Contamination of water in Oliwski Stream after the flood in 2016

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Abstract. In the article pollution of stream waters with surface runoff from an urbanized area caused by an extremely high rainfall is discussed. The analyzes were carried out after the rainfall of the depth 152 mm which took place in Gdańsk on 14th and 15th July 2016. This extreme rainfall caused urban flooding, damage of several retention ponds and pollution of surface waters. In the article the results of physical and chemical analyzes of the water samples from Oliwski Stream, inflowing to the Gulf of Gdańsk at the beach in Jelitkowo, are presented. The samples were collected at six points along the Stream in order to evaluate potential pollution sources. The results of the study indicated elevated concentrations of phosphorus compounds and nitrates (V). Additionally, the concentrations of total suspended solids (TSS), solids granulometry and grain size distribution along the stream was investigated.

1 Introduction

Both quality and quantity of storm water runoff is varying in a wide range, depending on factors associated with the rain event, catchment characteristics and development etc. Every year is different in terms of annual precipitation, monthly precipitation or number of rainy days. The usual fluctuations of rainfall depth and intensity are becoming even more variable due to climate change. At the same time, due to intensive urbanization and the increase of paved areas, the runoff volume has grown rapidly over the last few decades [1]. The existing urban drainage systems are no longer capable of safe collection of the increased amount of runoff, quite often resulting in urban flooding. The phenomenon of rapid urban flood has been repeated so often in different locations of the biggest world cities that a special term *flash flood* (FF) has been created to name it [2].

In addition to the increased amount of run-off, another hot environmental problem is runoff quality, often being the cause of pollution of receiving surface waters. Storm water is delivered to the surface waters by several pathways, including direct precipitation, infiltration followed by groundwater outflow, urban storm water sewers discharge and surface runoff. According to [1] the atmospheric pollution accounts for only 10-20% of storm water contamination, while the actual pollution is created when the contaminants from the catchment are washed out by the runoff [3–5].

Total suspended solids (TSS) is considered to be the major pollutant of storm water runoff [6], not only due to its large contents in the runoff, but also due to the fact that it carries a lot of adsorbed pollutants to mention just heavy metals [7,8], total nitrogen, COD and BOD_5. The loads of pollutants discharged to surface receivers with the runoff depend to

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some extent on atmospheric pollution but mainly on characteristic of watershed, including the intensity of road transportation, vicinity of industry and type of land usage.

The flooding events are known to have significant impact on aquatic ecosystems due to major changes of physical, chemical and microbiological properties of surface waters. This is especially true for urban flooding events when many anthropogenic substances, toxic to biota, are washed away from the urbanized area and discharged to the surface waters. The analyzes of pollutants concentrations (TSS, COD, BOD_5 and dissolved organic carbon DOC) were carried out by Hidehikoi et al [9]. These authors examined the pollutants concentrations in the vertical profile, concluding that there was no statistically significant relationship between depth and pollutant concentrations.

The solution to the problem of too high amounts of impurities could be wetland systems. The first systems were already built in Gdansk, in ZOO (Catchment Rynarzewski Stream, which flows into the Oliwski Stream) [10].

In this article the concentrations of pollutants in Oliwski Stream in Gdańsk after the urban flash flood event on 14th-15th July 2016 are presented. Oliwski Stream inflows directly to the Gulf of Gdańsk in Jelitkowo, where one of the most attractive Tricity beaches and bathing places is located. Thus, pollution of the stream has a direct impact on coastal waters. Moreover, the loads of nutrients discharged by streams and rivers contribute to eutrophication of the Baltic Sea, which is the high priority environmental issue.

2 Materials and Methods

2.1 Study site

Stormwater runoff from the city of Gdańsk is discharged to more than 20 streams. The largest of them, regarding flow rate (0.29 m^3/s) and the second longest (9.57 km) is Oliwski Stream. The average hydraulic slope of the stream is 14.1‰ [11]. The stream takes its origin near Złota Karczma and its catchment area is approximately 3050 ha [12]. The major inflows are Graniczny Channel, Rynarzewski Stream, Czysta Woda Stream, Bernard's Stream and Zajączkowski Stream. The Oliwski Stream receives runoff from diverse catchment including forests, streets, parks, residential districts as well as the city zoo in Gdańsk, which is located directly at Rynarzewski Stream.

In the catchment area of the Oliwski Stream there are thirteen retention ponds [12] of the total retention volume equal to 70 000 m^3 and the total area of 13.5 ha. Apart of retention, they also have recreational function.

2.2 Collecting of samples

The analyzes of water of Oliwski Stream were carried out after the extremely intensive rainfall episode in July 2016. The samples of water were taken from the mainstream using a scoop and poured into 1 liter glass bottles.

The sampling points location was selected after analysis of catchment characteristics and development (Fig. 1). Six representative points were chosen:

1. The Valley of Joy – sampling point located in the forest with limited access of mechanical vehicles. Potential pollution sources at the distance from the stream source: the motorway S6, run-off from forest area.
2. The Valley of Joy – sampling point located in the forest with limited access of mechanical vehicles. Potential pollution sources between sampling points 1 and 2: a single residential building, the motorway S6, run-off from forest area.

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3. Below retention pond no. 11 – crossroads of Bytowska and Kwietna streets, below the bridge. Potential pollution sources between sampling points 2 and 3: allotments, fishery ponds.
4. Before retention pond no. 8 near Spacerowa street. Potential pollution sources between sampling points 3 and 4: roads, residential buildings, zoo.
5. Residential District Przymorze Małe, Rzepicha Str. Potential pollution sources between sampling points 4 and 5: roads, residential buildings, animal faeces, city park in Oliwa.
6. The discharge in Jelitkowo, Jantarowa Str. Potential pollution sources between sampling points 5 and 6: roads, residential buildings.

The samples from each point were taken in triplicate.

The samples of water were immediately transported to the laboratory in cooling conditions were physical and chemical analyzes of pollutants concentrations were performed.

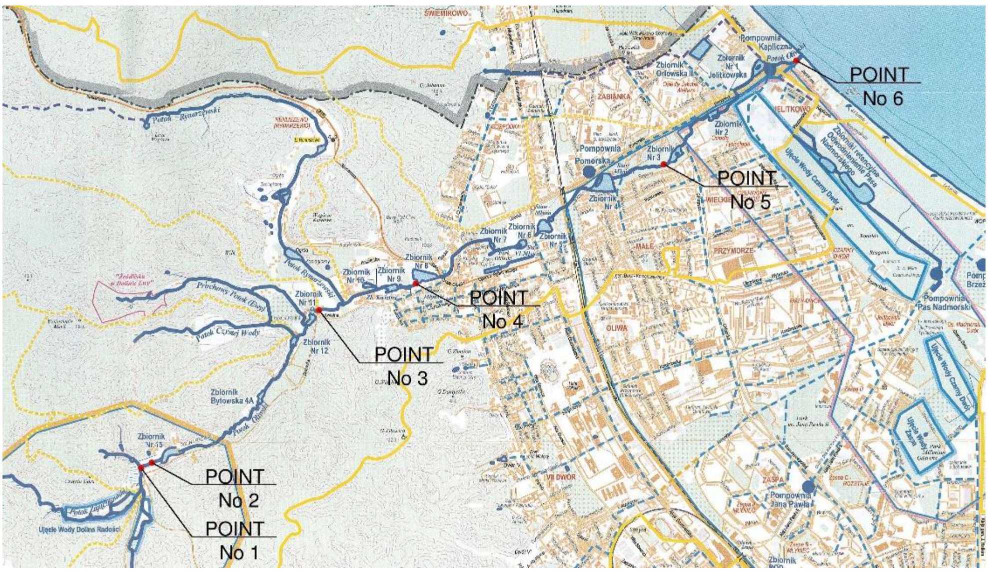

Fig. 1. Six representative sampling points.

2.3 Analytical methods

In the collected samples of water from Oliwski Stream the concentrations of the following pollutants were measured: TSS, COD, ammonia NH_4^+, NO_2^-, NO_3^-, PO_4^{3-} and total phosphorus (Ptot). The chemical analyses were carried out using cuvette tests LCK Hach and spectrophotometer VIS DR3900 Hach, according to the following standards:
NH_4^+ - ISO 7150-1, DIN 38406 E5-1,
NO_2^- - EN ISO 26777, DIN 38405 D10,
NO_3^- - ISO 7890-1-2-1986, DIN 38405 D9-2,
PO_4^{3-} - ISO 6878-1-1986, DIN 38405 D11-4,
Ptot - ISO 6878-1-1986, DIN 38405 D11-4),
COD - ISO 6060-1989, DIN 38409-H41-H44)
TSS concentration was measured according to PN-EN 872:2007.

Granulometric composition of suspended solids was measured using laser granulometer produced by Malvern Instruments Ltd 2000 allowing for volumetric analysis of solids size during diffraction of laser beam. The instrument allowed for measurement of solids size in the range from 0.02 to 2000 µm. The volume of analyzed samples was equal to 0.6 dm^3.

3 Results and Discussion

3.1 Hydrological characteristics of the catchment area

The average precipitation in Oliwa in the period 2007-2014 was equal to: annual – 670.8 mm, monthly (July) – 91.0 mm. The rainfall depth on 14th July 2016 was equal to 152 mm (Fig. 1), being two times higher than in the whole July 2013. The annual and monthly (July) precipitation in Oliwa in the years 2007-2014 are presented in Table 1.

Table 1. July and annual precipitation [mm] in the years 2007-2014 measured at meteo station located in Gdańsk Oliwa [12].

Date	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**average**
July	92.4	65.2	124.4	119.7	77.6	148.5	77.5	22.7	91.0
annual	771.6	669.9	659.8	863.2	445.0	826.9	647.7	482.2	670.8

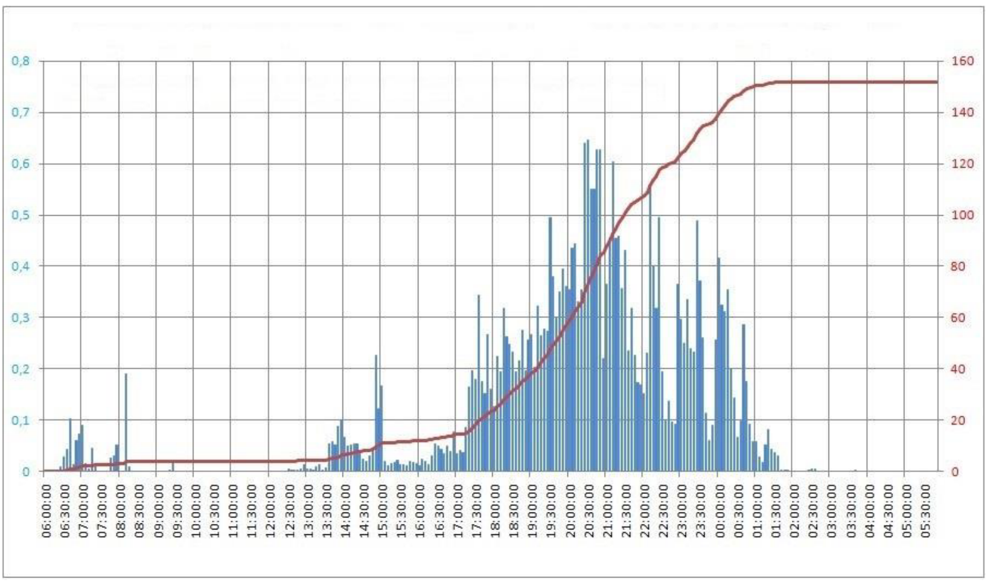

Fig. 2. Rainfall intensity [mm/min] and mass curve of rainfall in Oliwa between 6:00 14.07 and 6:00 15.07 [13].

Due to intensive extreme rainfall and large surface runoff discharged to receiving surface waters numerous locations in the city of Gdańsk were flooded. The catchment area of Oliwski Stream was one of most affected. Water of the Stream overflowed several retention ponds, flooding residential areas and the zoo. At one of the retention ponds the floodgate was damaged, which caused further flooding of the nearby area.

3.2 Concentrations of nutrients and organic matter

Results of chemical analyzes of collected samples of water are presented in Table 2. The analyzes of nutrients concentrations included ammonia, nitrates (III), nitrates (V), orthophosphates and total phosphorus. Ammonia originates during biochemical decay of organic matter, It is also released with domestic wastewater. High concentrations of ammonia in surface water indicate contamination with sanitary sewage or animal faeces.

Nitrates (III) are formed during decay of nitrogen present in organic matter or reduction of nitrates (V) in anaerobic conditions. Concentrations of nitrates (III) in surface waters are usually low due to oxidation of NO_2^- to NO_3^-. Presence of nitrates (III) indicate contamination with fish faeces or animal decaying remains. Since nitrates (III) are transitory form between NH_4^+ and NO_3^-, they should be determined together with nitrates (V). Nitrates (V) are the final product of nitrogen transformation, thus their presence in surface waters at low concentrations are quite typical. Additional sources of nitrates (V) are municipal and industrial wastewater as well as artificial fertilizers washed away by surface runoff. Nitrates (V) present at higher concentrations are responsible for eutrophication of surface waters. Phosphorus compounds undergo biochemical changes in the environment as nitrogen species and the final form are orthophosphates. Orthophosphates in surface waters originate from sanitary sewage, surface runoff and fish breeding. Otherwise than nitrogen, phosphorus mobility is low, thus large quantities are deposited in the sediments.

Organic matter in the surface water is formed during natural decay processes of animal and plant detritus. Allochtonic organic matter is delivered with wastewater inflow. Organics in higher concentrations disturb self-cleaning process and cause deterioration of organoleptic properties of water. Within this study COD was measured as an indicator of organic matter concentration.

Table 2. Concentrations of organic matter and nutrients in Oliwski Stream after the extreme rainfall on 14-15.07.2016.

Analyzed parameter		**POINT 1**	**POINT 2**	**POINT 3**	**POINT 4**	**POINT 5**	**POINT 6**	**Rainless period (average)**
NITRATES III (NO_2^-)	[mg/dm^3]	0.04	0.04	0.08	0.09	0.11	0.07	0.02
NITRATES V (NO_3^-)	[mg/dm^3]	1.61	1.83	1.75	2.18	2.29	1.37	0.57
AMMONIA (NH_4^+)	[mg/dm^3]	0.19	0.50	0.20	0.18	0.13	0.14	0.05
ORTOPHOSPHATES(PO_4^{3-})	[mg/dm^3]	0.42	2.25	0.68	2.16	0.88	0.55	0.45
COD	[mg/dm^3]	23.00	24.30	30.00	30.90	31.70	22.50	8.68
TOTAL PHOSPHORUS P_{TOT}	[mg/dm^3]	0.63	0.27	0.79	0.24	0.18	0.15	0.08

The concentrations presented in Table 2 were compared with the values given in Regulation of Environment Minister from 21st July 2016 regarding classification of surface waters and environmental quality standards for priority pollutants. Concentration of ammonia at point 2 and 3 exceeded the boundary value for I class. Concentrations of nitrates (III) corresponded to the II class at all sampling points. Nitrates (V) concentrations at sampling points 1,2,3 and 6 was within the limits for II class, while at points 4 and 5 exceeded the boundary value for II class. During floods sanitary sewage are often discharged to surface waters (for instance from pumping stations) which may be the reason of deterioration of the stream quality. Concentrations of orthophosphates exceeded the values for II class. Total phosphorus was out-of-class at point 1 and 3, while at sampling points 2 and 4 it corresponded to the II class limits. At sampling points 5 and 6 the I class limits for total phosphorus concentrations were fullfilled. The significant increase of orthophosphates concentration at sampling point 4 was caused by flooding of the city zoo.

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Another reason for the increase of total phosphorus concentration could be resuspension of phosphorus deposited in the bottom sediments during turbulent flow of water.

Concentrations of COD at sampling points 1, 2 and 6 corresponded to the I class limits, while at sampling points 3, 4 and 5 the limits for II class were exceeded. This was obviously caused by flooding of animal cages at the zoo as well as damage of retention tank and the stream bed below it which causes additional inflow of organic matter from the catchment area.

3.3 Concentrations and granulometric analyzes of suspended solids

Total suspended solids concentrations, measured as a weight of solids in the volume of analyzed sample, is a standard determination bringing just quantitative information. Qualitative analysis of solids can bring more information about solids granulometry that can be useful for instance in designing of storm water treatment devices and has already been performed for some areas in Poland [14, 15].

Fig. 4 presents concentrations of TSS in water samples from Oliwski Stream measured according to PN-EN 872:2007. Fig. 4 presents characteristic diameters of solids: d 0.1 (solids of this diameter and smaller represent 10% of the total solids number), d 0.5 and d 0.9 (solids of this diameter and smaller represent 50% and 90% of the sample, respectively). Fig. 6 presents granulometric spectrum of suspended solids, measured with laser granulometer.

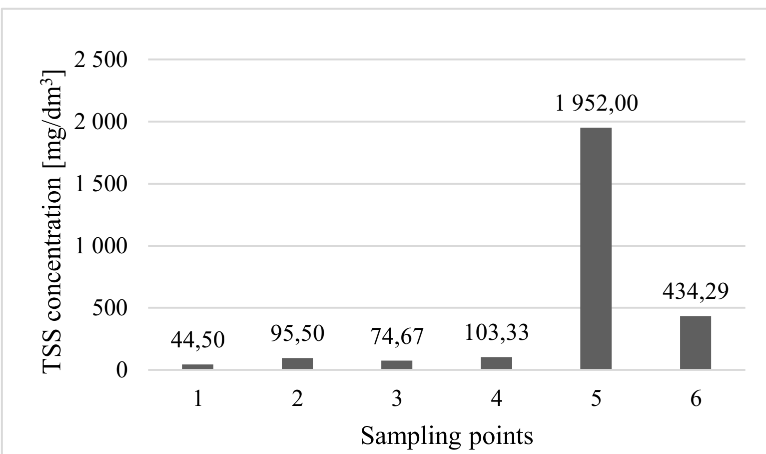

Fig. 3. TSS concentration in sampling points 1 – 6, 15.07.2016.

TSS concentrations at sampling points 1-3 were below the limits defined by Regulation of Environment Minister [16]. At sampling points 4-6 the increased surface runoff and, most of all, damage of the overflow of one of retention tanks, resulted in the increase of TSS concentrations, with the maximum at sampling point 5 (1 952 mg/dm^3 = 1,95 g/L). Similarly, in sampling points 1-3 the bigger solids were dominating (Figs. 4 and 5), while at sampling points 4-6 size of the solids was variable. Granulometric analyzes (Fig.6) shows that the sizes of solids were decreasing downstream, which is opposite to the situation during dry weather, when solids sizes are increasing in sampling points downstream.

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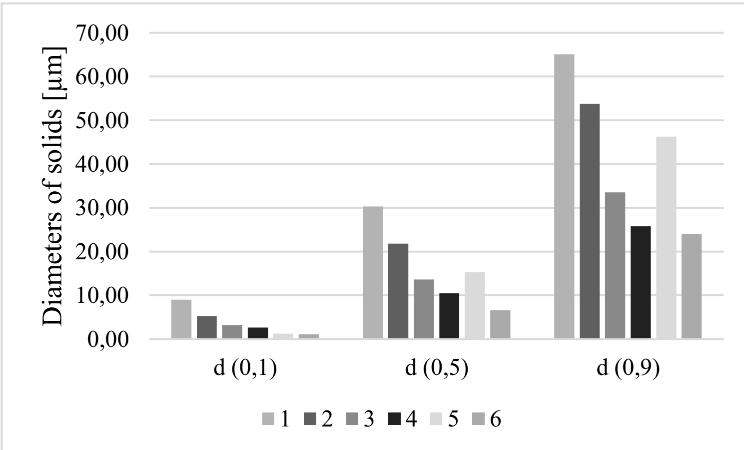

Fig. 4. Characteristic diameters of solids in sampling points 1 – 6, 15.07.2016.

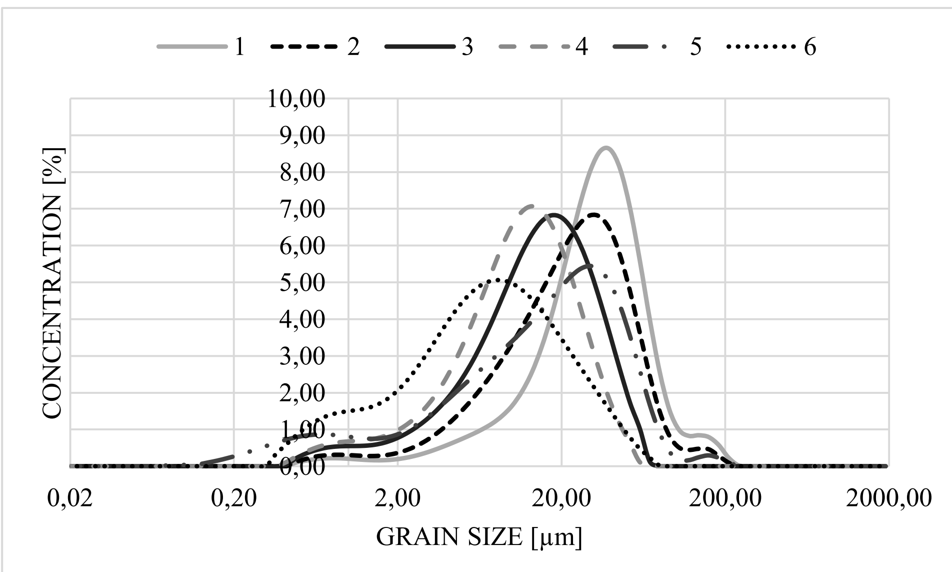

Fig. 5. Granulometric spectrum of suspended solids in sampling points 1 – 6, 15.07.2016.

4 Conclusions

1. Urban storm water system cannot safely drain the runoff produced by rainfall of the depth of 152 mm during 16 hours, which results in urban flood.
2. As a result of urban flood on 15 July 2016 the waters of Oliwski Stream got polluted and could be defined as out-of-class since some of the analyzed parameters exceeded the limits of II class water.
3. Pollution of Oliwski Stream resulted mostly from surface runoff from the zoo area, resuspension of bottom sediments and damages of retention ponds.
4. The decrease of concentrations at subsequent sampling point downstream can result from retention of polluted runoff in the retention tanks and dilution.

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