were nine rainfall events which occurred in 2013 on the following days: 2nd/3rd May, 30th May, 5th June, 23rd June, 24th June (two events), 24th/25th June, 5th July, 12th July, and ten rainfall events which occurred in 2014 on the following days: 26th May, 28th May, 7th July, 9th July (three events), 31st July, 4th August, 13th/14th August, and 8th September. For each of these, rainfall intensity was calculated in mm/min^{-1} alongside rainfall total in mm and duration in min. Additionally, each of the analysed rainfall events was classified according to Chomicz's scale (Kotowski *et al.* 2010) in order to single out maximum rainfall events, especially heavy rainfalls, rainstorms and torrential rains.

Two cases of the most unfavourable rainfall events were observed, i.e. ones whose rainfall totals were the highest in a given year of observation. These are events from 24th/25th June 2013 (Table 2) and 9th July 2014 (Table 3) for which hyetographs were designed (Figure 2). Hyetographs will allow for a location-wise comparison of maximum rainfalls at different precipitation stations in the Cracow area in future observations.

Table 2. Rainfall events with the highest rainfall totals during the time of occurrence from 24th/25th June 2013 in the Cracow area

NO.	PRECIPITATION STATION	RAINFALL EVENT DATE	P mm	t min	I mm/ min	RAINFALL CATEGORY ACCORDING TO CHOMICZ
1	Pomp. Rzepichy	24/25.06.2013 23:40-02:20	30.2	170	0.18	GRADE II RAINSTORM (A_2)
2	Baza Lindego	24/25.06.2013 23:40-02:30	29.4	180	0.16	GRADE II RAINSTORM (A_2)
3	O.Ś. Kostrze	FAILURE OR NO RAINFALL				
4	Pomp. Zawiła	24/25.06.2013 23:30-02:10	21.0	170	0.12	GRADE I RAINSTORM (A_1)
5	Senatorska	24/25.06.2013 23:30-02:20	29.2	180	0.16	GRADE II RAINSTORM (A_2)
6	Pomp. Witkowice	FAILURE OR NO RAINFALL				
7	Pomp. Wilga	24/25.06.2013 23:30-02:40	32.2	200	0.16	GRADE II RAINSTORM (A_2)
8	PFZ Stojałowskiego	FAILURE OR NO RAINFALL				
9	Syfon Dąbie	24/25.06.2013 23:10-02:40	27.6	210	0.13	GRADE I RAINSTORM (A_1)
10	O.Ś. Płaszów	FAILURE OR NO RAINFALL				
11	Pomp. Jeziorany	24/25.06.2013 00:20-03:00	31.8	160	0.20	GRADE II RAINSTORM (A_2)
12_1	Pomp. Żaglowa	24.06.2013 04:20-05:50	36.2	100	0.36	GRADE III RAINSTORM (A_3)
12_2		25.06.2013 00:30-02:40	30.4	140	0.22	GRADE II RAINSTORM (A_2)
13	O.Ś. Kujawy	FAILURE OR NO RAINFALL				

(P – the peak rainfall total during time t, I – rainfall intensity) (source: own)

Table 3. Rainfall events with the highest rainfall totals during the time of occurrence from 9th July 2014 in the Cracow area

NO.	PRECIPITATION STATION	RAINFALL EVENT DATE	P mm	t min	I mm/ min	RAINFALL CATEGORY ACCORDING TO CHOMICZ
1	Pomp. Rzepichy	09.07.2014 19:10-23:30	30.2	260	0.12	GRADE I RAINSTORM (A_1)
2	Baza Lindego	09.07.2014 18:40-23:00	28.2	260	0.11	GRADE I RAINSTORM (A_1)
3	O.Ś. Kostrze	09.07.2014 18:50-23:10	28.4	260	0.11	GRADE I RAINSTORM (A_1)
4	Pomp. Zawiła	09.07.2014 16:30-23:10	40.2	390	0.10	GRADE II RAINSTORM (A_2)
5	Senatorska	09.07.2014 19:00-23:00	32.0	240	0.13	GRADE II RAINSTORM (A_2)
6	Pomp. Witkowice	09.07.2014 18:40-22:50	42.8	250	0.17	GRADE II RAINSTORM (A_2)
7	Pomp. Wilga	09.07.2014 18:50-23:00	39.6	250	0.16	GRADE II RAINSTORM (A_2)
8	PFZ Stojałowskiego	09.07.2014 16:30-02:10	40.6	600	0.07	GRADE I RAINSTORM (A_1)
9	Syfon Dąbie	09.07.2014 18:40-22:50	31.0	250	0.12	GRADE I RAINSTORM (A_1)
10	O.Ś. Płaszów	09.07.2014 18:50-23:00	31.8	250	0.13	GRADE II RAINSTORM (A_2)
11	Pomp. Jeziorany	09.07.2014 16:10-17:40; 18:30-22:40	59.0	360	0.16	GRADE III RAINSTORM (A_3)
12	Pomp. Żaglowa	09.07.2014 16:00-17:30; 18:20-22:40	55.0	380	0.14	GRADE II RAINSTORM (A_2)
13	O.Ś. Kujawy	09.07.2014 16:00-17:20; 18:40-22:50	53.4	370	0.14	GRADE II RAINSTORM (A_2)

(P – the peak rainfall total during time t, I – rainfall intensity) (source: own)

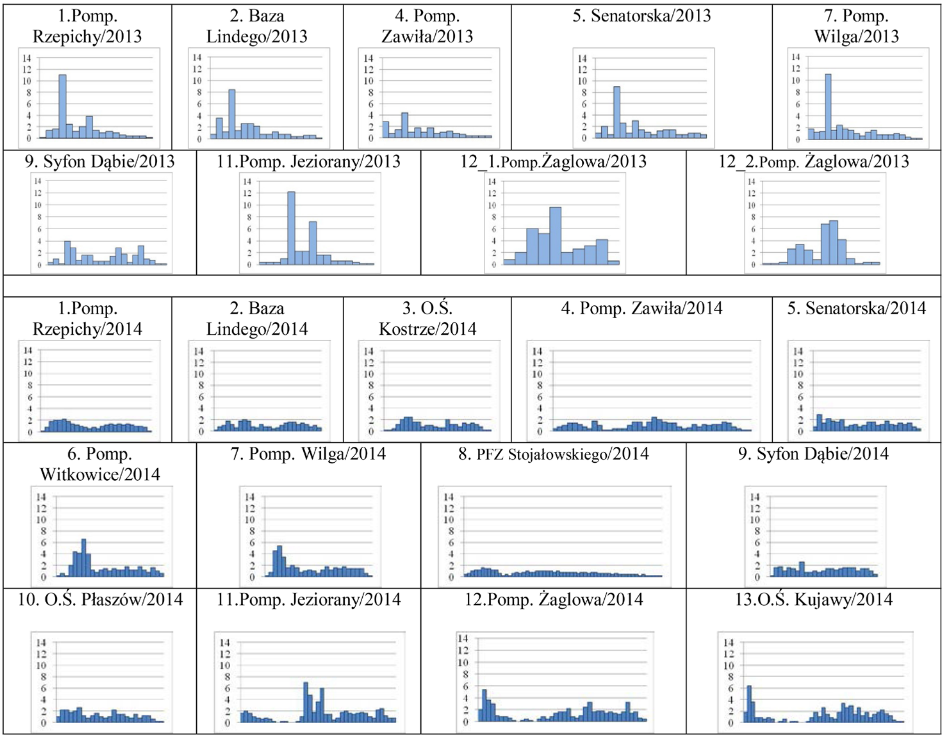


Figure 2. Hyetographs of the most unfavourable rainfall events from 24th/25th June 2013 (light blue) and 9th July 2014 (dark blue) designed based on 10-minute data from the MPWiK precipitation stations. The vertical axis indicates the scale of rainfall amount in mm while the horizontal axis indicates the number of 10-minute rainfall intervals (source: own)

RAINFALL CHARACTERISTICS IN THE CRACOW AREA

Although the dates of rainfall occurrences from 2013 did not coincide with the dates from 2014, it was attempted to compare two of the most unfavourable cases of rainfall events which occurred on 24th/25th June 2013 and 9th July 2014. It was observed that the following were registered in 2013 at eight precipitation stations: 2 cases of grade I rainstorm (A_1) – (Syfon Dąbie, Pomp. Zawiła) and as many as 6 cases of grade II rainstorms (A_2) – (Pomp. Rzepichy, Baza Lindego, Senatorska, Pomp. Wilga, Pomp. Wilga, Pomp. Żaglowa). At the same time, in case of Pomp. Żaglowa, the highest maximum rainfall of the intensity of grade III rainstorm (A_3) was registered the day before, i.e. on 24th June 2013.

Maximum rainfall totals were between 21 mm and 36.2 mm, and duration – between 100 min and 210 min (Figure 3).

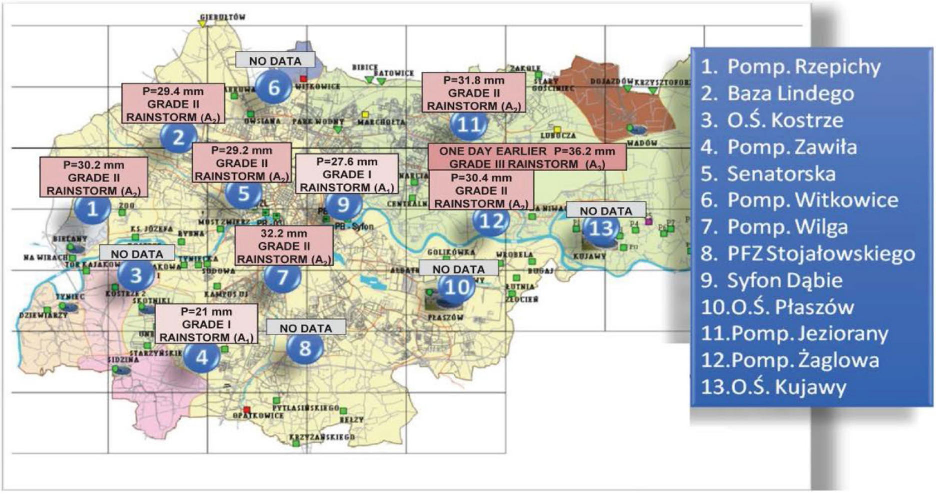


Figure 3. Rainfall events from 24th/25th June 2013 in Cracow (own work based on the map from MPWiK) (source: own)

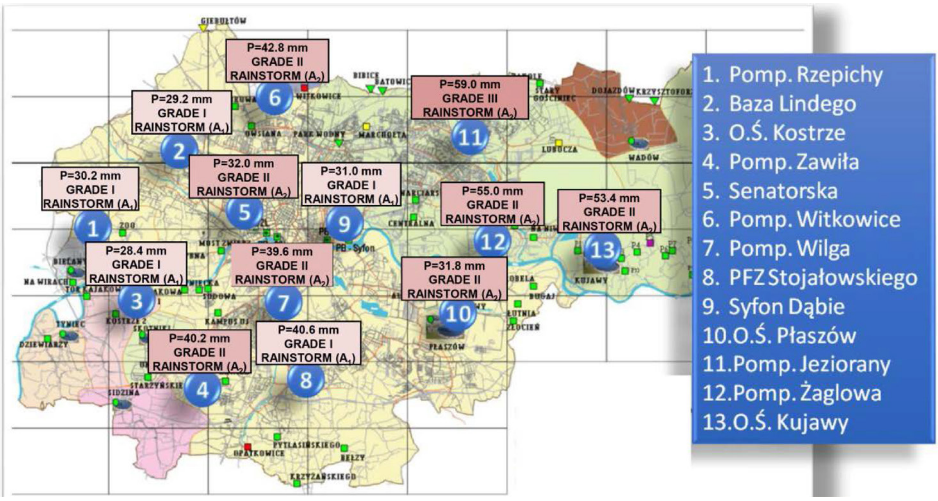


Figure 4. Rainfall events from 9th July 2014 in Cracow (own work based on the map from MPWiK)

It was observed that the following were registered in 2014 at thirteen precipitation stations: 5 cases of grade I rainstorms (A_1) – (Pomp. Rzepichy, Baza Lindego, OŚ Kostrze, PFZ Stojałowskiego, Syfon Dąbie), 7 cases of grade II rainstorms (A_2) – (Pomp. Zawiła, Senatorska, Pomp. Witkowice, Pomp. Wilga, OŚ Płaszów, Pomp. Żaglowa, Pomp. Żaglowa) and 1 case of grade III rainstorm (A_3) – (Pomp. Jeziorany). Maximum rainfall totals were between 28.2 mm and 59 mm, and duration – between 240 min and 600 min (Figure 4).

It is also worth paying attention to single cases of rainfall events, whose totals were similar to maximum but duration much shorter. These include: two episodes from 12th July 2013 with totals of 18.8 mm (Senatorska) and 21.6 mm (Pomp. Wilga) and with the same rainfall duration (only 20 minutes), one episode from 28th May 2014 with a total of 40.4 mm (Pomp. Wilga) and duration of 100 min, and one episode from 9th July 2014 with a total of 26.8 mm (Pomp. Żaglowa) and duration of 40 min. In categories stipulated by Chomicz, this corresponds to grade IV rainstorms (A_4) for all of the abovementioned cases. The only case of grade I torrential rain (B_1) with a total of 39.8 mm and duration of 40 minutes was registered on 9th July 2014 at the OŚ Kujawy precipitation station (Figure 5).

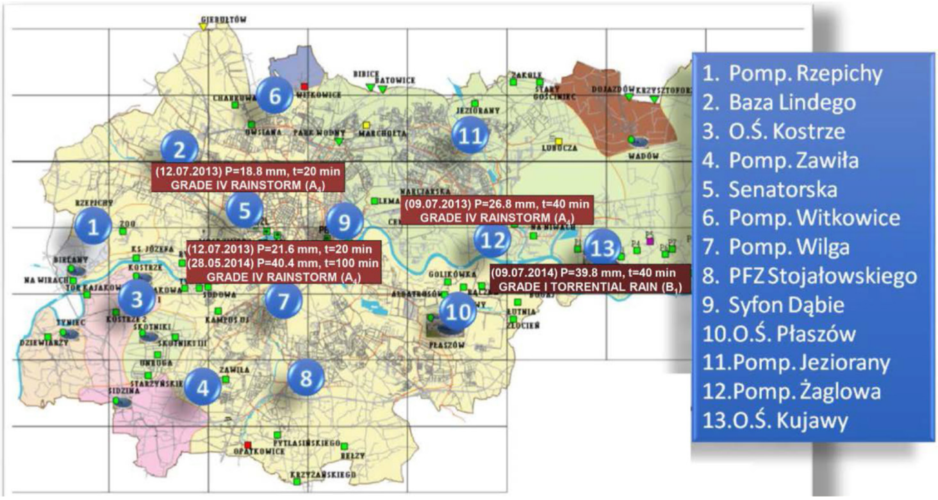


Figure 5. Single cases of rainfall events with maximum totals and short duration in 2013 and 2014 (own work based on the map from MPWiK)

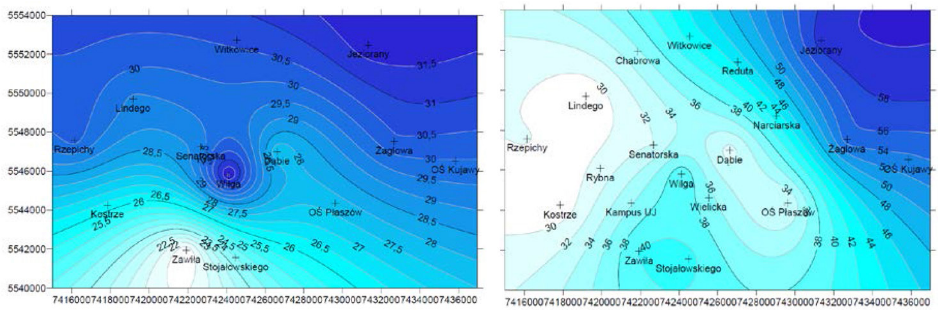
The most intense rainfalls occurred in June 2013 and July 2014. Despite the short period of observation, some regularity was observed which proved repeatability of rainfalls according to the Chomicz scale. Both in 2013 and 2014, type A_1 rainfalls occurred in the area of Cracow represented by the station Syfon

Dąbie while type A_2 rainfalls occurred in the areas represented by the following stations: Senatorska, Pomp. Wilga and Pomp. Żaglowa. For each of these cases, rainfall total in 2014 was higher than the total from 2013.

Moreover, it was noted that in the area represented by the Pomp. Zawiła station rainfall changed its quantity and category from A_1 (in 2013) to A_2 (in 2014) while in the area of the Pomp. Jeziorany station, from A_2 (in 2013) to A_3 (in 2014). And, conversely, in the areas represented by Pomp. Rzepichy and Baza Lindego stations rainfall changed from A_2 (in 2013) to A_1 (in 2014).

RAINFALL SCOPE IN THE CRACOW AREA

Hydrological hazard may be caused by both heavy rainfalls characterised by high intensity and short duration affecting local area and widespread rainfalls of lower intensity but longer duration and affecting larger areas. Intense and short-duration rainfalls often occur at a local level. The territorial scope of rainfalls depends on their intensity; the higher the intensity, the smaller the scope which, usually, is less than 5-10 km^2. Very rarely is it possible to observe an occurrence of a long-lasting high-intensity rainfall that covers a larger area (Lambor 1971).



a) b)

Figure 6. Map of rainfall scope for rainfall events with the highest totals during observation period: a) from 24th/25th June 2013, b) from 9th July 2014 in Cracow based on the MPWiK precipitation stations; the depth of the blue colour indicates increasing rainfall totals (source: own)

Determining the scope of rainfall is an important issue, however, at the same time, precise determining the scope of particular rainfall events poses a real challenge. This is often due to a scarce gauging system on the observed area which, consequently, does not provide enough observation data.

Maps of rainfall scope for rainfall events whose totals were the highest in a given observation year and which occurred in Cracow on 24th/25th June and 9th July 2014 were designed based on the existing recording network of the MPWiK (Figure 6). The maps of rainfall scope were created using Surfer v.10 software and interpolated by means of the kriging method. Out of the twelve in-built software functions, this method was decided to best fit the data characteristics.

At highest risk of high-intensity rainfalls in 2013 and 2014 were the areas located in the vicinity of the following stations: Pomp. Wilga and Pomp. Żaglowa, Pomp. Jeziorany and OŚ Kujawy.

CONCLUSION

The article presents a preliminary analysis of high-intensity short duration rainfall events occurring in the Cracow area. The short period of rainfall observation is a result of the initial stage of research after setting up the rain gauges by the MPWiK.

Based on the selected rainfall events, the popular statement stipulating that rainfall is a random phenomenon changing in time and space, can be confirmed to be true. The intensity of the occurring rainfall varied from rainstorms A_1 to torrential rain B_1 in the observed period at gauging stations located in varying proximity but within the area of one city, i.e. Cracow. These variations could be attributed to different factors, not only meteorological or climate-related but, most probably, they were also related to the landscape, geology, or an overlap of a number of weather phenomena, not necessarily of extreme character. The initial stage of research does not allow for a reliable defining of the causes yet, therefore there are plans set out for further stages of work based on rainfall data collected in later years of observations, i.e. 2015-2017.

The varying intensity of rainfall in a given area is vital to designing rainfall runoff from the area to the receiver. Knowledge on the most frequently occurring realistic rainfall scenarios in a given area in different locations in Cracow could be used for creating reference rainfall scenarios, later utilised as input data for designing rainfall-runoff models.

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Dr inż. Elżbieta Jarosińska
Cracow University of Technology
Institute of Water Engineering and Water Management
ul. Warszawska 24,
31-155 Kraków
ejarosin3@gmail.com

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