Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25836

199 (2020) 169–178
September

Occurrence of the pollutant first flush phenomenon on the example of the stormwater sewer system in Kielce – case study

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Received 17 October 2019; Accepted 12 March 2020

ABSTRACT

This paper attempts to describe the occurrence of the pollutant first flush phenomenon in the stormwater sewer system in two urban catchments located in different parts of the city of Kielce. The research covered measurements of concentration variations of the total suspended solids (TSS) during runoff events caused by precipitation of varied nature and events resulting from snowmelt. The flow rates and precipitation values recorded were used for the analyses. Based on the calculations, pollutographs were plotted to illustrate the characteristics of the first flush phenomenon in the catchments in question. Nine events from the period of 2009–2010 and five events from 2018 were selected for the analysis. In the first case, the maximum flow rates and durations of the event ranged as follows: 0.037–0.312 $m^3 s^{-1}$ and 120–540 min, in the second: 0.209–4.530 $m^3 s^{-1}$ and 150–1,000 min. They were caused by precipitation depth of 3.6–20 mm. The greatest TSS concentration recorded for the rainfall events was 10,621 mg dm^{-3}, and for snowmelts – 7,432 mg dm^{-3}. An analysis of the occurrence of the pollutant first flush, in relation to the mass of TSS in individual events, showed significant differences in the course of the process. The first flush phenomenon does not occur in smaller catchment areas, and those with a greater degree of land sealing. The first 30%, 25%, and 20% of the runoff volume (%V) carried up to 47%, 40%, and 34% of the TSS mass (%M). In the larger catchment, having six times greater area and a slightly lower degree of land sealing, the first flush phenomenon occurs virtually for every event (depending on the criterion %M/%V adopted). The initial 30%, 25%, and 20% of the cumulated runoff volume carried respectively: from 53% to 75%, from 47% to 69%, and from 39% to 60% of the TSS mass.

Keywords: Stormwater; First flush phenomenon; Total suspended solids; Urban catchment

1. Introduction

Due to the continuous growth of urban settlements, precipitation events pose an ever-growing concern in urban areas. Higher sealing degree in the catchment area leads to increased surface runoff, while the specific land use and sources of air pollution affect the quality of the stormwater. Separation of sewage and stormwater drainage showed a negative impact of the latter on the receiver waters. The basic parameters describing the stormwater include the pH, total suspended solids (TSS), petroleum derivatives, chlorides, chemical oxygen demand, biochemical oxygen demand (BOD_5), heavy metals, and biogenic compounds [1–4]. One of the most significant indicators are the TSS values due

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Presented at the 14th Conference on Microcontaminants in Human Environment, 4–6 September 2019, Czestochowa, Poland

1944-3994/1944-3986

to solids ability to absorb heavy metals, which are particularly hazardous due to their bioaccumulation potential in the environment [5–6].

Based on the research conducted in Poland [4,6,7] and abroad [8–12], it can be concluded that the concentrations of pollutants in stormwater coming from areas subjected to strong anthropogenic pressure differ significantly, even if the catchments are characterized by similar land use. Therefore, a hypothesis can be formulated that a typical composition of stormwater is impossible to establish. It depends on a number of factors, including air pollution [13,14], precipitation characteristics (duration, intensity and depth, and rainless period) [11], season (rainfall and snowmelt events) [15], wind direction, topography, and development of the catchment area (in particular the percentage of impervious surfaces) [16], the method of winter road clearing and maintenance, traffic volume, and technical condition of vehicles [4], the magnitude of pollutant deposition on the land surface [17], and even the type of roofing materials [18].

Precipitation and snowmelt waters are characterized by an uneven pollutant load discharges in a unit of time. It is assumed that the first flush phenomenon occurs when in the first phase of the stormwater flow, the pollutant concentrations are much higher than in the later period [19–21]. Relying exclusively on concentration values in defining the phenomenon being analyzed [22] is insufficient since it does not reflect the level of impact of a given indicator on the receiver aquatic environment. Additionally, when designing stormwater treatment facilities, to determine their capacity, it is important to apply pollution loads. The first flush phenomenon is most often defined by comparing the total pollution load with the accumulated runoff volume. It includes the pollutant mass percentage in a given stormwater/wastewater volume, expressed as a percentage (%M/%V). According to Saget et al. [23], such a phenomenon occurs when 80% of the pollutants are transported in 30% of the total outflow volume (80/30). Other authors, however, quantify the above relationship as 40–60/25 [24], 40/20 [25], 50/25 [26,27], and 80/20 [28].

Analyzing the research conducted in many countries (Japan [29], Italy [30], Korea [31], Australia [32], USA [33], and Poland [34]), it can be found that different conclusions are drawn with respect to the causes, pattern, and magnitude of the first flush phenomenon. In the case of stormwater sewer system, this phenomenon may occur frequently, but not for all precipitation events [25]. The significance of the first flush phenomenon is most often noticeable in small catchments with a high degree of sealing (the runoff coefficient in the range of 0.7–0.8), in contrast to larger catchments [20,35,36]. In the latter case, the phenomenon (if present) is much milder due to the mixing of different runoff flushes from the catchment within a long-time-interval.

Innovative approach to the analysis of the first flush magnitude and pattern can be found in the studies by Bach et al. [37] and Todeschini et al. [38]. The authors suggested that the first flush from the catchment could be quantified by means of the runoff volume that is necessary to lower stormwater pollutant concentrations in the catchment to background levels. In order to assess the runoff volume, the average pollutant concentrations for a given increment of discharged volume must be found. That is done by producing pollutographs of events The characteristic pollutograph is obtained with the use of non-parametric statistics. Runoff increments that are statistically indifferent (the so-called slices) are pooled together. When describing the dynamics of different types of pollutants in precipitation runoff, the method proves to be accurate and effective. Also, the method makes it possible to assess of the first flush magnitude, and to specify the runoff volume that is able to bring down pollutant concentrations to the background levels that are characteristic of a given catchment.

The aim of this paper is to analyze the occurrence of the pollutant first flush phenomenon in relation to TSS loads based on the pollutographs drawn for two different urban catchments.

2. Materials and methods

2.1. Study area

The research was conducted in two urban catchments of different sizes and characteristics of land use, located in Kielce, Poland (Fig. 1). In order to compare both areas, six specific land cover types were distinguished (Table 1): asphalt roads (including sidewalks), gravel roads, roofs, car parks (including squares paved with various materials such as asphalt, clay paver, cellular paving, and concrete slabs), and green areas (including playfields with surfaces other than asphalt or concrete).

The first catchment, located in the centre of Kielce (Fig. 1a), is intersected by the main traffic arteries of the city. The development includes mainly service buildings, high-rise residential buildings, and commercial buildings (including the provincial office). The total catchment area is 62 ha, and the highest and the lowest elevations of the area are, respectively: 271.2 and 260.0 m a.s.l., with an average gradient of 0.71%. The diameters of the primary channel, about 1.5 km long, vary from 600 to 1,250 mm, and those of the 17 side channels from 300 to 1,000 mm [6]. Before being discharged to the receiver (the Silnica River), the stormwater is pre-treated in the stormwater treatment plant (SWTP) located in IX Wieków Kielc Street (Fig. 1b). The facility consists of two horizontal settling tanks with a length of 30 m each, and a coalescence separator with a diameter of 3.0 m. The catchment is characterized by a high degree of land surface sealing, areas with a runoff coefficient above 0.8 constitute 51.5% of the total area, including asphalt roads 26.0%, car parks 14.3%, and 11.2% roofs (Table 1).

A separate sewer system operates in the catchments of concern, sanitary sewage, and storm or snowmelt waters are drained by different sewers.

The other catchment, located in the northern part of Kielce (Fig. 1a), has a typical industrial nature. Its area is dominated by service and production facilities, storage yards, and low-rise residential buildings that account for no more than 20% of the total catchment area which is 400 ha. The highest point of the land is at the ordinate 315.0 m a.s.l., and the lowest at 265.0 m a.s.l. The average land gradient is 2.65%. The degree of the catchment sealing is high, with asphalt and gravel roads accounting for 19.7%, roofs 11.5%, car parks 11.2% of the total area (42.4% altogether).

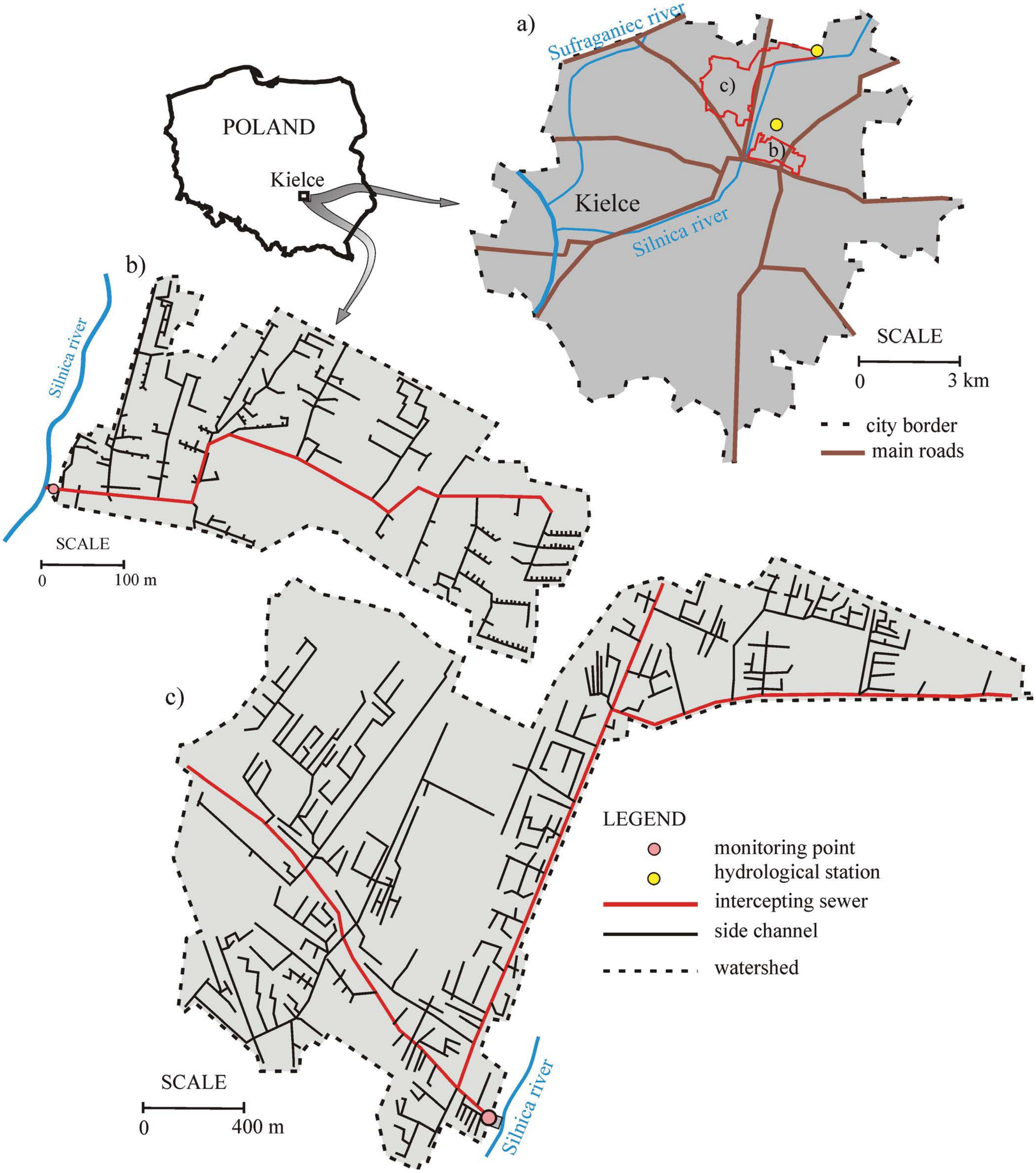

Fig. 1. Study area (a) location in the city of Kielce, (b) IX Wieków Kielc SWTP catchment, and (c) Jesionowa SWTP catchment.

The sewer system consists of two main collectors with diameters and lengths of 600–1,500 mm, 1.6 km, and 600–1,200; 3.2 km, respectively. The other lateral sewers (500–1,200) have a total length of approximately 10.5 km. The stormwater is discharged through four outlets to the Silnica River after being treated at the SWTP in Jesionowa Street (Fig. 1c). The facility consists of two process lines, each comprising vortex settling tanks with an internal diameter of 11.5 m, and a coalescence separator dimensioned 5.66 m × 2.36 m.

Table 1
Overview of the catchments studied

Catchment	Total area	Height difference	Average slope	Surface type				
				Roads		Car parks	Roofs	Green spaces
				Asphalt	Gravel			
	ha	m	%	ha				
IX Wieków Kielc SWTP	62	11.2	0.71	16.1	0.0	8.9	6.9	30.1
Jesionowa SWTP	400	50.0	2.65	45.2	33.6	44.8	46.0	230.4

2.2. Measurement apparatus

The measurement apparatus was installed in the sewer inlets to the separation chambers (monitoring point – Fig. 1) of both treatment plants. The test benches were equipped with automatic stormwater sampling devices of the ISCO 6712 type (Teledyne ISCO, Lincoln, NE, USA), meeting the requirements of the United States Environmental Protection Agency (US EPA).

The sampling frequency depended on the expected event duration (for rainfalls from 5 to 10 min, for snowmelt from 15 to 20 min), the number of samples (maximum 24 bottles, capacity 0.5–1.0 dm^3). The sampling device triggering was configured using a fill probe coupled to the device. Unstabilized samples were immediately transported to a chemical laboratory in order to determine the selected quality indicators. The TSS determination was performed according to the PN-EN 872:2007 Standard [39] (Jesionowa SWTP) and PN–72/C–04559 Standard [40] (IX Wieków Kielc SWTP).

2.3. Data analysis

On the basis of measurement results and analyses of stormwater quantity and quality in observed runoff waves, the following were determined: concentrations, loads and mass of TSS, and also volume of runoff waves. Instantaneous loads of TSS ($ł$) specified in sapling were calculated from Eq. (1):

$$ł = c_m \times Q, \quad \mathrm{g\,s^{-1}} \tag{1}$$

where c_m is the measured concentration of TSS (g m^{-3}), Q is the stormwater flow rate (m^3 s^{-1}).

To calculate cumulative loads of TSS in the peak runoff wave, it is necessary to know concentrations at an arbitrary moment of the event duration. To this end, the measured values of concentrations of TSS were smoothed using the equation of the form: $c_a = f(t^m)$ and $c_a = f(e^{mt})$, where t is the time from the event beginning, and m is the exponent. That allowed the determination of concentration values beyond the time intervals in which stormwater was sampled for analyses. The measure of the accuracy of the regression fit to empirical data was the coefficient of determination R^2. In a majority of peak flow events, R^2 values were closest to the value of "1" for the exponential function. The values of approximated loads of TSS in time t_i of the peak runoff event were calculated from Eq. (2):

$$ł_{ai} = c_{ai} \times Q_i, \quad g\,s^{-1} \tag{2}$$

where c_{ai} is the approximated concentration of TSS in time t_i (g m^{-3}), Q_i is the stormwater flow rate in time t_i (m^3 s^{-1}).

The cumulative mass of TSS M_{sum} which flew during the peak runoff event was determined from Eq. (3):

$$M_{\text{sum}} = \sum_{i=1}^{n}\left(\frac{ł_{ai} + ł_{a(i+1)}}{2}\right) \times \frac{\Delta t}{1{,}000}, \quad \mathrm{kg} \tag{3}$$

where $ł_{a\,i}$, $ł_{a\,(i+1)}$ are the approximated load of TSS for time t_i and time t_{i+1}, respectively (g s^{-1}), calculated from Eq. (2), n is the number of time steps, Δt is the time step, $\Delta t = t_{i+1} - t_i$ (s).

The cumulative volume V_{sum} of a given wave of the peak runoff event was calculated from Eq. (4):

$$V_{\text{sum}} = \sum_{i=1}^{n}\left(\frac{Q_i + Q_{i+1}}{2}\right) \times \Delta t, \quad \mathrm{m}^3 \tag{4}$$

where Q_i, Q_{i+1} are the flow rates in time t_i and time t_{i+1}, respectively (m^3 s^{-1}).

As regards time steps in Eqs. (3) and (4), the number n and the quantity Δt are 200–821 and 15–300 s, respectively. Those values are related to two different rates of data recording by flowmeters, which depended on the fill level of the sewer.

The characteristics of rainfalls causing the runoff analyzed and precipitation preceding them, including the rainless period, are summarized in Table 2. Moreover, the runoff parameters and basic statistics of the measured TSS concentrations (maximum, minimum, mean, and median) are shown in Table 3. The course of the selected first flushes, rainfall patterns, and TSS concentrations (measured and approximated) are shown in Figs. 2 and 3. In order to describe the first flush phenomenon, dimensionless graphs describing the relationship of the summarized general suspended solids mass M/M_{sum} vs. the summarized volume of the runoff V/V_{sum} were plotted (Figs. 4 and 5) showing curves for all first flushes studied. The reference of the results obtained to the literature criteria of the occurrence of the first flush phenomenon is given in Table 4.

Based on the analysis of stormwater drainage system operation, the following parameters were adopted in the study – minimum inter-event (rainless) time (t_{ie}): 4 h (DWA A-118 [41]) and minimum rainfall depth (P): 2.0 mm. Although average weighted catchment retention is higher

Table 2
Selected precipitation characteristics

No.	Date	Parameters of the precipitation of concern				Parameters of the precipitation that preceded the precipitation of concern				
		P	t_r	I_{avg}	I_{max}	t_{ie}	P	t_r	I_{avg}	I_{max}
		(mm)	(min)	(mm min^{-1})		(h)	(mm)	(min)	(mm min^{-1})	
IX Wieków Kielc SWTP										
K1	11.05.09	4.7	180	0.026	0.10	59	2.6	60	0.043	0.1
K2	10.11.09	5.2	424	0.012	0.10	28	2.8	204	0.014	0.10
K3	26.04.10	3.6	92	0.039	0.15	288	3.7	460	0.008	0.10
K4	05.05.10	6.6	298	0.022	0.30	14	8.1	544	0.015	0.20
K5	24.05.10	7.2	24	0.3	1.00	88	3.6	102	0.035	0.40
K6	30.05.10	5.4	56	0.096	0.80	153	7.2	24	0.3	1.00
K7	04.06.10	6.3	106	0.06	0.35	52	4.7	194	0.024	0.60
Jesionowa SWTP										
J1	29.04.18	5.8	140	0.042	0.58	62.7	2.1	23	0.091	0.27
J2	16.05.18	20.0	300	0.067	0.20	400.9	5.8	140	0.042	0.58
J3	17.05.18	14.2	964	0.015	0.47	4.3	20	300	0.067	0.20
J4	23.05.18	16.2	84	0.193	1.50	122.7	3.1	430	0.007	0.24
J5	12.06.18	12.2	418	0.029	0.20	421.5	5.4	71	0.076	0.90

Notations: P – cumulative precipitation depth during a rainfall event t_r, I_{avg} – mean precipitation intensity for time t_r, I_{max} – maximum precipitation intensity over the duration of one minute, t_{ie} – the inter-event time.

Table 3
Concentration, loads, and mass of TSS and basic parameters of runoff events

No.	Number of samples	Measured concentrations				Parameters of runoff events		
		Minimum	Maximum	Mean	Median	Q_{max}	t	V_{sum}
		(mg dm^{-3})				(m^3 s^{-1})	(min)	(m^3)
IX Wieków Kielc SWTP								
K1	8	144	287	222	250	0.076	120	200
K2	12	899	1,533	1,225	1,258	0.274	405	1,233
K3	9	60	100	83	88	0.111	262	327
K4	24	70	169	106	89	0.148	516	1,174
K5	9	90	150	117	112	0.173	164	425
K6	9	120	125	135	123	0.277	162	685
K7	14	70	177	106	89	0.312	215	756
K8*	12	4,181	7,432	5,514	5,422	0.042	515	672
K9*	12	3,281	6,675	4,654	4,328	0.037	540	607
Jesionowa SWTP								
J1	8	295	844	535	459	0.209	160	1,081
J2	24	315	10,621	2,160	855	4.494	320	46,801
J3	23	47	286	142	139	4.29	1,000	120,723
J4	16	35	827	161	130	4.53	150	20,643
J5	24	60	1,829	470	281	4.408	450	73,194

Notations: Q_{max} – maximum stormwater flow rate, t – total duration of the flow, V_{sum} – cumulative volume of the whole first flush event; *snowmelt runoff event (K8 – 23.02.10 and K9 – 24.02.10).

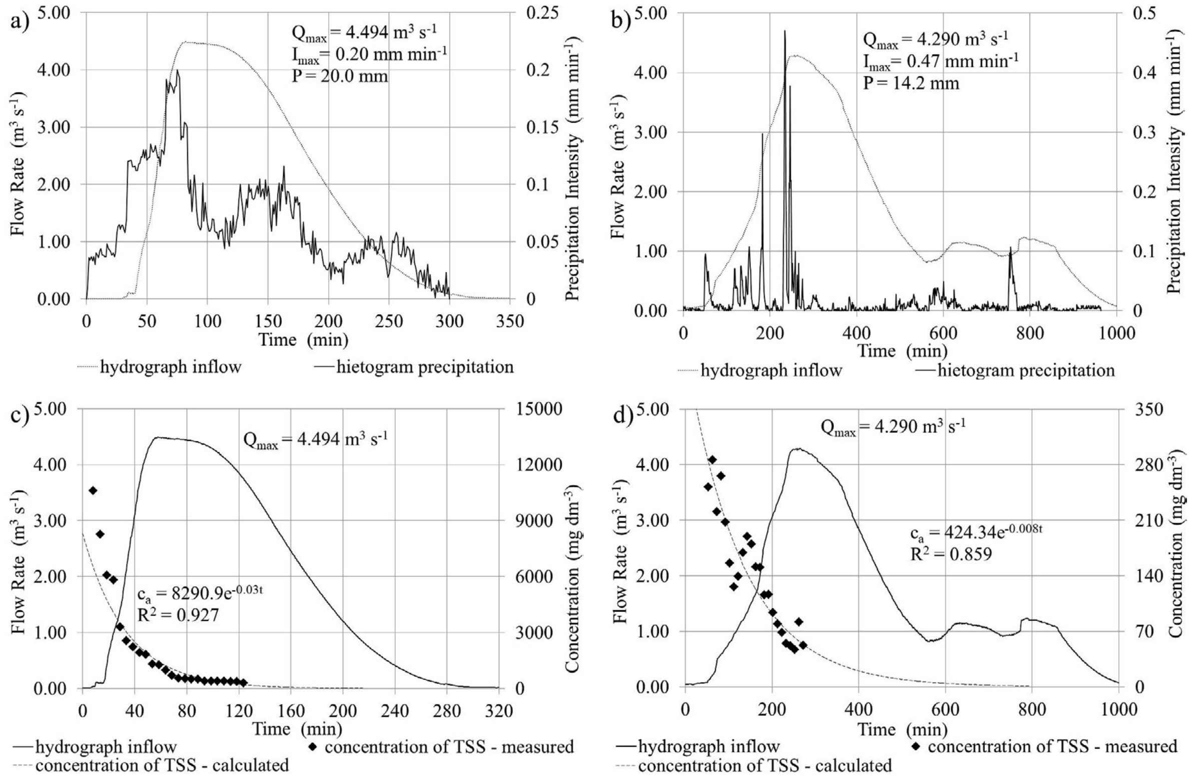

Fig. 2. Characteristics of selected peak rainfall runoff events on 16 May 2018 (a and c) and 17 May 2018 (b and d) for the Jesionowa SWTP catchment with respect to stormwater flow rate, precipitation intensity, and also concentrations of TSS.

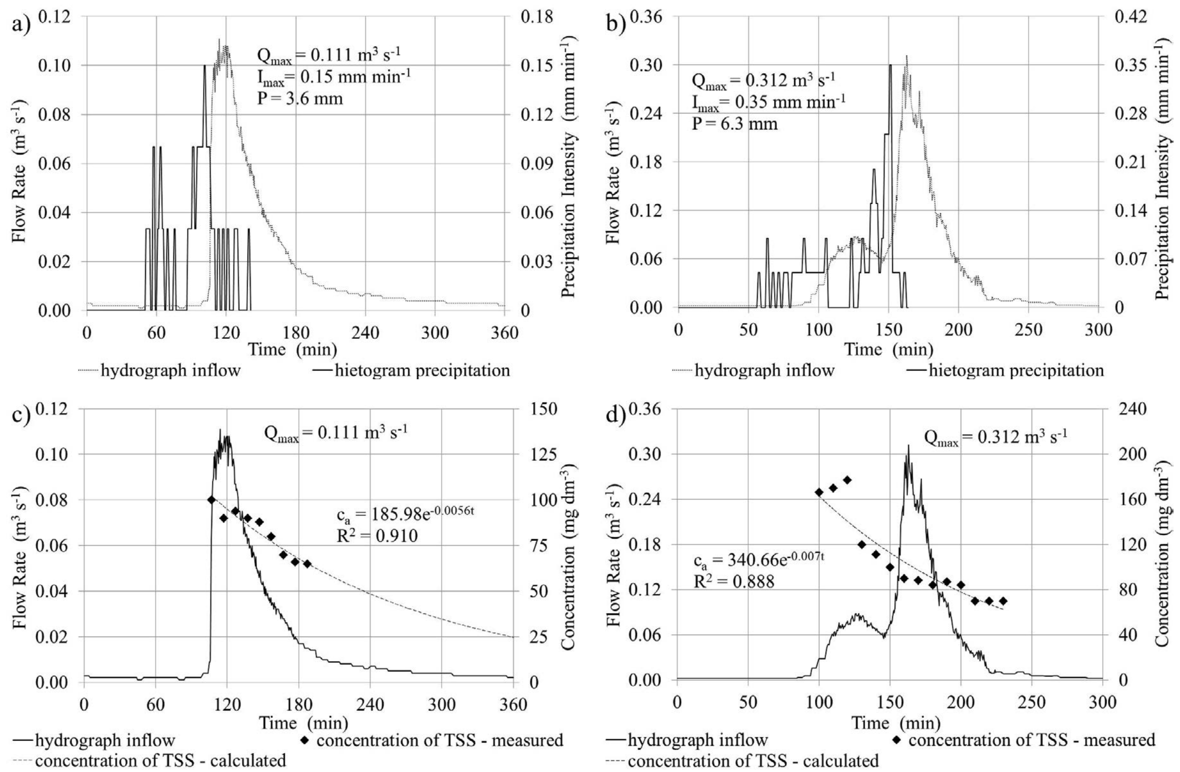

Fig. 3. Characteristics of selected peak rainfall runoff events on 26 April 2010 (a and c) and 04 June 2010 (b and d) for the IX Wieków Kielc SWTP catchment with respect to stormwater flow rate, precipitation intensity, and also concentrations of TSS.

Table 4
Analysis of the pollutant first flush occurrence

No.	Criterion %M/%V				
	80/30 [23]	40–60/25 [24]	40/20 [25]	50/25 [26,27]	80/20 [28]
K1–K9	N	N	N	N	N
J1–J3, J5	N	Y	Y	Y	N
J4	N	Y	N	N	N

Notations: Y – occurs, N – does not occur.

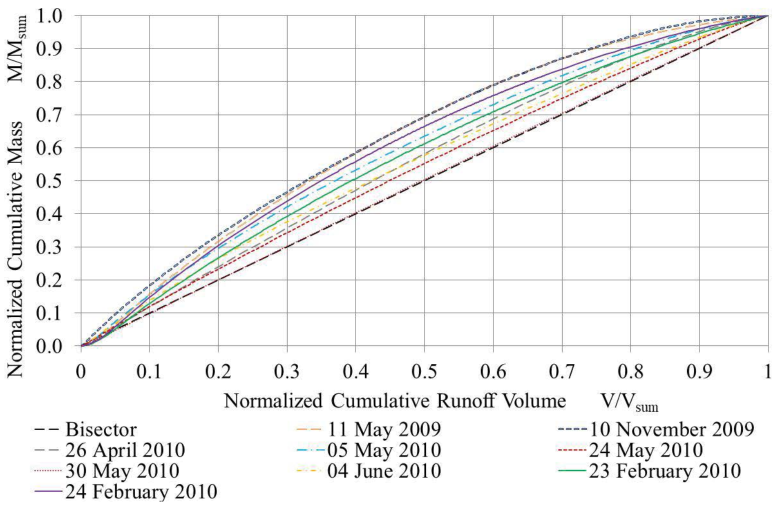

Fig. 4. Dimensionless curves of cumulative TSS mass vs. cumulative discharged volume for the IX Wieków Kielc SWTP catchment.

and amounts to 3.81 mm [42], rainfall with smaller P value may induce runoff, which is determined by specific rainfall distribution within the catchment area.

3. Results and discussion

Nine events (K1–K9) from the period 2009–2010 recorded for the IX Wieków Kielce SWTP catchment were chosen for analysis (including two snowmelt events K8 and K9). As regards the Jesionowa SWTP catchment, five events (all of them resulting from rainfall events) (J1–J5) from 2018 were taken into account. The precipitation events had distinctly different characteristics regarding the rainfall depth (P), its duration (t_r), and the maximum (I_{max}) and mean rainfall intensity (I_{avg}) (Table 2).

The first flushes studied showed a different pattern, and the maximum flow rates were several times higher in the Jesionowa SWTP catchment (maximum 4.530 $m^3 s^{-1}$) than in the IX Wieków Kielc catchment (maximum 0.313 $m^3 s^{-1}$) – Table 3. That resulted not only from the precipitation characteristics, but it was substantially affected by the catchment size and the associated surface runoff height. The rainfall depths for events J1–J5 varied from 5.8 to 20.0 mm, whereas for events K1–K7, the depths ranged from 3.6 to 7.2 mm. The values t_r varied accordingly: in the ranges 24–424 min and 84–964 min. For the runoff pattern and dynamics, the I_{max} is significant (Figs. 2 and 3). The value ranged 0.20–1.50 mm min^{-1} for the Jesionowa SWTP catchment, and for the other catchment it was 0.10–1.00 mm min^{-1}. The maximum value of I_{avg}, found in the event K5, was associated with a very short t_r = 24 min. For times t_r above 400 min, I_{avg} varied from 0.012 to 0.029 mm min^{-1}. Additionally, the rainfalls preceding the events analyzed were characterized, including the duration of the rainless period t_{ie} which was the highest for events J2 and J5 (400.9 and 421.5 h, respectively) – Table 2. In that case, it had an effect on the concentrations of TSS which reached the highest values among rainfall first flushes (J2 – maximum 10,621 mg dm^{-3}, J5 – maximum 1,829 mg dm^{-3}). Comparable values of TSS concentrations were only found for snowmelt events in the IX Wieków Kielce SWTP catchment (K8 – maximum 7,432 mg dm^{-3}, K9 – maximum 6,675 mg dm^{-3}) – Table 3. However, it should be noted that the concentrations of TSS for the J2 event must be considered with caution since, in the catchment, in the immediate vicinity of the SWTP, earthworks started, connected with the construction of four multi-family residential buildings. Precipitation depth of P = 20.0 mm could have caused washing out of deposits built up in the sewer and the sampler probe could have been periodically covered with mineral suspension, consequently so high concentrations of TSS were observed. The TSS value range obtained for the J2 event (315–10,621 mg dm^{-3}) fit within the range specified by Królikowski et al. [15] for an urban catchment in Białystok (10–40,000 mg dm^{-3}), but the values are more than twice as high as those found in Serbia (189–4,820 mg dm^{-3}) according to the studies carried out in Belgrade center, in the car park

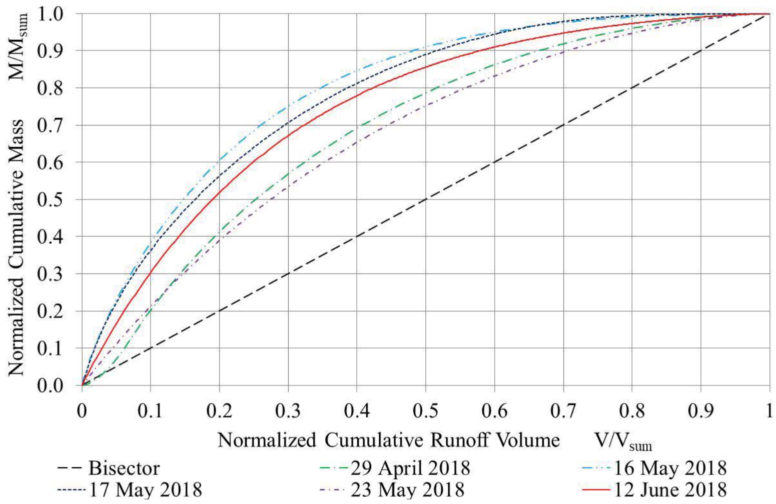

Fig. 5. Dimensionless curves of cumulative TSS mass vs. cumulative discharged volume for the Jesionowa SWTP catchment.

of the University of Belgrade [43]. Majority of the maximum TSS concentrations in rainfall events in the IX Wieków Kielc SWTP catchment (K1, K3–K7) is congruent with the data from studies carried out in Paris (maximum 254 mg dm^{-3}) [44] and Lahti (maximum 348 mg dm^{-3}) [45].

TSS concentrations are notably reduced during the event, which may indicate a greater pollutant runoff in the first phase of water flow in the sewer. A more dynamic drop in TSS concentrations is found in the Jesionowa SWTP catchment (Figs. 2c and d) than in the IX Wieków Kielc catchment (Figs. 3c and d). However, only the calculation of the TSS mass based on the recorded flows gives an indication of the strength of the first flush phenomenon. The shape of the curves showing the percentage of the mass of pollutants in a given volume of water, indicates a clearly different course in both catchments studied (Figs. 4 and 5). For the SWTP IX Wieków Kielc catchment, those curves are gentler in shape, close to the straight section (bisector) expressing an even M/V ratio, and, for the first flush of 30 May 2010, virtually coinciding with that section (Fig. 4). Assuming the given criteria (Table 4), it can be concluded that the first flush phenomenon did not occur in any of the events examined. The first 30%, 25%, and 20% of the runoff volume carried up to 47%, 40%, and 34% of the TSS mass. Those are lower value ranges than those provided by Li et al. [46] for the catchment of Wuhan (1.3 km^2) in China, where the research demonstrated that 30% of the surface runoff removed 52.2% – 72.1% TSS. Quite similar results were reported by Nazahiyah et al. [47] for the Skudai catchment (Malaysia) with a housing development, where 20%–30% of surface runoff washed 15% – 78% of TSS.

The dimensionless curves made for the SWTP Jesionowa catchment, however, showed a completely different pattern (Fig. 5). In all events in the first phase of the runoff, the pollutant runoff is much greater than it was in the IX Wieków Kielc catchment. The initial 30%, 25%, and 20% of the cumulated runoff volume carried respectively: from 53% to 75%, from 47% to 69%, and from 39% to 60% of the TSS mass. According to the criterion adopted by Vorreiter and Hickey [24], it can be concluded that the first flush phenomenon occurred for all events of concern. However, applying the 40/20 criterion [25] and 50/25 [26,27], four out of five events could be classified as first flushes, that is, except for those of May 23, 2018 (J4) – Table 4. None of the events meets the 80/30 [23] or 80/20 criteria [28].

The results obtained demonstrate that the first flush phenomenon is not always notably intense in small catchments, or those with a high surface sealing degree. Even though the 62 ha area studied (SWTP IX Wieków Kielc) was characterized by a significant percentage of sealed surfaces (51.5%), with a substantial runoff coefficient (above 0.8), no first flush phenomenon was observed. However, in the other catchment, industrial in character, with a much greater total area (400 ha) but a similar degree of sealing, the first flush occurred several times (depending on the criterion adopted). In addition to a specific land use in the catchment area, the phenomenon is affected by substantial duration of rainless periods that preceded individual events, and also several times greater precipitation depths. Infrastructural projects carried out in a given area were also an important contributing factor.

4. Conclusions

The means of reducing the adverse impact of stormwater on the aquatic environment has been investigated for many years. When planning and designing sewer systems for anthropogenically transformed areas, the issues related to the effect of stormwater must be dealt with. The first flush phenomenon, as defined in the literature, is not always observed. The analysis of data obtained from the urban catchments in Kielce demonstrated that for the IX Wieków Kielc SWTP, the first flush phenomenon did not occur in any of the nine events. Conversely, for the Jesionowa SWTP catchment, the phenomenon was observed in most events. The distribution of TSS load depends, to a large extent, on the percentage of sealed surfaces in the catchment (especially those that are subject to cleaning and winter maintenance), the intensity of rainfalls and their distribution over time, season of the year (rainfalls and snowmelts) and rainless periods. The length of the inter-event period, however, was not a crucial factor in the case of the IX Wieków Kielce SWTP catchment.

The study shows that majority of pollutants cannot be assumed to be captured by just catching the first flush and directing it to the SWTP processing facilities. Without conducting field research, it is safer to make an assumption that pollutant first flush is not present. If the occurrence of the first flush is confirmed by investigations, when taken into account, it might affect the dimensioning of stormwater overflow or capacity of TSS settling tanks.

For the majority of events, higher concentrations of TSS were observed at their first phase than in the final phase. For the IX Wieków Kielc SWTP catchment, those values were approximately twice as high, while for the Jesionowa SWTP catchment, they were nearly 30 times higher.

For the TSS concentrations measured, the calculated average values do not generally reflect the average condition of stormwater contamination. The reason for that are the outlier values, mostly the maximum ones. As a result, it seems reasonable to apply the values of medians when estimating the pollution level.

Dimensionless nature of the adopted first flush identification approaches disregards the impact of the stormwater volume. Consequently, the adopted approach, by itself, is not useful when developing guidelines for decision taking and sizing criteria in stormwater quality control.

Acknowledgments

This research was funded from the program of the Minister of Science and Higher Education entitled "Regional Initiative of Excellence" in 2019–2022 project number 025/RID/2018/19 financing amount PLN 12,000,000.

Project co-funded by the European Union from the European Regional Development Fund Operational Program of the Świętokrzyskie Voivodship for the years 2007–2013. Project number UDA-RPSW, 02.01.00–26–005/11–00 – purchase of pluviometer.

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