Original Research

Sanitary Analyses of Runoff Water a River

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Abstract

The aim of this study was to determine the microbiological quality of runoff from an urban area with different catchment land use flowing into the Cybina River in Poznań, Poland. Water samples were taken from October 2009 to March 2011 at five research stations situated at the outlets of sewers draining a road surface, a car park, and residential and industrial areas. Microbiological analyses included: total bacterial count at 22ºC and at 37ºC, coliform group and faecal coliform bacteria. In each sample the coliform group and faecal coliform bacteria, probably of animal origin, were present. MPN coliform group ranged from 48 to $24 \cdot 10^5$ cells in 100 ml. The results indicated that quality of stormwater depended on such factors as duration of the rainless period, season, and size and state of the impervious area. High microbiological contamination betokens an adverse influence on the water quality of the Cybina, and therefore treatment of this sewage before the outlets to the receiver is necessary.

Keywords: coliform group, rainwater runoff, water quality, urban areas, land use

Introduction

Urban stormwater is one of the major problems related to potential contamination of the receiver. The amount of water flowing into rainwater sewage differs significantly in time and a great load of pollution can be supplied to a receiver in a short period of time [1-3].

The amount of total suspended solid and bacterial contamination is the main cause of low water quality in rivers [4]. Faecal pollution of surface waters is a worldwide problem. It has a significant effect on both public health and the economy, plus degradation of drinking water sources [5]. Rainwater discharge is one of the most significant microbiological contamination sources [6]. The urbanization process contributes to an increase of impervious areas and thus leads to an increase in the amount of rainwater [7].

Rainwater is already contaminated during precipitation but, in general, much more pollution comes from surface runoff. Many studies have indicated that even roof-collected rainwater has poor physicochemical quality and high levels of bacterial contamination [8-14]. Apart from the level of air contamination, runoff water quality depends on many other factors such as profile and land use of the catchment area, the amount of the impervious area and greenery, season, frequency and downfall length, and many other secondary factors [1, 15-18]. The strong impact on the concentration of fecal bacteria in the runoff have e.g. application of poultry litter to small watersheds when runoff occurs a few days after litter application [19]. The potential for soil erosion and surface runoff means that poultry waste could degrade surface and ground water quality [20].

One of the largest sources of contaminants to surface waters is urban stormwater [18] owing to high concentrations of numerous pollutants. Furthermore, the high percentage of impervious surfaces leads to higher volume of urban stormwater runoff than from natural catchment of the equivalent area [21]. Urban stormwater runoff contains large quantities of both faecal microbes and sediment, contributing to surface water quality decrease [22, 23]. Due to the fact that urbanization grows abruptly, the problem of proper rainwater treatment becomes more and more important.

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There are very few rainwater sanitary analyses hitherto. Most research has been done outside Europe [9, 12, 13, 24, 25]. Abundant research involves analysis of lake and river water quality after a rain event, but not directly rainwater quality [26-40].

Polish law referenced rainwater contamination for the first time in 1992. Since then, an increased number of papers describing the contamination of rainwater and gradual deployment of proper devices for protection of water environment against such contamination could be observed [1, 41-44].

In terms of microbiological analyses, rainwater runoff is still poorly known; therefore, there is an urgent need to fill this gap. The main aim of this study was a microbiological assessment of rainwater flowing into the Cybina River in the area of Poznań. It was analyzed in comparison with various land uses of the drained catchment area, which is a new approach to support the solution of this problem. This study was part of more extensive research related to rainwater runoff [3]. Chemical data are still under preparation for publication.

Materials and Methods

The Cybina is a right-bank tributary of the Warta River. It is a typical third-order river situated in the Wielkopolska Region (midwestern Poland). The Cybina has a length of 41 km and its catchment area is 195.5 km^2 [45]. The lower course is located in the area of Poznań City – from Swarzędzkie Lake to the river mouth into the Warta.

Analyses were carried out from October 2009 to March 2011. In this period water samples were collected 10 times at five research points (Fig. 1):

1. Outlet of sewer situated below Swarzędzkie Lake, collecting rainwater from the residential area with 28.9% impervious area, treated in sedimentation tank with PAH separator.
2. Outlet of sewer equipped with Imhoff tank, collecting stormwater from the area of a car production factory and a section of 745 m of national route (51.6% impervious area).
3. Outlet of sewer that collects rainwater from glassworks transported into the Antoninek Reservoir (88% impervious area).
4. Outlet of sewer that collects stormwater from the area occupied by a car dealer together with a car parts warehouse and a car park, transported into the Antoninek reservoir (76% impervious area).
5. Outlet of sewer situated below the Olszak Reservoir, which collects untreated rainwater from a short section of road (149 m), and the area of multi-family housing estates (26.7% impervious area).

Altogether, 38 samples were taken during the period of research (7 at stations 1 and 4, and 8 samples at stations 2, 3, and 5). All of the samples were taken directly from outlets of sewers into sterile bottles during a rain event. Raining intensity estimation on a four-point scale was made during the sampling. Water samples were transported to the laboratory and immediately processed for bacterial analysis. The research of water comprised analysis of total bacterial count at 22ºC, total bacterial count at 37ºC, most probable number (MPN) of coliform group, and MPN of faecal coliform bacteria. The total bacterial counts at 22ºC and at 37ºC were analyzed using the plate count method. To determine the number of psychrophilic and psychrotroph bacteria, the plates were incubated in an inverted position at 20-22ºC for 72 hours and, to determine the number of mesophilic bacteria, at 37ºC for 24 hours. Analysis for the coliform group and faecal coliform bacteria were carried out by the multiple-tube fermentation technique. The number of positive tubes in each of the three selected dilution inoculations was used to determine the MPN in 100 ml. Proper confirmatory tests also were done [46, 47].

Statistical analyses were done using STATISTICA 5.5 software. Differences between the stations were tested with the nonparametric Kruskal-Waliss test for non-matched groups.

Results and Discussion

The amounts of particular bacterial groups in the analyzed period were highly variable between sites and sample dates.

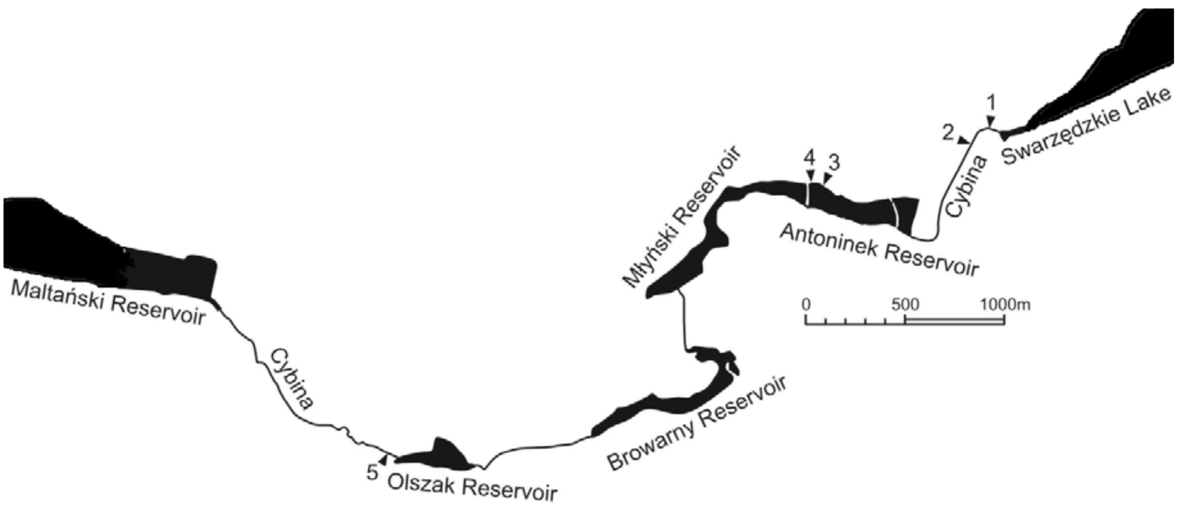

Fig. 1. The location of research stations Nos. 1-5 (acc. to 3, changed).

Table 1. Comparison of faecal coliform bacteria (MPN·100 ml^{-1}) at particular stations.

Station	Minimum value	Maximum value	Mean value	Standard deviation	Number of samples
1	150	39,000	8,173	824	7
2	23	110,000	14,530	1,053	8
3	21	2,400	837	1,028	8
4	480	1,100,000	231,754	490,346	7
5	23	240,000	37,752	657	8

Total bacterial counts at 22ºC (psychrophiles and psychrotrophs) were always higher than total bacterial counts at 37ºC (mesophiles). Every sample also comprised coliform group and faecal coliform bacteria at all stations. The presence of psychrophilic and psychrotrophic bacteria indicates contents of organic matter flushed from the catchment area, whereas coliforms are an indicator of faecal contamination and the possible presence of the pathogenic bacteria. The mean values of mesophiles, psychrophiles, and psychrotrophs were different between stations. The highest values of these indicators were noted at station 4 and the lowest at station 3 (Fig. 2). The mean values of psychrophiles and psychrotrophs were similar at stations 1, 2, and 3.

The first contamination of rainwater is due to rinsing the lower atmosphere. The air is not a good environment for microorganism growth, but it is the main environment to dispersal between microorganisms and abiotic matter. Depending on many factors, the amount of microorganisms in the air is from a few to 10^7 colony-forming units (cfu) in 1 m^3. They originate from various environments such as ground and water surface, plants, and feces [48-51]. The contamination of rainwater collected from roofs depends on various factors [9, 10, 12-14]. There are two separate derivations of microbiological contamination: either direct depositions by birds and small mammals or atmospheric deposition of airborne microorganisms [12, 13]. In the case of rainwater flowing into the Cybina, most mesophilic bacteria originate presumably from animal feces.

The differences between minimum and maximum values were high among the stations (Table 1). The highest minimum and maximum values were observed at station 4. Variability of the MPN coliform group, which was observed between stations, was statistically significant (KW-H (4;38)=11.5, $p<0.05$). The highest concentration of total bacterial count was at 22ºC and at 37ºC; coliform group and faecal coliform bacteria occurred in samples from the car dealer area (station 4). This catchment area does not have the biggest impervious area, but it has a high share in total area. There also is a modern infrastructure that makes infiltration impossible and almost all of rainwater fits the sewer as an overland flow. Also at the catchment area with the glassworks (station 3) there is a high percentage of impervious surfaces, but the concrete surface is old and fissured there, which could cause a decrease in the amount of rainwater.

High variability among stations could also be due to the fact that rainwater runoff is characterized by inhomogeneous volumetric flow. This has an influence on the value of contaminant concentrations in runoff originating from roads. Other reasons for contamination are intensity and duration of downfall period, duration without downfall, road type, traffic intensity, and roads precincts. All of those factors cause considerable fluctuations of contaminant concentration in rainwater runoff. The highest contaminations are observed in the first runoff. In the first 15-60 minutes of downfall there are maximum values of contamination [16, 17, 52]. Excessive amounts of coliform bacteria were observed more often in rainwater runoff from urban areas with a significant section of impervious areas [53].

Dependence of the amount of bacteria in rainwater on the duration of the rainless period was confirmed in Nigeria [25].

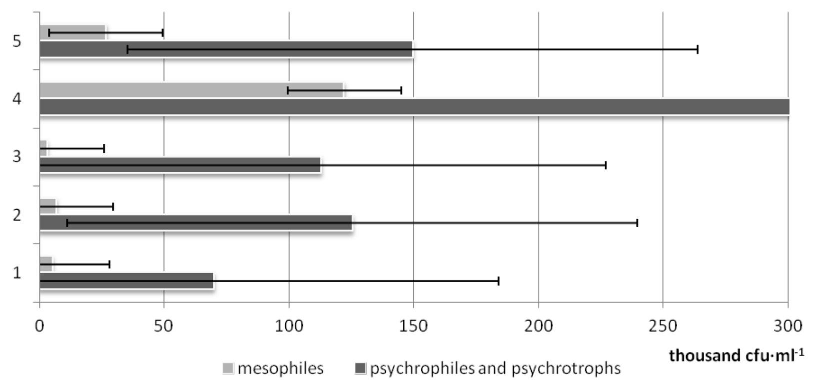

Fig. 2. Comparison of mean values ± standard deviation of mesophiles and sum of psychrophiles and psychrotrophs at particular stations.

American research confirmed the influence of the amount of bacterial contamination of rainfall on the range of faecal microbiological indicators in Florida's rivers [33]. Also, surface runoff during heavy rainfalls caused an increase of microbiological contamination of bathing waters, which resulted in a deterioration of quality of those waters [37]. Increased amounts of coliform group and *Escherichia coli* after rain events also were noted in another stream in the USA [36], but not in all sampling dates. Copious rainfalls in August could cause an augmented wash of faecal material before the day when samples were taken. Similar results were observed in rainwater runoff flowing into the Cybina. November 2010 was rainy and lower levels of *Escherichia coli* were found in the samples from this month. This might have been significantly influenced by *inter alia* rainfall duration just before sampling. For example, on the 18th of May 2010 the amount of mesophilic bacteria was low. On this day samples were taken two hours after the beginning of the rain, which could flush the contamination before sampling. Similar data was observed in October 2009. There was not any rain for four days before the sampling day, so the contaminations accumulation was anticipated, but morning rain before sampling probably rinsed the contamination from the surface, hence the amounts of bacteria were not very high. However, low values of mesophilic bacteria in January 2011 were not an effect of rinsing, but low temperature. The influence of rainfall intensity on the amount of bacteria in runoff also was noted. On the 12th of May 2010 samples were taken from stations 2, 3, and 5 during heavy rain in the fourth point intensity. These samples included the highest amount of psychrophiles and psychrotrophs at stations 2 and 5, which could have been caused by a stronger elution of bacteria from the soil. This relationship was not observed at station 3, probably due to a high percentage of impervious area in this catchment area.

Contaminations of rainwater runoff from roads and roofs in Częstochowa also vary significantly depending on the site, sampling date, and rainwater duration [54]. In samples of rainwater flowing into the Cybina, contaminations were also various, especially in rainwater runoff from a motorway. Sanitary water contamination caused by rainwater runoff can increase several times during rainfall. Besides, rainwater is characterized by patchy runoff in time, a so-called *shock effect* [1, 16, 52].

The amount of total suspended solids that significantly exceeds the allowed limit is the main problem of urban runoff [55]. Contamination accumulates on the suspension, and merely part of them is water-soluble. Suspended solids, especially soil particles, play a vital role in the transport of bacteria [1, 56]. High amounts of psychrophilic and psychrotrophic bacteria in rainwater flowing into the Cybina followed an abundance of suspension content. High values of the bacteria occurred in March due to snow melting, which influenced both suspended solids and the bacteria content in runoff.

Green belts in the catchment area influence the faecal coliform bacteria number in surface runoff, decreasing their content, but usually not enough to fulfill water quality standards [20]. The impact of greenery on curtailment runoff and decrease of coliform group content in rainwater also was proved by American researchers [57].

The literature points to significant contamination of runoff water and its impact on surface water deterioration [29, 33, 34, 40, 58, 59]. Bacterial contamination of rainwater flowing through storm drains into the Cybina influences river water quality as well [60]. Coliform group and faecal bacteria contamination of rainwater flowing into the Cybina are high; therefore, they indicate the necessity of better treatment of this rainwater runoff before the discharge to the receiver. The results of the research proved that settling tanks at stations 1, 2, and 4 do not fulfill effectively their role and scantily protect the Cybina against bacterial contamination.

Conclusions

The studies were carried out from October 2009 to March 2011 to determine the microbiological quality of runoff water flowing into the Cybina in Poznań. The stations were situated at the outlets of sewers draining catchments with different land uses.

Rainwater runoff composition depends on many factors, such as the duration of the rainless period, season, and size and state of impervious area. Values of particular bacterial groups were highly variable between sites as well as between sample dates, which caused difficulties in stating their typical composition. The highest contaminations were noted in the first period of rainfall.

The coliform group in water indicates faecal contamination and its presence points to other pathogenic organisms of faecal origin. In the case of rainwater runoff from the studied catchment they originate mainly from animal a feces. Psychrophilic and psychrotrophic bacteria indicate suspended solids content washed from the surface of the catchment.

It was proved that rainwater runoff through storm drains from an urban area can input high bacterial contamination load into receiving waters. Therefore, a better treatment of this runoff before the outlets is necessary.

Urban stormwater is one of the major problems related to potential contamination of receivers, especially in town and metropolitan areas. Microbiological contamination is of vital importance due to the recreational use of these waters, therefore the problem needs an urgent solution.

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