INTERNATIONAL JOURNAL
OF
CONSERVATION SCIENCE

ISSN: 2067-533X Volume 12, Special Issue 1, August 2021: 713-730 www.ijcs.ro

STORMWATER AS AN ALTERNATIVE WATER SOURCE: QUALITY CHANGES WITH RAINFALL DURATION AND IMPLICATIONS FOR TREATMENT APPROACHES

Aleksandra PIENIASZEK[1] , Ewa WOJCIECHOWSKA[1*], Eliza KULBAT[1],
Nicole NAWROT[1], Janusz PEMPKOWIAK[2], Hanna OBARSKA-PEMPKOWIAK[1],
Krzysztof CZERWIONKA[1]

[1] Gdańsk University of Technology, Faculty of Civil and Environmental Engineering, Narutowicza 11/12, 80-233 Gdańsk, Poland

[2] Institute of Oceanology Polish Academy of Sciences, Marine Geotoxicology Laboratory, Powstańców Warszawy 55, 81-712 Sopot, Poland

Abstract

The pressure on the world's water resources is rapidly increasing due to population growth and climatic changes. Valorisation of stormwater as a water resource for non-potable reuse can reduce high-quality water demands and save it for potable uses. In this context, not only roof runoff but also drained stormwater outflow, representing considerably higher pollution levels, should be considered as a potential resource. We analysed the quality of stormwater runoff from the municipal separate sewer system in a residential catchment located in a medium-sized town in Poland. The changes in concentrations of TSS, COD, BOD_5*, and E. coli with rainfall duration were assessed during 7 torrential rainfalls with an intensity exceeding 15 L/s·ha. The concentrations of contaminants in the "first flush" of stormwater varied from 93 to 1598 mg/L TSS, from 112 to 815 mg* O_2*/L for COD, and from 7 to 48 mg* O_2*/L for* BOD_5 *and significantly dropped with rainfall duration. The number of E.coli in stormwater outflow fluctuated from* $2.5\cdot10^3$ *to* $8.1\cdot10^5$ *MPN/100 mL. Rapid filtration on sand filters was applied in laboratory-scale for the treatment of raw stormwater outflow, providing removal efficiencies of 87-88% for COD, 50-90% for TN, and 88-96% for TP. The quality of raw and treated stormwater was discussed with regard to the existing and developing European standards for water reuse. The results from our study show that treated stormwater outflows can be applied for landscape irrigation. Moreover, rapid filtration is appropriate for stormwater treatment and can be applied either with the support of pre-sedimentation or even as the only separation process.*

Keywords*: Stormwater; Resource; Harvesting; Rainfall duration; Alternative water sources*

Introduction

The linear model of water consumption, where freshwater is abstracted, digested, and finally released as wastewater (not fully treated on some occasions) is still the global norm. However, climatic change may force societies in both developing and developed regions to change the linear model of water consumption and adapt a circular economy strategy in the water sector within a relatively short timeframe [1, 2]. Cities, rapidly expanding in terms of both size and population, face unprecedented water shortages, leading to the more and more frequent urban droughts [3] as the water demands increase and water supply relying on freshwater or groundwater resources diminishes at the same time. To maintain the water

---

[*] Corresponding author: esien@pg.edu.pl

balance, alternative supply sources, like stormwater, grey water or treated wastewater are needed, since diversification of water sources seems to be the most reliable strategy to cope with water deficiencies and to increase urban resilience in the forthcoming decades [4].

Poland, with a population of 38.5 million people, is one of the European countries where climatic changes may lead to water shortages. Freshwater resources of Poland are estimated at $61.9 \cdot 10^6$ m^3. The water resources per capita are only equal to 1585m^3/year, which is substantially lower than the EU average of 8000m^3/year [5]. Due to the Water Exploitation Index (WEI), which is a ratio between the mean annual total abstraction of freshwater and the long-term average freshwater resources, Poland is already at the edge of water stress, as the WEI values oscillate only slightly below 20%, which is considered to be the limit above which water resources may be too low to cover the water needs. In the years 1999-2015 WEI raised above 20% three times and the situation is worsened due to a series of dry summers in the years 2013-2019 (with an exception of 2017). Some regions of central Poland already faced deficiencies in water supply in summer 2019, although total water abstraction by public water supply per capita is one of the lowest in the EU (53.4m^3 per capita) [5]. The climate change scenarios for Poland prognose the raise of average winter temperature by 3.5-5ºC, the raise of mean summer temperature by 3-3.5ºC, and diminishing snow fall and snow cover which will cause severe water shortages in the early stage of the vegetation season. The rainfall prognosis is unclear, but generally, the share of winter precipitation in the annual precipitation is going to rise, while summers will be dry and hot with occasional torrential rainfall events causing flood threats [1, 6].

Despite the quality degradation of the existing water resources in Europe and the fact, that domestic water consumption is one of the highest in the world, no legislative regulations of water reuse exist in the EU [7, 8]. However, scarcity of water resources has forced countries in the Mediterranean region to develop the reuse of treated wastewater. Currently, all Mediterranean countries, except Malta, have established national criteria for the reuse of water, focused mainly on agricultural applications (Table 1).

Table 1. Water reuse criteria in 6 EU-Mediterranean countries based on *Paranychianakis et al*. [7] and *Norton-Brandão et al*. [10].

Country		**Cyprus**	**France**	**Greece**	**Italy**	**Portugal**	**Spain**
Parameter	**Unit**						
TSS	mg/L	10[1] – no limits[2]	15[3] - *)	2[4] - **)	6.0 – 9.5	-	10 - 35
COD		-	60 - *)	-	100	-	
BOD_5		10[1] – 70[2]	-	10[4] – not defined[5]	20	-	
TN		-	-	45[6]	15[7]	-	10
TP		-	-	-	2[8]	-	-
E.coli	cfu/100mL	-	250L/week – no limits[9]	200[5] (median)	10[10]	-	0 - 10000
Faecal coliforms	MPN/100mL	5[1] – 10000[2]	-	-	-	100[11] – 10^4 [12]	-
Total coliforms	cfu/100mL	-	-	5 (80% samples) 20 (95% samples)[5]	-	-	-

[1] These values must not be exceeded in 80% of samples/month; all crops, but the irrigation of vegetables is not allowed; [2] Industrial crops; [3] Unrestricted irrigation of all crops including these accessed by the public; [4] Urban uses: public parks, recreational facilities, fire protection etc.,periurban green; [5] Restricted irrigation: Areas where public access is not expected, fodder and industrial crops, pastures, trees etc.; [6] 15 mgN/L in cases of vulnerable areas irrigation; [7] 35.0 mg N/L for irrigation use; [8] 10.0 mg P/L for irrigation use; [9] Forests with no access; [10] The limit must be met in 80% of samples, and none of them must exceed 100cfu/100 mL; [11] Vegetables consumed raw; [12] Cereals (except rice), vegetables for industrial process, crops for textile industry, crops for oil extraction, forest and lawns in places of restricted or controlled public access; *) In accordance with wastewater treatment standards (all crops except those consumed raw or green areas with public access; other ornamental crops, shrubs, cereals; horticultural crops drip irrigated, forests with controlled access; forests with no access); **) According to CMD 5673/400/1997 Greek wastewater regulation

Table 2. Minimum EU requirements for the reuse of water in agricultural irrigation as proposed by the European Parliament in comparison with the Polish Water Law Act

	Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse1)				**Council Directive 91/271/EEC2)**	**Polish Water Law Act3)**
	A	B	C	D		
TSS [mg/L]	≤10	According to Council Directive 91/271/EEC			35 (60)*)	100
COD [mgO$_2$/L]	-	-	-	-	125	
BOD$_5$ [mgO$_2$/L]	≤10	According to Council Directive 91/271/EEC			25	
E.coli [cfu/100mL]	≤10	≤100	≤1000	≤10,000		
Turbidity	≤5	-	-	-		
Other	*Legionella* spp.: <1,000 cfu/L where there is risk of aerosolization in greenhouses; Intestinal nematodes (helminth eggs): ≤1 egg/L for irrigation of pastures or forage.					

1)Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse COM/2018/337 final - 2018/0169; 2) Council Directive 91/271/EEC; 3)The Water Law Act dated 20 July 2017 published in the Polish Journal of Laws on August 23, 2017 (Dz.U. 2017 poz. 1566); *) 35 mg/L more than 10 000 p.e. and 60 mg/L from 2000 to 10 000 p.e. (population equivalent).

In spite of this, stormwater reuse can be a remedy for water shortages in some regions. The non-potable usage of stormwater could reduce potable water demand, following the concept proposed by *Goonetilleke et al*. [4] of "water fit for purpose" meaning that water of the highest quality should be saved exclusively for direct consumption while for other uses it can be replaced by the water of reduced quality. Currently, open-space irrigation of urban green areas seems to be the closest perspective of treated stormwater reuse. According to NRMMC-EPHC-NHMRC [10], other reuse options include toilet flushing, car washing, street cleaning, firefighting, food crop irrigation (home grown or commercial), as well as agricultural and industrial uses. All pose a higher risk in terms of human contact and require more stringent criteria, especially microbiological, than landscape irrigation. In the case of irrigation, contact can be minimised by partial public access restriction (to certain areas or during certain hours). Due to the absence of fit-for-purpose water quality requirements, the criteria for landscape irrigation could be based upon class D requirements according to European Commission [9] or on the requirements for industrial crops irrigation according to national regulations adopted in some Mediterranean countries (Table 1).

The huge difference in the quality of roof runoff and drained stormwater outflows has to be distinguished [11]. While the first type is relatively clean and the reuse creates low health and ecological risks, the latter may exhibit different and fluctuating pollution levels due to washing out of numerous pollutants from the urban catchments, including solids, oil, grease, organics, and nutrients as well as heavy metals, PAHs, PCBs, alkyl-phenols, phthalates, and VOCs [12-14] and pathogens [15]. The type and concentration of pollutants in stormwater are largely affected by the land use [16, 17] although it also differs with climatic and weather conditions, mostly, rainfall frequency, intensity, and duration, as well as the duration of the dry period preceding rainfall event [18]. Though the first flush effect and its negative impact on stormwater quality is a known phenomenon, the research studied describing the changes of stormwater composition in time during the rainfall event in the recent years are scarce. Moreover, Müller et al. [13] emphasize that a recent couple of years may have brought a serious change in the composition of stormwater runoff due to the implementation of new technologies and rapid advancements in clean manufacturing and pollution control, thus the previously reported data on stormwater quality may be dated. The temporary high fluctuations in stormwater volume and composition create serious challenges for providing safe and stable quality in case of reuse, thus prohibiting stormwater utilisation on a wider scale. Hence, the first step to be undertaken towards stormwater valorization for landscape irrigation is recognition of the quality fluctuation during rainfall events.

The objective of the study was to analyse the quality of stormwater runoff from the separate municipal sewer system in a residential catchment located in Świecie, a medium-sized town in Poland, in the context of reuse for urban landscape irrigation. The chosen town is located in the Kujawsko-Pomorskie province, which is one of regions the most seriously struck with rainfall deficiencies and droughts in recent years. The important aspect of our study was the assessment of the changes in stormwater outflow composition with rainfall duration. The quality of the stormwater drain outflow was assessed within 10 minutes intervals during 7 torrential rainfalls with an intensity exceeding 15L/s·ha. The effectiveness of purification of stormwater collected during subsequent time intervals during rapid filtration on sand filters was tested. The quality of the drained stormwater outflow was discussed with regard to the existing and developing European standards for water reuse. The findings of our study contribute to the state-of-the-art concerning the quality of stormwater outflows and prospective treatment efficiencies with one of the available treatment technologies (rapid filtration on sand beds) for the reclamation of stormwater to be reused for landscape irrigation.

Experimental part

Study site description

Świecie is a town of 26,000 inhabitants located in the northern part of Poland, in the Kujawsko-Pomorskie voivodship (Fig. 1), at the inflow of river Wda to the Vistula river.

The sewer system in Świecie can be partly classified as combined and partly as separate. There are also many cross-connections between both systems. The municipal wastewater is collected from 94.5% of utilities. The stormwater sewer system is fully gravitational. The stormwater receivers include open ditches, lakes Large and Small Blankusz, the Struchawa Stream, and the river Wda. The town is divided into 22 catchments with a total area of 548.3ha. The largest catchment covers an area of 102.3ha. The storm sewers range in diameter from 200 to 1000mm. The outlets are equipped with pre-treatment devices consisting of sand traps and oil separators (Masterplan of modernisation and development of the sewerage system of Świecie, [19]).

The studied stormwater catchment area of 4.006 ha is located in the central part of Świecie. From the south, the catchment area borders the Struchawa Stream. The location of the catchment area with marked sampling points is presented in Figure 2.

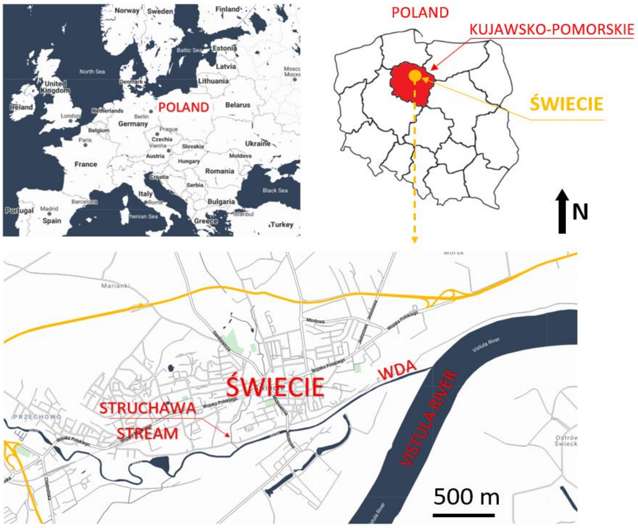

Fig. 1. Location of the study area; source: http.snazzymaps.com

The land use of the catchment is mostly residential with single-family and row houses. There are two large public buildings in the area: a primary school and a sports and entertainment hall. There is also a public park adjacent to the Struchawa Stream. The paved area constitutes approximately 56.8% of the total area. The sewer system is fully separate with no cross-connections between the sanitary and storm sewers, which were carefully checked by study analysis and field surveys prior to selecting the investigation area. The storm sewer diameters range from 250 to 800 mm. The outlet of the drainage system is located at the Struchawa Stream (Fig. 2).

Fig. 2. The analysed stormwater catchment in Świecie with the marked sampling point

Sampling

The sampling of stormwater was performed between September 2019 and June 2020. The samples were collected from one of the outlets of the urban drainage collection system in Świecie. The rainfall depth, duration time, and intensity were also recorded.

Stormwater outlet

Stormwater samples were collected during 7 torrential rainfall events (with rainfall intensities ≥15L/s·ha) between September 2019 and June 2020 from the outlet (800 mm diameter) of the analysed catchment into Struchawa Stream. The location of the sampling point is marked in figure 2 (D_out). Once the rainfall started, the outlet was observed and the moment of the first outflow was noted. The first sample was collected within the first 5-10min from the moment when the outflow started. The subsequent samples were collected in 10min time intervals. In the case of rainfall 1, the sampling schedule was somewhat different: the delay between the outflow start and the collection of the first sample was about 20 min and then the subsequent samples were collected in 20min intervals. This sampling schedule was forced by the fact that the initial outflow volume was very small. Four subsequent samples were collected for each rainfall. The time schedule of the sampling is presented in figure 3.

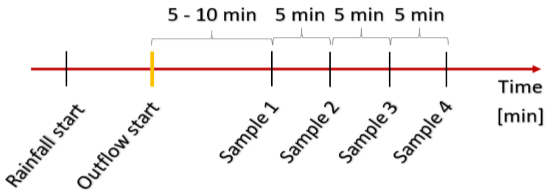

Fig. 3. Time schedule of samples collection from storm water drain outlet to the Struchawa Stream

The samples were collected by a 14L polypropylene sampling device and transferred to smaller laboratory vessels to determine the total suspended solids (TSS) – 1000 mL; organics (BOD_5 and COD) – 1000mL and *Escherichia coli* – 200mL sterile vessels. In the case of rainfalls 6 and 7, additional samples (5L) for the filtration experiment were collected. The sub-samples were stored in a portable refrigerator until the end of the sampling campaign and then transported to the laboratory in cooling conditions (temperature below 4°C). The laboratory analyses were conducted within 2-3 hours after the samples were delivered. The sampling dates and corresponding rainfall characteristics are given in Table 3.

Table 3. Characteristics of the analysed rainfalls

Rainfall number	**Date**	**Total height**	**Duration**	**Maximum intensity in 5 min intervals***	**Time of the peak flow (since the beginning of the rainfall)**	**Time of the peak flow (since the beginning of the outflow)**
	(date)	(mm)	(min]	($L\cdot s^{-1}\cdot ha^{-1}$)	(min)	(min)
rainfall 1	09 Sept 2019	1.819	12		18	8
rainfall 2	17 Sept 2019	1.213	10	30.301	26	16
rainfall 3	19 Sept 2019	0.758	7	15.167	14.5	8.5
rainfall 4	29 Oct 2019	1.516	15	30.301	19	9
rainfall 5	04 Nov 2019	1.061	13	20.204	18	8
rainfall 6	12 March 2020	6.518	13	467.34	12	9
rainfall 7	18 June 2020	9.852	24	208.42	16.5	8.5

* maximum of 5 minutes intervals intensities calculated according to formula (1)

Rainfall characteristics

The rainfall height was measured using two compact weather stations Netatmo NWS03 that have a declaration of compliance with EU Directive 2014/53/EU [20] and ROHS 2011/65/EC [21]. The wind direction and velocity, air moisture, and temperature were also recorded (data not shown). The weather stations were mounted on flagpoles secured with a ballasting plate, placed in an open space at a minimum distance of 3.0m from buildings or trees.

The rainfall gauges were mounted at a height of 1 m above terrain level. The weather stations were equipped with WiFi modems and power banks to enable the online transfer of the measurement data. The measurement data were recorded in 5 min intervals. The rainfall intensity q [L/s·ha] was calculated using the formula (1):

$$q = 166,7\frac{H}{t}\ [L\cdot s^{-1}\cdot ha^{-1}] \qquad (1)$$

where: q – rainfall intensity ($L\cdot s^{-1}\cdot ha^{-1}$); H – rainfall height (mm); t – rainfall duration time (min).

The basic characteristics of rainfall, including, rainfall height, duration, and maximum intensity are presented in Table 3.

Analytical methods

In the raw stormwater samples the concentrations of organic matter expressed in total COD (tCOD) (after homogenization) and dissolved COD (dCOD) (after filtration through 0.45µm pore size Millipore nitrocellulose filters, Billerica MA, USA), BOD_5, total nitrogen (TN), total phosphorus (TP) as well as the total suspended solids (TSS) were determined. The COD, TN, and TP concentrations were also determined in the effluents from the filtration column.

TN concentrations were determined using a TOC analyser (TOC-V_{CSH}) coupled with a TN module (TNM-1) (SHIMADZU Corp., Kyoto, Japan). COD and TP concentrations were established using Hach-Lange cuvette tests on a DR2000 spectrophotometer (Dr Lange GmbH, Berlin, Germany). The BOD_5 was analysed using the manometric respirometric BOD OxiTop® method. The concentrations of TSS were made in accordance with Standard Methods for Examination of Water and Wastewater [22]. All determinations were carried out in 3 replications.

For identification of coliforms and *E. coli*, the modern Colilert testing method developed by IDEXX was used, which detects coliforms and *E. coli* in water within 24 hours [23, 24]. To confirm the results, the standard method for the isolation of coli-thermotolerant bacteria by membrane analysis on m-FC medium [22] was used.

Rapid filtration experimental setup

A filtration experiment was performed in order to test the removal efficiency of colloidal and particulate pollutants from stormwater. Stormwater samples 1-4 collected during rainfall 6 were used in the experiment. The laboratory setup consisted of a filtration column made of organic glass (Plexi). The dimensions of the filtration column were 4cm (diameter) and 110cm (total height). The filtration medium consisted of the following layers (from the bottom): 10cm support layer composed of gravel (diameter 5-7mm) and 40cm of filtration layer composed of quartz sand (diameter 1-2mm). The maximum level of water above the filtration medium was 55cm, which was secured by the emergency overflow. The raw stormwater was dosed at the top of the filtration column by the feeding system equipped with a peristaltic pump. The filtrate was collected by the overflow system at a regulated level. During the experiment, the overflow was fixed at the top level of the filtration medium. The capacity of the peristaltic pump was adjusted to the assumed filtration velocity equal to 5m/h, which corresponds to the lower velocities used in a rapid filtration process [25]. The scheme of the laboratory filtration setup is presented in figure 4.

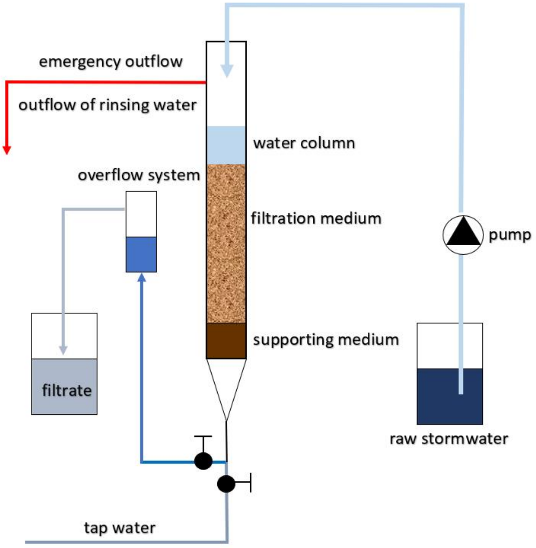

Fig. 4. Scheme of laboratory rapid filtration setup

The samples of the filtrate were collected after passing a minimum of 3 volumes of supporting medium, filtration medium, and 10cm layer of water above the filtration medium (together 60cm height, which corresponded to 0.75L). This sampling scheme was adapted to ensure that the tap water used for filter rinsing after each experiment was removed before the filtrate sample was collected. During the experiment, the water level above the filtration medium was also measured starting from the beginning until 25min into the test, with time intervals of 1, 2.5, and 5min in order to establish the change of filtration resistance to the flow.

Results and discussion

Concentrations of contaminants in drained stormwater outflow vs irrigation requirements

Total suspended solid

The concentrations of TSS in stormwater outflow to Struchawa Stream vs rainfall duration time are presented in figure 5. In absence of specific requirements for stormwater reuse for irrigation, the TSS concentrations were compared to the levels defined by European Commission [9] corresponding to A, B, C, and D water classes (Table 2), marked with horizontal lines in figure 5. For classes B-D a reference concentration of 35mg/L was adopted, as the stricter of two TSS levels defined in Council Directive 91/271/EEC [26] (Table 2).

During all rainfall events, the TSS concentrations decreased with time, according to the "first flush" phenomenon [11, 18]. Generally, the TSS concentrations for the samples 1-2 were above 100 mg/L, which is the maximum allowable concentration in stormwater sewer outflows according to Polish regulations (Water Law 2017 [27]). In the last series of samples (collected 25-35min after the outflow started) the TSS concentrations decreased to below 100mg/L in some cases (rainfalls 1 -3). During the same three rainfall events, the value of 35mg/L recommended by the European Commission [9] was almost reached, though during other rainfall events the TSS concentrations after 35min were still well above this limit.

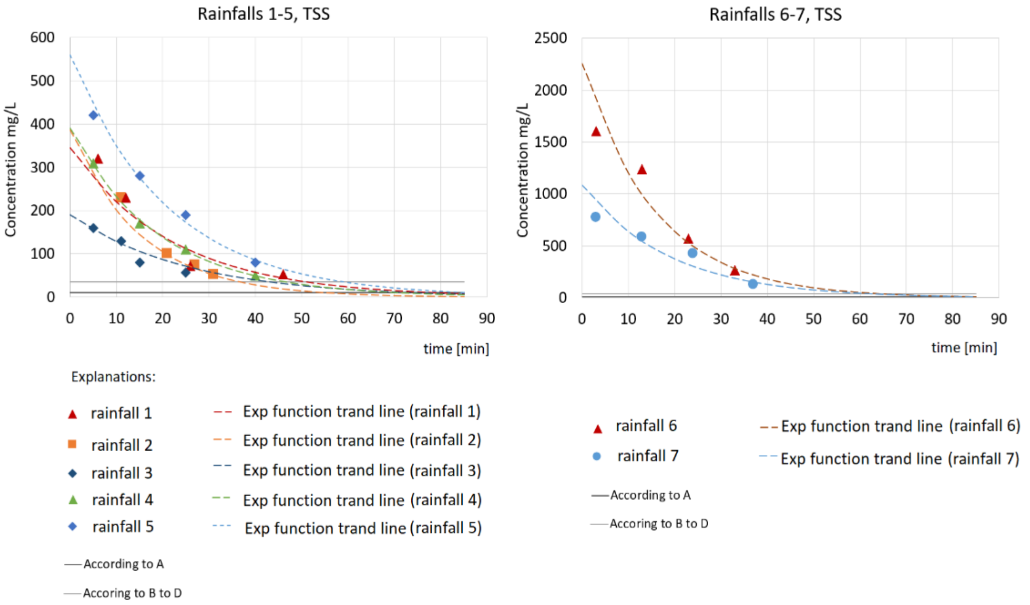

Fig. 5 Concentrations of TSS [mg/L] in stormwater collected from the outlet to Struchawa Stream vs time of rainfall [min]. Please note: time "0" is the moment when the first outflow was observed. Please also note the different scale for rainfalls 6-7. A-D – water classes based on the proposal for a Regulation of the European Parliament and of the Council [9]

The outstandingly high concentrations of TSS were observed for samples collected during rainfall 6, which occurred in March 2020. This rainfall event, definitely the highest in terms of depth and intensity, also produced an extensively polluted outflow, with the initial TSS concentration of almost 1600mg/L, while the highest value measured during autumn rainfalls was 320mg/L. Though the TSS concentrations decreased substantially in subsequent samples, the concentration was still 258mg/L after almost 35 minutes. The second highest TSS concentrations were measured for rainfall 7 (18th June 2020). The TSS concentrations obtained for the rainfalls 1-5 fitted within the range of values (11 – 430mg/L) reported by *Zgheib et al.* (2012) [12] for three storm sewers outflowing to the Seine in Paris and its suburbs (data from 20 rainfall events). However, the enormously high TSS concentrations measured during rainfalls 6 and 7 exceeded not only the values reported by *Zgheib et al*. [12] but also those from other studies. *Lee & Bang* [28] reported a maximum TSS of 874 mg/L; a similar concentration (864mg/L) was also detected by *Ociepa et al.* [29] in stormwater runoff from a motorway in Częstochowa (Poland). Furthermore, in a study performed in Österlund, Sweden [30] the highest TSS concentration was 670mg/L. These extremely high concentrations obtained in our study resulted from the high rainfall intensities (Table 1) which caused dynamic wash-off. Correlation between TSS concentration and flow rate in storm sewers was confirmed by *Galfi et al.* [30]. Another relevant factor in the case of rainfall 6 was the fact that it occurred in early spring when the soil surface was exposed and no green cover was present yet. This can account for the intensification of the wash-off processes, as described in earlier studies [31-33]. It is worth noting that rainfalls 1-5 were autumn rainfalls, while rainfalls 6 and 7 occurred in spring and summer, accordingly. This shows that either rainfall characteristics or wash-off dynamics can be season dependent.

COD AND BOD$_5$

Polish regulations do not limit the COD and BOD$_5$ concentrations in stormwater outflows. The Proposal for a Regulation of the European Parliament and of the Council [9] only sets the limit for BOD$_5$ at 10mg O_2/L for class A and 25mg O_2/L for classes B, C, and D, following the quality requirements of Directive 97/271/EEC [26]. Obligatory COD concentrations are not defined in the proposal, so here we used the value of 125mg O_2/L defined in the Directive 97/271/EEC [26] as a reference concentration. The COD concentrations in our analyses showed a decreasing trend with rainfall duration, though in case of rainfall 5 COD concentrations oscillated near 50mg O_2/L in three first samples (Fig. 6). The maximum concentrations again were measured for rainfalls 6 and 7 (827 and 541mg O_2/L, respectively). COD concentrations for autumn rainfalls 1-5 were definitely lower, in the range from approximately 50 to 250mg O_2/L in the samples collected in the first minutes of rainfall duration. The COD concentrations for rainfalls 1-5 were similar to the results from the study conducted by *Zgheib et al.* [12] in Paris who reported the concentration range from 14 to 320mg O_2/L. The COD concentrations measured for rainfall 6 was closer to the values reported for combined sewer overflows [34]. On the other hand, *Lee & Bang* [28] reported the range of COD concentrations in stormwater sewer outflow at between 70 and 1455mg O_2/L. The COD values for the autumn rainfalls decreased below 125mg O_2/L in subsequent 10 or 20 minutes, while in the case of spring and summer rainfall 6 and 7 through the decreasing tendency was strong, the limit of 125mg O_2/L was not reached even in samples collected after 45 minutes from the beginning of the precipitation (Fig. 6).

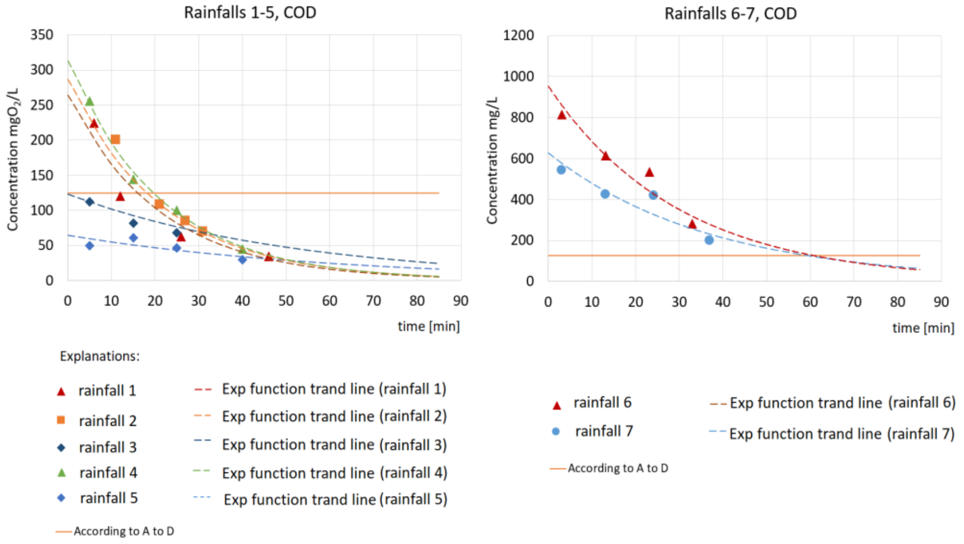

Fig. 6 Concentrations of COD [mg O_2/L] in stormwater collected from the outlet to Struchawa Stream vs time [min]. Please note: time "0" is the moment when the first outflow was observed. Please also note the different scale for rainfalls 6-7. A-D – water classes based on the proposal for a Regulation of the European Parliament and of the Council [9]

The BOD$_5$ concentrations also tended to decrease with rainfall duration time (Fig. 7). The concentrations for the initial samples (taken during the first 10 minutes of rainfall duration) varied in a broad range from 7mg O_2/L for rainfall 5 to 48mg O_2/L for rainfall 4. Surprisingly, BOD$_5$ concentrations for rainfall 6 were not higher than for other rainfall events, as observed for TSS and COD, indicating that organic matter was mostly present in a barely biodegradable form (COD), like plant litter after winter. This was in line with the high TSS concentration observed during this rainfall event.

The only pronounced difference was the fluctuation of BOD_5 concentrations in subsequent samples (there was an increase in concentration between 15 and 25 min of outflow, followed by another drop in concentration). In the case of six rainfall events (except for rainfall 6) the BOD_5 concentration after 25min from the start of the outflow was below 25mg O_2/L (the limit value for B, C, and D quality classes). In the case of two rainfalls events (rainfalls 1 and 5) the BOD_5 concentration measured in the final sample was even below 10mg O_2/L, which corresponded to quality class A. In the case of rainfall 6, the BOD_5 concentration also dropped below 25mg O_2/L, although this took longer (around 35 minutes after the outflow start). The BOD_5 concentrations for rainfalls 1-6 were similar or lower to the average value (54mg O_2/L) reported for the urban catchments [11].

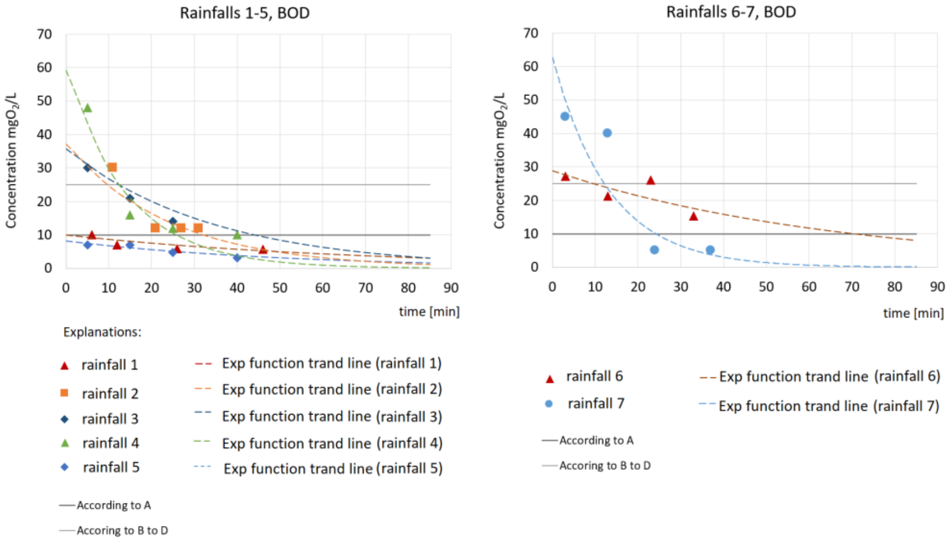

Fig. 7. Concentrations of BOD_5 [mg $_{O2}$/L] in stormwater collected from the outlet to Struchawa Stream vs time [min]. Please note: time "0" is the moment when the first outflow was observed. Please also note the different scale for rainfalls 6-7. A-D – water classes based on the proposal for a Regulation of the European Parliament and of the Council [9]

Nutrients

Concentrations of TN and TP were measured for rainfalls 6 and 7 (Fig. 8), so the data set obtained in this study is limited. However, the rainfalls 6 and 7 were characterized by the highest intensity among all analysed rainfall events. Also the concentrations of TSS and COD were significantly higher than during other rainfalls, so the TN and TP concentrations measured for this rainfall could potentially outline one of the higher contamination levels. The TN and TP concentrations in stormwater were compared to the values set in the Directive 97/271/EEC [26] (15mg N/L and 2 mg P/L, respectively) since the Proposal for a Regulation of the European Parliament and of the Council [9] does not define the recommended nutrient concentrations. Also, Polish regulations [27] do not set minimum concentrations of TN and TP in stormwater outflowing to freshwater receivers.

Both TN and TP concentrations decreased for subsequent samples taken in 10-minute. In the case of TN, only the concentration in the initial sample exceeded the recommended value of 15mg N/L, while in terms of TP, the recommended level of 2mg/L was reached in the third sample in case of rainfall 6 and in the second sample in case of rainfall 7. The TP concentrations for rainfall 6 were close to the 0.3-3.52mg/L range reported by Zgheib et al. [12]. Despite the fact that the initial level in our study was slightly above the reported range, the concentrations in subsequent samples already fitted within it. In case of rainfall 7 the concentrations of TP in all subsequent samples were within the range reported by *Zgheib et al.* [12].

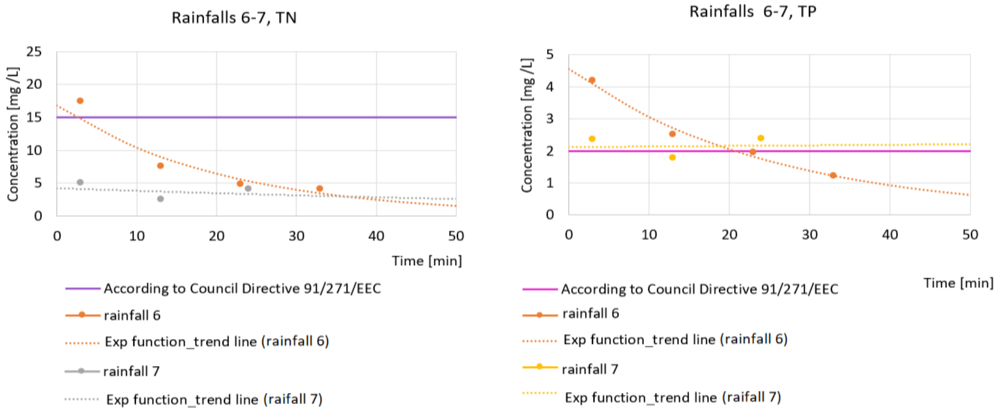

Fig. 8. Concentrations of TN and TP [mg/L] in stormwater collected from the outlet to the Struchawa Stream vs time of rainfall [min] – rainfall 6 and 7

Faecal indicator bacteria (FIB)

The numbers of *Esherichia coli* in the stormwater samples collected from the outlet to Struchawa Stream are presented in figure 9. The horizontal lines on the graphs correspond to the proposal of a Regulation of the European Parliament and of the Council on minimum requirements for water reuse: minimum reclaimed water quality classes C and D.

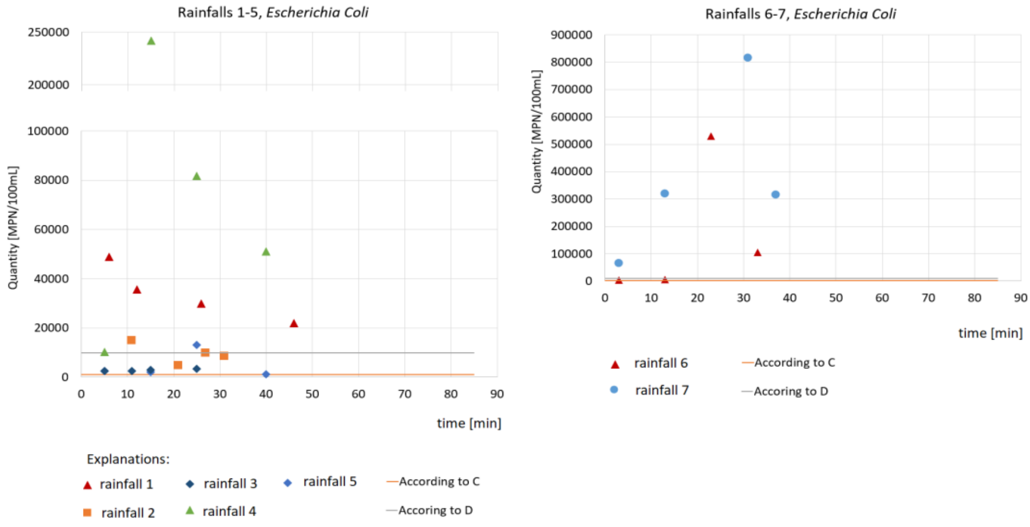

Fig. 9. Quantity of E.coli [MPN/100 mL] in stormwater collected from the outlet to Struchawa Stream vs time of rainfall [min]. Please note the different scale for rainfalls 6-7. C-D – water classes based on the proposal for a Regulation of the European Parliament and of the Council [9]

Generally, the microbiological quality of stormwater collected from the outlet to Struchawa Stream was poor. The level of 10^4MPN/100mL (corresponding to water quality class D) was frequently exceeded. It was quite characteristic that the number of coliform bacteria grew with time – in the case of rainfalls 4, 5, 6, and 7 the increases were sharp. The high *E.coli* number could be due to some faecal contamination of the stormwater, although the catchment area was carefully chosen to avoid cross-connections between sanitary and storm sewers.

Nevertheless, some faulty or illegal connections between both systems could account for the bad microbiological quality of collected stormwater. *Sidhu et al.* [35] observed *E. coli* numbers in stormwater from the municipal area of Brisbane, Australia between $8 \cdot 10^1$ (dry period) and $1 \cdot 10^3$ per 100 mL (wet period) – a level similar to rainfalls 3 and 5 in this study. According to NRMMC-EPHC-NHMRC [11], the average *E.coli* number in drained stormwater from urban catchments was $5.9 \cdot 10^4$. *Parker et al*. [36] reported concentrations of FIB in runoff samples collected during storm events in North Carolina (USA) as high as $2.39 \cdot 10^6$ and $1.20 \cdot 10^5$MPN per 100mL for total coliforms and *E. coli*, respectively. *Galfi et al.* [30] analysed FIB in stormwater outflows from four types of catchments: recreational, residential, mixed land-use, and institutional in Östersund, Sweden, characterised by an absence of sanitary and storm sewers cross-connections. The levels of coliforms were highest for recreational catchments (from $2.5 \cdot 10^2$ to $2 \cdot 10^5$), while the *E.coli* numbers were highest in the residential area (from 10^1 to $1.3 \cdot 10^4$). These discrepancies in results obtained in different studies confirm that the FIB ranges in stormwater can vary greatly. Probably, the rainfall intensity may turn out to be one of the key influencing factors apart from the land use of the stormwater catchment. In the case of our study, all the measurements were conducted for rainfall with the intensity over 15L/s·ha and rainfall 6 was characterised by the highest intensity. Unfortunately, we did not find the rainfall characteristics in the studies reporting FIB levels in stormwater. On the other hand, cluster analysis performed by *Galfi et al.* [30] indicated a correlation of FIB to other stormwater constituents, which in turn were correlated to the flow rate.

Removal of contaminants during rapid filtration

Results from our study on the quality of drained stormwater from a residential catchment generally correspond well to the ranges reported in the literature in case of autumn rainfalls [11, 12, 30]. However, the concentrations measured during rainfall 6 and 7 (specifically TSS) were outliers from the reported range, probably due to rainfall high intensities combined with the season. The concentrations of TSS, as the only parameter defined in Polish legislation [27] in stormwater outflows, clearly exceeded the limit value of 100mg/L. Beyond the question of potential stormwater reuse, these shows that pre-treatment of stormwater discharge is relevant for maintaining the good ecological status of surface waters. Also, high *E.coli* levels in stormwater can affect the status of receiving water bodies. While considering landscape irrigation reuse, the treatment of stormwater is also required.

Filtration is a basic treatment process used for clearing of stormwater, tertiary treatment of wastewater, and water reclamation. Both slow filtration [37] and rapid filtration [38, 39] can be used. In our study, filtration treatment was conducted for stormwater samples collected during rainfall 6 characterized with very high TSS concentrations, typical for raw wastewater rather than for stormwater (Fig. 5). Since the previously performed investigations [25] confirmed the feasibility of applying rapid filtration (4-12.5m/h) to pre-treat raw wastewater, we decided to employ rapid filtration in our study, without pre-treatment of stormwater in the sedimentation process. Despite very high initial TSS concentrations, the effluent from sand filters after a rapid filtration process with 5m/h filtration velocity was visually clarified. That was in line with the findings of Williams et al. [39], who reported low turbidity in the filtrate received during rapid filtration of biologically treated wastewater (1.06 NTU with filtration velocity of 12.2m/h), which corresponded to 80% removal of turbidity. The concentrations of contaminants and treatment efficiencies obtained in our study for rainfall 6 samples are presented in figure 10.

Removal of suspended fractions during filtration resulted in a substantial decrease of COD concentration to a level about two times as high as dCOD (except for sample 4, were both concentrations were similar). The efficiency of COD removal was high and varied between 87.2% and 87.9%. This confirms that the majority of contaminants in stormwater runoff were associated with solids. *Langeveld et al.* [40] reported only 36% COD removal efficiency from stormwater during rapid filtration (at 10m/h), significantly lower than in our study. Furthermore, the removal of COD from biologically treated sewage (rapid filtration at 5m/h) in 3 treatment plants in Kuwait was considerably lower and varied from 22 to 38% [38]. A COD removal efficiency similar to our study (80%) was achieved in a slow filtration process through sand filters (0.1m/h) preceded by sedimentation in traditional wet detention ponds as the first treatment step [37]. Recently, *Gavrić et al*. [41] provided an extensive review of stormwater treatment in grass swales, reporting COD removal efficiencies ranging from 3 to 84%, with the upper range on a level similar to this study.

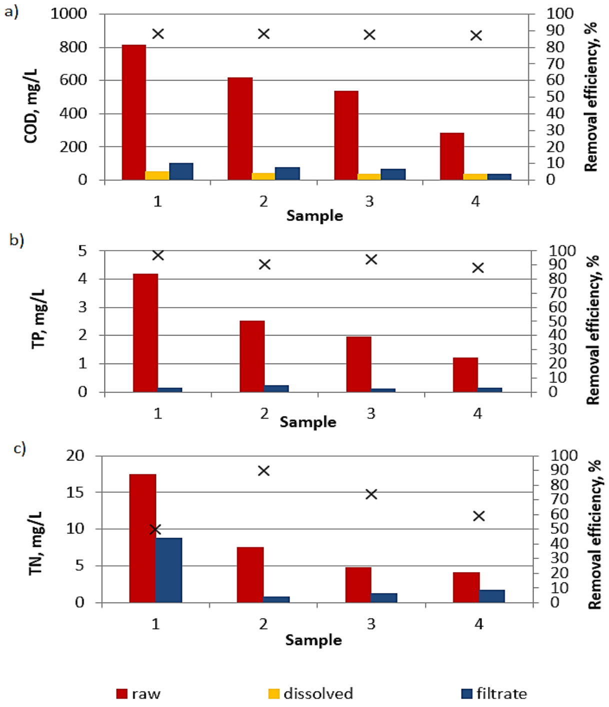

Fig. 10. Concentrations and removal efficiencies of contaminants in raw stormwater (rainfall 6) and in the effluent from filtration columns (filtrate) a) COD (also dCOD), b) TP, c) TN. Please note: samples 1, 2, 3, 4 – subsequent samples collected during rainfall 6: sample 1 – 5 min after the outflow started; samples 2-4 in 10 min intervals

Additionally, in the case of TP, the concentrations in the effluent from quartz sand filters dropped to very low values (from 0.116 to 0.235mg P/L), which corresponded to removal efficiencies of between 88 and 96%. Quartz sand has no sorption capacity for phosphate ions; hence, the high TP removal efficiency clearly indicates that phosphorus was mainly present in a suspended form. The TP removal efficiencies through quartz sand filters reported in the literature are considerably lower both for slow (28%) [37] and rapid filtration (53%) [39].

The efficiency of TN removal varied between the samples. For samples 1 and 4, it ranged between 50-60% while for samples 3 and 2 it was higher (70% and 90%, respectively). TN concentration in the filtrate varied from 0.7 to 1.7mg N/L for samples 2-4, while for sample 1 it was significantly higher (8.8 mg N/L). This could suggest that nitrogen was present in ammonia or organic form since TKN removal efficiencies during rapid filtration through sand filters (mean 38%) were reported [40]. Again, this suggests the existence of some cross-connections between the storm and sanitary sewers.

Due to the fact that no sedimentation was performed prior to filtration, there was a risk of clogging the surface layer of the filtration bed, which would cause a substantial increase of flow resistance and the rise of water level above the filtration bed. The initial flow resistance for pure quartz sand in our setup amounted to 0.05m. Figure 11a presents the increase in flow resistance during the first 25min of the filtration process.

For each sample, the resistance initially grew significantly and then stabilised. The time needed for flow resistance stabilisation depended on the TSS concentration in raw stormwater and could be described with the formula (2):

$$\Delta H = 0.0002TSS + 0.0251 [m\ of water\ column] \quad (2)$$

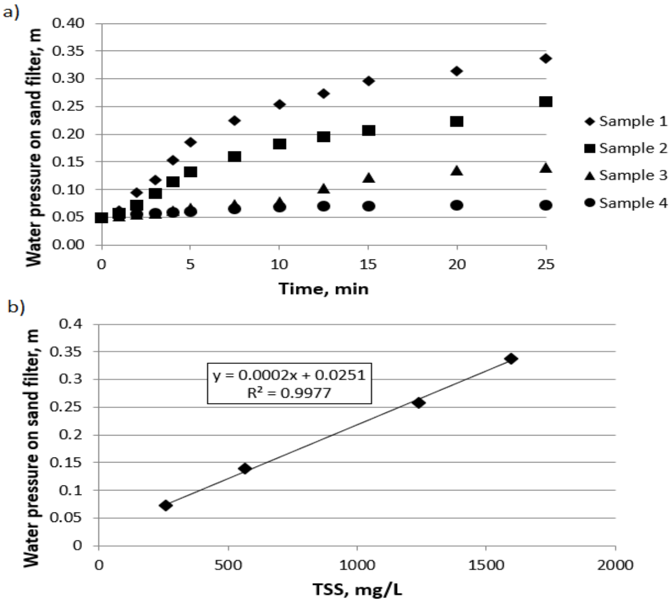

Fig. 11. Flow resistance during filtration of stormwater collected during rainfall 6 change in time for samples 1-4 and flow resistance as a function of TSS concentration in raw stormwater samples

The coherence of the experiment results with the curve was very high, which is confirmed by correlation factor $R^2 = 0.998$ (Fig. 11b).

During the investigations performed by *Vollertsen et al*. [37], the increase of flow resistance during slow filtration of stormwater through the horizontal sand filter (0.1m/h), proceeded by sedimentation in traditional wet detention ponds varied from 0.05 to 0.15m, depending on the outflow from the facility. Comparing to our experiment, the flow resistance for samples 1-2 stabilised at a higher level, while in the case of samples 3-4 the flow resistance was lower (below 0.15 and below 0.1 for samples 3 and 4, respectively).

Considerations on stormwater treatment prior to reuse for landscape irrigation

Due to Australian guidelines [9], there are three objectives of stormwater treatment when reuse for landscape irrigation is planned: a) associated with ecological hazards, b) associated with health hazards, and c) required to assure the technical reliability of irrigation devices. To summarise these goals can be called: a) environmental, b) health, and c) technical. The environmental hazards include potential impacts on plants and soils that can become polluted as a result of stormwater application; according to NRMMC-EPHC-NHMRC [9], the probability is low. The next criterion, associated with public health, is definitely of the greatest concern, as was also pointed out by *Bichai & Aschbolt* [8]. To minimise health hazards, two parallel prevention routes should be established. One of them relies on effective disinfection and quality control under fit-for-purpose elaborated legislative framework. The second prevention route is based upon the appropriate organisation of the irrigation process. The solutions minimising human exposure include using drippers (especially subsurface) as a preferable irrigation technique and restricting the public access by using delineation fences and borders, information signs, etc. According to NRMMC-EPHC-NHMRC [9], spray irrigation is only permitted for low-throw sprinklers and in areas with 25-30m buffer zones from the irrigation perimeter. Finally, technical issues associated with providing a long life span of irrigation installation will focus on some additional irrigation water parameters like turbidity, hardness, or Fe concentration that can result in blocking the irrigation system units. Stormwater storage requires the removal of organic matter to avoid decomposition processes and odours, as well as nutrients to prevent algal blooms in storage tanks.

The basic treatment line of stormwater, consisting of the equilibration step, followed by sedimentation, filtration, and disinfection is presented in figure 12a. The equilibration step helps equalise the contaminant concentrations and offers an emergency buffer in the event of accidents leading to unexpected quality drop like major sewer overflows inside the catchment. In the sedimentation step, coarse solids are removed which enables high filtration efficiency in the next stage. The filtration process can be performed in many devices including sand filters, biofilters, constructed wetlands, vegetated swales, and other bioretention units [42]. In the case of disinfection, the UV radiation seems the most convenient option, though other processes (ozonation, chlorination, electrochemical oxidation) can also be applied [43, 44]. As stated by *Goonetilleke et al*. [4] technical solutions are already available.

Basing on the results of this study obtained for rainfall 6 with a contamination level considerably exceeding previously reported values, a simplified line of stormwater treatment including rapid filtration and final disinfection is possible. The scheme of an example treatment line based on rapid filtration is presented in figure 12b. The results of our study also show that rapid filtration offers effective treatment of even upmost contaminated first flush with the outstandingly high concentrations of TSS and COD.

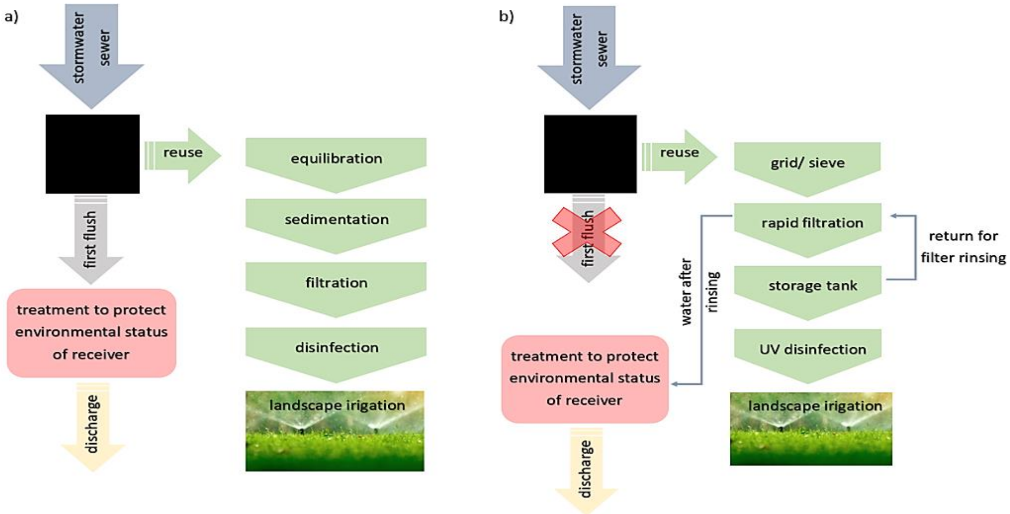

Fig. 12. a) Proposition for a typical treatment line for stormwater for landscape irrigation reuse and b) Scheme of a treatment line for stormwater for landscape irrigation reuse based on a rapid filtration process

This is of particular interest in view of the perspective of climate change and summer droughts threatening Poland and other European countries. As the summer rainfalls are likely to become rare but very intensive, it would be beneficial to harvest and treat the whole outflow and store it for the irrigation of green areas during forthcoming droughts. The treatment proposed in figure 12a-b addresses environmental, health, and technical objectives, though additional checking of hardness would be advised to protect the irrigation system against blocking. Fe concentrations are not likely to pose problems while using the rapid filtration treatment method since this is a commonly used process for Fe removal.

Conclusions

Stormwater as an alternative water resource remains underestimated. Landscape irrigation seems to be the closest perspective of stormwater reuse due to the low probability of direct human contact and minimised health risks. Difficulties in stormwater reuse are associated with huge quality fluctuations between rainfall episodes and rainfall duration time. The results of our study performed for a residential catchment in a medium-sized town in Poland showed fluctuations of the contaminants concentration in the “first flush” stormwater from 93 to

1598mg/L TSS, from 112 to 815mg O_2/L for COD and from 7 to 48mg O_2/L for BOD_5. Chemical contaminant concentrations considerably decreased with rainfall duration time for all analysed rainfall episodes. The amount of *E.coli* in stormwater outflow ranged from $2.5 \cdot 10^3$ to $8.1 \cdot 10^5$MPN/100mL. The highest level of contamination was observed during high-intensity rainfalls that occurred in early spring and in the summer season. The rapid filtration treatment applied to raw stormwater collected during this spring rainfall was successful in contaminant removal, providing the treatment efficiencies of 87-88% for COD, 50-90% for TN, and 88-96% for TP. The rapid filtration method proved to be adequate for stormwater treatment. It can be applied either with the support of pre-sedimentation or even as the only separation process. In both cases, disinfection of stormwater before reuse would be mandatory.

The key implication from our study is that drained stormwater can be reused for landscape irrigation when properly treated and that rapid filtration can be applied as a reliable treatment option even of the upmost contaminated first flush. Definitely, in view of water deficiencies and perspectives for climate change, irrigation reuse of drained stormwater should draw more attention as it would enable the savings of potable water. The elaborating of fit-for-purpose criteria and management practices, taking into account the differences between stormwater and treated wastewater composition, is a key challenge.

Acknowledgments

The study was carried out as a part of a Ph.D. thesis by Aleksandra Pieniaszek, Gdansk University of Technology, Poland. The authors wish to thank Waterworks and Sewerage Company in Świecie, Poland for the assistance and support throughout this study.

References

[1] N.W. Arnell, B. Lloyd-Hughes, *The global-scale impacts of climate change on water resources and flooding under new climate and socio-economic scenarios*, **Climatic Change**, **122**, 2014, pp. 127–140. DOI 10.1007/s10584-013-0948-4

[2] N.W. Dunford, A.C. Smith, P.A. Harrison, D. Hanganu, *Ecosystem service provision in a changing Europe: adapting to the impacts of combined climate and socio-economic change*, **Landscape Ecoli, 30**, 2015, pp. 443–461 DOI 10.1007/s10980-014-0148-2

[3] X. Zhang, N. Chen, H. Sheng, C. Ip, L. Yang, Y. Chen, …, D. Niyogi, *Urban drought challenge to 2030 sustainable development goals*, **Science of the Total Environment**, **693**, 2019, Article Number: 133536. https://doi.org/10.1016/j.scitotenv.2019.07.342

[4] A. Goonetilleke, A. Liu, S. Managi, C. Wilson, T. Gardner, E.R. Bandala, L. Walker, J. Holden, M.A. Wibowo, S. Suripin, H. Joshi, D.M. Bpnotto, D. Rajapaksa, *Stormwater reuse, a viable option: Fact or fiction?* **Economic Analysis and Policy, 56,** 2017, pp. 14-17.

[5] * * *, https://ec.europa.eu/eurostat/[accessed on 8th August 2020].

[6] * * *, **National Energy and Climate Plan for the years 2021-2030**, https://www.gov.pl/web/klimat/national-energy-and-climate-plan-for-the-years-2021-2030 [accessed on 8th August 2020].

[7] N.V. Paranychianakis, M. Salgot., S.A. Snyder, A.N. Angelakis *Water Reuse in EU States: Necessity for Uniform Criteria to Mitigate Human and Environmental Risks*, **Critical Reviews in Environmental Science and Technology**, **45**(13), 2015, pp.1409-1468, DOI: 10.1080/10643389.2014.955629.

[8] F. Bichai, N. Ashbolt, *Public health and water quality management in low-exposure stormwater schemes: A critical review of regulatory frameworks and path forward*, **Sustainable Cities and Society 28**, 2017, pp. 453-465.

[9] **European Commission,** *Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse*, **Journal of Chemical Information and Modeling, 53**(9), 2018, pp. 1689–1699. https://doi.org/10.1017/CBO9781107415324.004 and Annexes to the Proposal.

[10] D. Norton-Brandão, S.M. Scherrenberg, J.B. van Lier, *Reclamation of used urban waters for irrigation purposes – A review of treatment technologie*s, **Journal of Environmental Management, 122**, 2013, pp. 85-98.

[11] * * *, **Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse** (Phase 2). Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra, 2009.

[12] S. Zgheib, R. Moilleron, G. Chebbo (2012). *Priority pollutants in urban stormwater: Part 1 - Case of separate storm sewers*, **Water Research**, **46**(20), 2012, pp. 6683–6692. https://doi.org/10.1016/j.watres.2011.12.012.

[13] A. Müller, H. Österlund, J. Marsalek, M. Viklander, *The pollution conveyed by urban runoff: A review of sources*, **Science of The Total Environment**, **709**, 2020, Article Numbner: 136125, https://doi.org/10.1016/j.scitotenv.2019.136125.

[14] N. Nawrot, E. Wojciechowska, S. Rezania, J. Walkusz-Miotk, K. Pazdro, *The effects of urban vehicle traffic on heavy metal contamination in road sweeping waste and bottom sediments of retention tanks*, **Science of The Total Environment**, **749**, 2020, Article Number: 141511, https://doi.org/10.1016/j.scitotenv.2020.141511.

[15] W. Ahmed, K. Hamilton, S. Toze, S. Cook, D. Page, *A review on microbial contaminants in stormwater runoff and outfalls: Potential health risks and mitigation strategies*, **Science of the Total Environment, 692**, 2019, pp. 1304-1321.

[16] S. Zgheib, R. Moilleron, G. Chebbo, *Influence of the land use pattern on the concentrations and fluxes of priority pollutants in urban stormwater*, **Water Science and Technology, 64**(7), 2011, pp. 1450-1458.

[17] H. Song, T. Qin, J. Wang, T.H.F. Wong, *Characteristics of Stormwater Quality in Singapore Catchments in 9 Different Types of Land Use*, **Water, 11**(5), 2019, Article Number: 1089; https://doi.org/10.3390/w11051089

[18] B. Wijesiri, A. Liu, A. Goonetilleke, *Impact of global warming on urban stormwater quality: From the perspective of an alternative water resource*, **Journal of Cleaner Production, 262,** 2020, Article Number: 121330.

[19] * * *, **Masterplan of Modernization and Development of Sewerage System for Świecie City**, Division of water and sewage engineering Aqua-Project in Bydgoszcz, Bydgoszcz 2016.

[20] * * *, Directive **2014/53/EU** of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the member states relating to the making available on the market of radio equipment and repealing directive, 1999/5/EC.

[21] * * *, Directive **2011/65/EU** of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

[22] * * *, *Standard Methods for Examination of Water and Wastewater, 21st ed. American Public Health Association*, American Public Health Association, American Water Works Association, Water Pollution Control Federation, and Water Environment Federation, Washington, D.C. 2005.

[23] J.K. Cowburn, T. Goodall, E.J. Fricker, K.S. Walter, C.R. Fricker, *A preliminary study of the use of colilert for water quality monitoring*, **Letters in Applied Microbiology, 19**(1), 1994, pp. 50–52.

[24] E.J. Fricker, C.R. Fricker, *Use of two presence/absence systems for the detection of coli and coliforms from water*, **Water Research**, **30,** 1996, pp. 2226–2228.

[25] A.F. van Nieuwenhuijzen, *Scenario studies info advanced particle removal in the physical-chemical pretreatment of wastewater*, **PhD Thesis,** Delft University of Technology, Delft, The Netherlands, 2002.

[26] * * *, Council Directive **91/271/EEC** of 21 May 1991, Concerning urban waste-water treatment.

[27] * * *, The **Water Law Act** dated 20 July 2017 published in the Polish Journal of Laws on August 23, 2017 (Dz.U. 2017 poz. 1566).

[28] J.H. Lee, K.W. Bang, *Characterization of urban stormwater runoff*,. **Water Research, 34**, 2000, pp. 1773-1780.

[29] E. Ociepa, A. Kisiel, J. Lach, *Contamination of rainwater flowing into sewage systems* (in Polish). **Proceeding of ECOpole**, 4(2), 2010, .

[30] H. Galfi, H. Österlund, J. Marsalek, M. Viklander, *Indicator bacteria and associated water quality constituents in stormwater and snowmelt from four urban catchments,* **Journal of Hydrology, 539,** 2016, pp. 125-140.

[31] E. Wojciechowska, S. Pietrzak, K. Matej-Łukowicz, N. Nawrot, P. Zima, D. Kalinowska, P. Wielgat, H. Obarska-Pempkowiak, M. Gajewska, G. Dembska, P. Jasiński, G. Pazikowska-Sapota, K. Galer-Tatarowicz, L. Dzierzbicka-Głowacka, *Nutrient loss from three small-size watersheds in the southern Baltic Sea in relation to agricultural practices and policy*, **Journal of Environmental Management, 252**, 2019, DOI: 10.1016/j.jenvman.2019.109637

[32] E. Wojciechowska, N. Nawrot, J. Walkusz-Miotk, K. Matej-Łukowicz, K. Pazdro, *Heavy Metals in Sediments of Urban Streams: Contamination and Health Risk Assessment of Influencing Factors*, **Sustainability**, **11**, 2019, Article Number: 563, DOI10.3390/su11030563.

[33] K. Matej-Łukowicz, E. Wojciechowska, N. Nawrot, L. Dzierzbicka-Głowacka, *Seasonal contributions of nutrients from small urban and agricultural watersheds in northern Poland*, **PeerJ**, **8**, 2020, Article Number: e8381, DOI: 10.7717/peerj.8381

[34] J. Gasperi, S. Zgheib, M. Cladière, V. Rocher, R. Moilleron et al., *Priority pollutants in urban stormwater: Part 2 - Case of combined sewers,* **Water Research**, **46**(20), 2012, pp. 6693-6703. 10.1016/j.watres.2011.09.041. hal-00657039.

[35] J.P.S. Sidhu, L. Hodgers, W. Ahmed, M.N. Chong, S. Toze, *Prevalence of human pathogens and indicators in stormwater runoff in Brisbane, Australia,* **Water Research 46**(20), 2012, pp. 6652–6660.

[36] J.K. Parker, D. McIntyre, R.T. Noble, *Characterizing faecal contamination in stormwater runoff in coastal North Carolina, USA*. **Water Research, 44,** 2010, pp. 4186-4194.

[37] J. Vollertsen, K.H. Lange, J. Pedersen, P. Hallager, A. Brink-Kjær, A. Laustsen, V.M. Bundese, H. Brix, C. Arias, A.H. Nielsen, N.H. Nielsen, T. Wium-Anderse, T. Hvitved-Jacobsen, *Advanced Stormwater Treatment—Comparison of Technologies,* P**roceedings of the 11th Nordic/Nordiwa Wastewater Conference**; Odense, Denmark, Nov 10–12, 2009, pp 44–53.

[38] M.F. Hamoda, I. Al-Ghusain, N.Z. Al-Mutairi, *Sand filtration of wastewater for tertiary treatment and water reuse,* **Desalination, 164**(3), 2004, pp. 203-211.

[39] G.J. Williams, B. Sheikh, R.B. Holden, T.J. Kouretas, K.L. Nelson, *The impact of increased loading rate on granular media, rapid depth filtration of wastewater,* **Water Research, 41**(19), 2007, pp. 4535-4545.

[40] J.G. Langeveld, H.J. Liefting, F.C. Boogaard, *Uncertainties of stormwater characteristics and removal rates of stormwater treatment facilities: Implications for stormwater handling*, **Water Research, 46**, 2012, pp. 6868-6880.

[41] S. Gavrić, G. Leonhardt, J. Marsalek, M. Viklander, *Processes improving urban stormwater quality in grass swales and filter strips: A review of research finding,* **Science of the Total Environment, 669**, 2019, pp., 431–447.

[42] E.G. Payne, D.T. McCarthy, A. Deletic, K. Zhang, *Biotreatment technologies for stormwater harvesting: critical perspective,* **Current Opinion in Biotechnology**, **57**, 2019, pp. 191–196. https://doi.org/10.1016/j.copbio.2019.04.005.

[43] W. Feng, D.T. McCarthy, Z. Wang, X. Zhang, A. Deletic, *Stormwater disinfection using electrochemical oxidation: A feasibility investigation,* **Water Research, 140,** 2018, pp. 301-310.

[44] S.G. Eblin, K.S. Konan, O.M.J. Mangoua, V. Nedeff, A.V. Sandu, N. Barsan, I. Sandu, *Nitrate Pollution of Groundwater Based on GIS in the City of Daloa, West-central Cote d'Ivoire,* **Revista de Chimie, 70**(7), 2019, pp. 2579-2583.

Received: April 11, 2021
Accepted: July 20, 2021