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THE EFFECT OF THE TYPE OF ROOFING AND THE SEASONS ON THE MICROBIOLOGICAL QUALITY OF RAINWATER

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ABSTRCT: This paper presents the results of research on the bacteriological quality of rainwater collected directly from precipitation and various roof surfaces – concrete and ceramic roof tiles, galvanised sheet and a terrace covered with epoxy resin. Samples for the research were collected in a suburban area in 2015-2016. The quality of rainwater was assessed based on the results of bacteriological analyses (the presence of indicator bacteria and the total mesophilic and psychrophilic bacteria count). The effect of the seasons and the type of roofing on the microorganism count was discussed. Significant differences in the quality of rainwater collected from various roof surfaces, related to the roughness and chemical composition of the materials covering the roofs were indicated. In the rainwater examined, significant numbers of potentially pathogenic microorganisms such as Escherichia coli, coliforms and faecal streptococci were detected. The results obtained were the basis for indicating the possibility of using rainwater for various household purposes. Rainwater is not suitable for uses requiring the quality of water intended for consumption due to a great number of psychrophilic, mesophilic and faecal bacteria.

KEY WORDS: rainwater, indicator microorganisms, pathogenic microorganisms

 JEL: Q53, Q56

Introduction

The widespread household use of rainwater is the basis for strategies allowing the water sector to adapt to the ongoing climate changes. In many countries in the world, including Poland, systems using rainwater in households are becoming more and more popular. In such countries as Japan, Germany and Australia, rainwater is collected and used for the maintenance of public buildings, e.g. airports, sports halls and business premises (Zawilski, Sakson, 2010). Rainwater is the basic part of water resources that provide water renewal, therefore it should be protected against contamination and be managed and used in the place of precipitation (Królikowska, Królikowski, 2012). The collection of rainwater and its subsequent use brings many benefits, both ecological and economic (Słyś, Stec, 2012). As an alternative source of water, it satisfies the needs for water of a lower quality, which enables significant savings of tap water, and is a way to use it in the place of precipitation without having to be discharged outside the catchment area. The use of rainwater is most frequently associated with its use for household and sanitary purposes, but also in agriculture or industry. Rainwater used in households should be:

- free from pathogenic bacteria and solid contaminants,
- poor in nutrients,
- neutral to the materials with which it is in contact.

An analysis of the structure of water consumption for household and sanitary purposes in residential buildings shows that about 50% of drinking water can be replaced by rainwater, and in public buildings nearly 65% (Ludwińska, Paduchowska, 2017). Although it is commonly believed that rainwater is relatively clean, the results obtained demonstrate its physicochemical and microbial contamination (Koszelnik, 2009). The research carried out so far has shown that the consumption of rainwater without its prior treatment is dangerous for potential consumers. Rainwater may contain pathogenic microorganisms that are washed away from the atmosphere and roofing. Some microorganisms found in the air, once got into the water, have the ability to live in an aquatic environment. Examples of pathogenic bacteria that live both in the air and in the water include *Yersiniapestis*, *Corynebacteriumdiphtheriae*, *Mycobacteriumtuberculosis*, *Legionella pneumophila* (Błaszczyk, 2010). In the composition of rainwater, the presence of many pathogens, including *Salmonella, Campylobacter, Legionella sp., Clostridium perfringens, Giardia duodenalis and Cryptosporidium parvum* which cause serious disease symptoms in humans, were found. Disorders occurring after the ingestion of bacteriologically contaminated water mainly include gastrointestinal disorders, as well as numerous infections, including mucosal, respiratory, urinary, nervous and systemic infections (Hadaś, Dera, 2014).

The quality of water determines the way it is used, generates costs, takes time and space to its treatment. Knowledge about the factors affecting the quality of rainwater can significantly impact the selection of the appropriate surface and method of collection.

The aim of the research was to determine the microbiological quality of rainwater collected from various roof surfaces, during different seasons and to indicate the possibility of its use for household purposes.

Research methods

The research was carried out in 2015-2016. Analyses were performed for the rainwater collected from the guttering of buildings with various roofing (concrete roof tiles, ceramic roof tiles, galvanised sheet and a terrace covered with epoxy resin). A control sample was the rainwater which had no contact with the roof surface and was collected directly from precipitation. Sampling was carried out in a suburban non-industrialised area, in accordance with PN-ISO 5667 – 8:2003, after rejection of the first runoff.

Microbiological tests were performed in compliance with the sterility rules under laminar flow cabinet conditions. All the analyses were carried out using the applicable and recommended methods (table 1).

Table 1. Scope and methodology for the number of microorganisms for the rainwater

Parameter	Method/standard
Escherichia coli	The method of membrane filters; PN-EN ISO 9308-1:2014-12
Fecal streptococcus	The method of membrane filters; PN-EN ISO 7889-2:2004
The total number of bacteria at 37°C after 24 hours	Platelet method on a standard nutrient agar; PN-EN ISO 6222:2004
The total number of bacteria at 22°C after 72 hours	
The number of *Clostridium perfringens*	The method of membrane filters; PN-EN ISO 14189:2016-10
ATP number	The luminometer marking
The number of particles of genetic material	Flow cytometry

Source: author's own work.

Results of the research

Table 2 summarises and describes two research cycles using the number of rain events, the sum of monthly rainfall, the length of breaks between rainfall and average air temperatures, 2015 was a year with fewer rain events, longer dry periods and higher air temperatures than 2016 (table 2).

Table 2. Characteristics of research cycles

Characteristic feature	2015	2016
Number of rain events	31	48
The number of rain events analyzed	11	23
Total precipitation from research months [mm]	254	413
Average air temperature in spring [°C]	12,3	12,2
Average air temperature in summer [°C]	24	19,5
Average air temperature in autumn [°C]	10,5	15,1
The longest break between precipitation [days]	40	27

Source: author's own work.

In all samples from both research cycles, great numbers of psychrophilic, mesophilic and faecal bacteria were found.

More psychrophilic bacteria were observed in the samples collected in 2015. In both research cycles, the highest psychrophilic bacteria count was recorded in the water collected from the terrace coated with epoxy resin – the median was 20,000 CFU/ml. Attention should be paid to the extreme values in 2015 (figure 1).

The reason for the poor sanitary condition of rainwater collected from flat surfaces can be the formation of mini hollows periodically filled with water in which the proliferation of bacteria and even the formation of a biofilm can take place. Such a biofilm is difficult to rinse due to the small pitch of flat roofs or terraces (Mendez et al., 2011).

The smallest number of potentially pathogenic (mesophilic) bacteria (figure 2) was in the samples of the water collected from the roof covered with concrete roof tiles, especially in 2015 (a smaller number of rain events compared to 2016).

The water collected from the roof covered with galvanised steel was also characterised by a small number of potentially pathogenic microorganisms. This is associated with the biocidal properties of zinc and the relatively smooth surface of the sheet, as well as fast heating in the period of high temperatures. Mendez et al. (2011) indicate that appropriate roofing can be an effective measure protecting against the growth of microorganisms. The relationship between the roughness of the roof material and the number of microorganisms was confirmed in the works of Leong et al. (2017) and Dobrowsky et al. (2014).

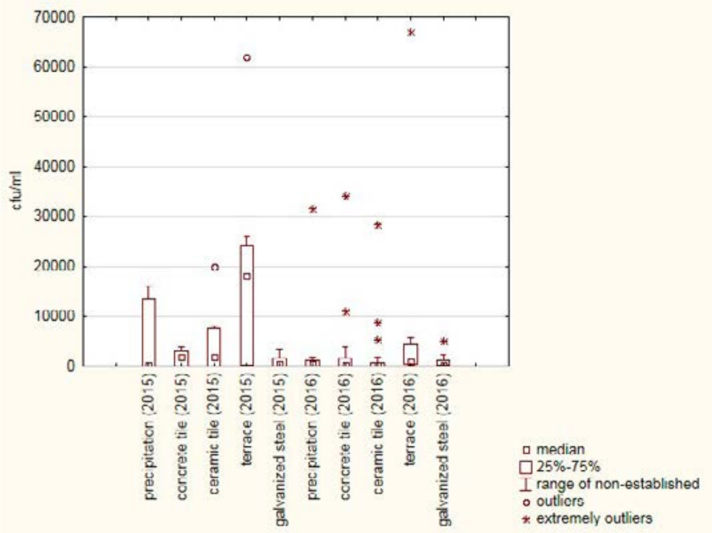

Figure 1. Statistical data for the number of psychrophilic bacteria present in rainwater
Source: author's own work.

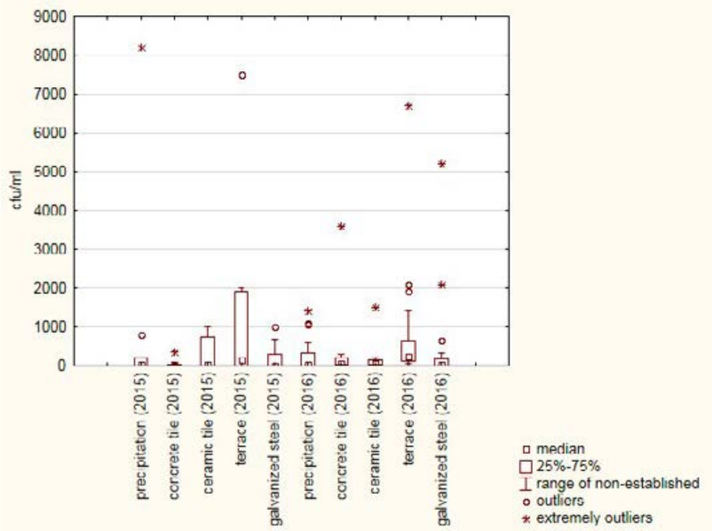

Figure 2. Statistical data for the number of mesophilic bacteria present in rainwater
Source: author's own work.

The highest count of mesophilic bacteria was found in the water collected during the summer and autumn seasons, while psychrophilic bacteria – in the spring and summer (figure 3 and figure 4).

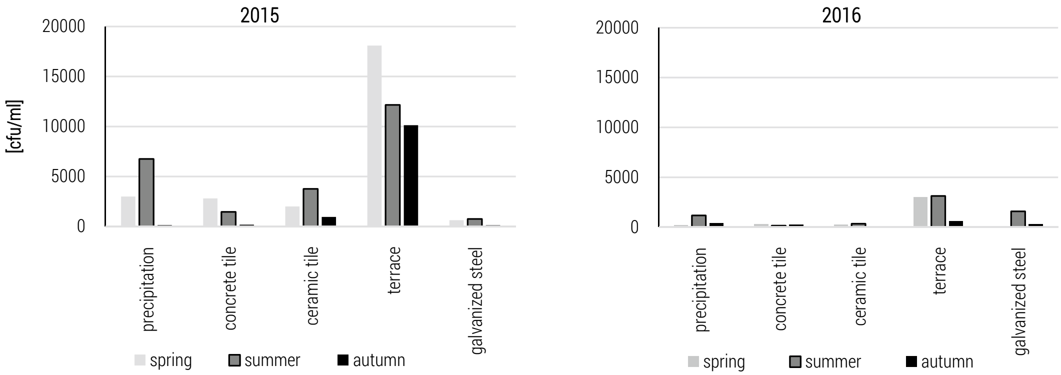

Figure 3. Medians of the number of psychrophilic bacteria in rainwater in various research seasons

Source: author's own work.

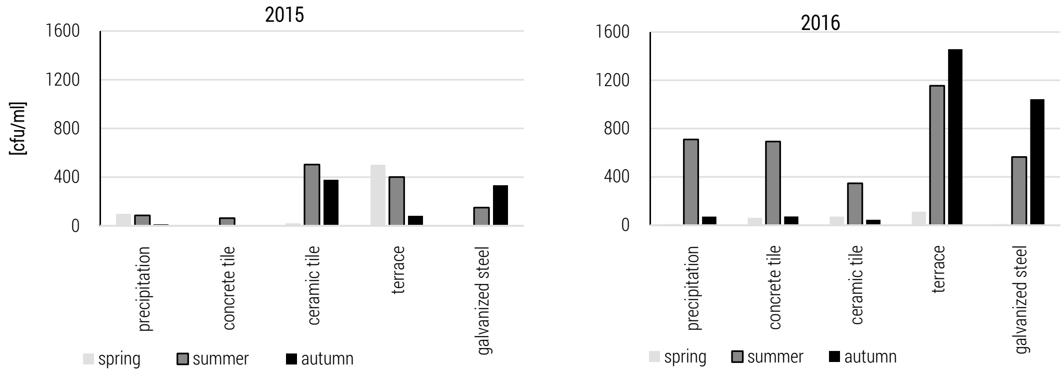

Figure 4. Medians of the number of mesophilic bacteria in rainwater in various research seasons

Source: author's own work.

This may mean that the main factor regulating their count is the air temperature and consequently the degree of heating of the roof surfaces. It was observed that the rainwater collected during warmer periods is more contaminated with bacteria.

The research carried out indicates the presence of significant numbers of potentially pathogenic bacteria in rainwater rinsing various types of roofs as well as that collected directly from the air in both research cycles. In the summer season, their number is much higher compared to colder seasons.

However, constant and clear relationships between the indicator microorganism count and the season cannot be indicated. Analysing figure 5 and figure 6 not only can differences between particular seasons but also between research cycles (2015 and 2016) be noticed, which reflects the dependence on the frequency and sum of rainfall (table 2).

The dependence on the air temperature and the surface from which rainfall is collected was observed by other researchers who recorded similar numbers of *E. coli* and faecal streptococci in the spring and summer seasons (Amin, Han, 2011).

In similar research, *E. coli* bacteria were detected in 50% of the examined samples in the summer season and only in 22% in the winter (Zhang et al., 2014).

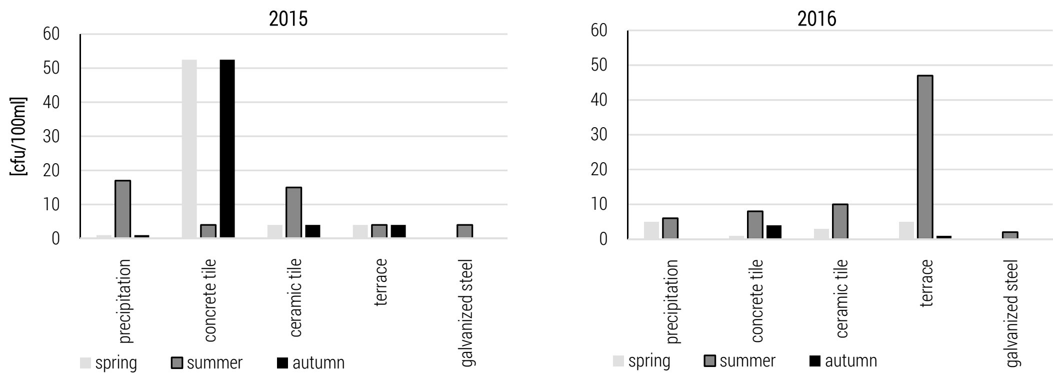

Figure 5. Medians of the number of *Escherichia coli* bacteria in rainwater at various research seasons

Source: author's own work.

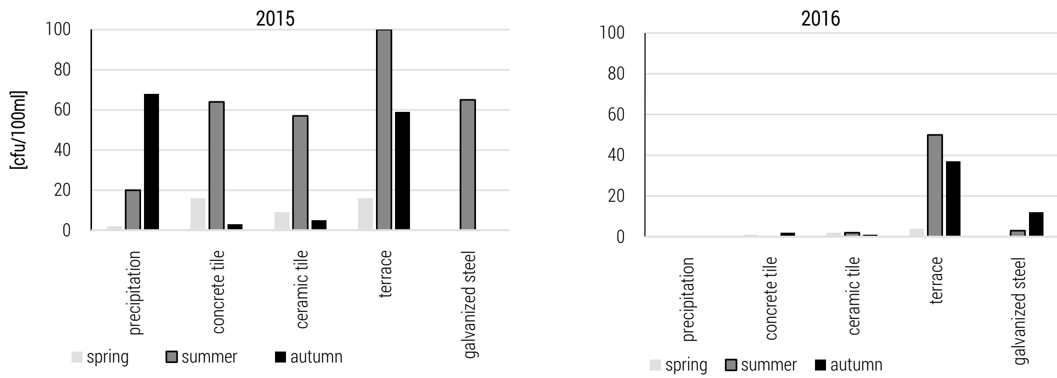

Figure 6. Medians of the number of *Enterococci* (fecal streptococci) in rain water in various research seasons

Source: author's own work.

In countries with moderate climate, the live bacteria count in the water, soil and air is variable and depends largely on temperature and humidity (Kaushik, Balasubramanian, 2012). The optimal temperature for the growth of pathogenic microorganisms (colonising warm-blooded organisms) is about 37°C, which explains the highest count of these bacteria during the summer season. Only in the rainwater collected from concrete roof tiles, the highest numbers of *E. coli* bacteria grew in the spring and autumn (figure 5). This may be due to the large thermal capacity of this roofing material, allowing the appropriate temperature for the growth of these bacteria to be maintained. The roof covered with galvanised sheet heats up very quickly, which may be a biocidal factor for bacteria, but it also cools down quickly, which may also inactivate cells and, despite viability, inhibit the ability to divide and grow on the medium (temperature shock) (Ding et al., 2017; Leong et al., 2017). The humidity of roofing is also important. It is on concrete roof tiles, with the greatest roughness, that humidity can be maintained much longer than on the other examined roofing. This enables microorganisms to survive in the periods between precipitation (Zhang et al., 2014). In the spring season, the number of these bacteria increases in the water taken from the roofs and directly from the air. In the summer season, a decrease in the number of microorganisms, despite the lack of a marked temperature fluctuation, may be caused by excessive heating of roofs and low humidity of the air.

The active cells of anaerobic bacteria *Clostridium perfringens* were most frequently detected just after the winter period (table 3). The presence of spores may be the evidence of former contamination, and due to their high resistance to environmental factors they may appear after longer periods without precipitation. A key role in the retention and accumulation of contamination may be played by the porosity of the roof surface and the roof pitch, making it difficult to effectively rinse with the first spouts of rain (Zdeb et al., 2016). The rainwater washing the terrace surface, collected in the spring, was found to be the most contaminated.

Due to the great number of psychrophilic and mesophilic bacteria, including faecal bacteria, rainwater is unsuitable for drinking, despite the fact that the latest Regulation of the Minister of Health does not specify the permissible number of psychrophilic microorganisms by introducing the provision "without abnormal changes" (Journal of Laws 2017 item 2294).

In countries deficient in groundwater and surface water resources, the use of rainwater for drinking is common (Gwenzi et al., 2015; Nalwanga et al., 2016). In the European reality, rainwater can be a valuable source of drinking water in crisis situations, caused by contamination of water taken to water supply systems: drought, large-scale floods or terrorist threats (biological weapon). This is allowed by Council Directive 98/83/EC of 3 November 1998,

Table 3. Number of *Clostridium perfringens* in the rainwater

Research cycle	Date of sampling rainwater	Clostridium perfringens [CFU/100 ml]				
		precipitation	concrete tile	ceramic tile	terrace	galvanized steel
2015	13.03	0	1	0	4	0
	30.03	0	0	0	2	0
	8.04	0	0	0	0	0
	7.05	0	0	0	0	0
	11.05	0	0	0	0	0
	21.05	0	0	0	0	0
	27.05	0	0	0	0	0
	13.07	0	0	0	0	0
	29.07	0	0	0	0	0
	10.11	0	0	0	0	0
	19.11	0	0	0	0	0
2016	8.03	0	0	0	6	0
	31.03	0	0	0	2	0
	8.04	0	0	0	0	0
	11.04	0	0	0	0	0
	15.04	0	0	0	0	0
	25.04	0	0	0	0	0
	28.04	0	0	0	0	0
	3.06	0	0	0	0	0
	15.06	0	0	0	0	0
	27.06	0	0	0	0	0
	6.07	0	0	0	0	0
	14.07	0	0	0	0	0
	18.07	0	0	0	0	0
	5.09	0	0	0	0	0
	19.09	0	0	0	0	0
	4.10	0	0	0	0	0
	27.10	0	0	0	0	0
	14.11	0	0	0	0	0

Source: author's own work.

stating that water intended for human consumption is "all water in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers".

Under conditions where it is impossible to obtain and maintain water of the highest quality, the presence of up to 10 CFU *E. coli* per 100 ml (Wisner, Adams, 2002 WHO) is allowed. The rainwater collected from the roof covered with galvanised sheet, as well as collected in the summer from the roof covered with concrete roof tiles, met the sanitary criteria for drinking water in crisis situations.

Due to the great number of *Escherichia coli* and mesophilic bacteria, rainwater cannot be fed directly into swimming pool basins used as bathing areas. Similar requirements can be applied to water used for hygienic purposes – bathing, brushing teeth, manual washing. During these activities water comes into contact with the digestive system, which, with significant microbiological contamination, causes gastric or intestinal disorders.

Rainwater collected from various roofing can be used only for purposes which do not require water of a good microbiological quality, e.g. for cleaning works in the curtilage and for flushing toilets. Rainwater could also be used for washing, provided that a temperature not lower than 60°C is used. The temperature, apart from detergents, guarantees the sanitary safety of clothing and materials after washing.

Due to the presence of *E. coli*, faecal streptococci and *C. perfringens*, there is a high risk of infection when using contaminated water for the irrigation of plantations where fruit cannot be washed.

Due to the great number of pathogenic microorganisms of *E. coli*, rainwater can be used for watering farm animals only after its disinfection.

In conclusion, rainwater without cleaning and disinfection processes cannot be used as an alternative to tap water, except for crisis situations.

Conclusions

Rainwater collected from roof surfaces is not suitable for uses requiring the quality of water intended for consumption, due to the great number of psychrophilic, mesophilic and faecal bacteria.

The worst microbiological quality was found in the rainwater collected in the summer (mesophilic and psychrophilic bacteria) and in the spring (*Clostridium perfringens*).

In crisis situations, when the requirements for the quality of water intended for consumption and hygienic purposes are less stringent, water collected from the roof covered with galvanised steel can be used without prior treatment.

Rainwater collected from flat and porous surfaces (ceramic, concrete roof tiles), due to its poor sanitary condition, cannot be used without prior treatment for:

- water supply intended for human consumption,
- the filling and refilling of swimming pool basins used as bathing areas,
- the watering of animals and the preparation of feed,
- the irrigation of plantations of vegetables and fruit consumed without heat treatment and thorough cleaning.

Rainwater collected from various roofing can be used for purposes which do not require water of a good microbiological quality, e.g. for cleaning works and flushing toilets. Rainwater can also be used for washing, provided that a temperature not lower than 60°C is used. The temperature, apart from detergents, guarantees the sanitary safety of clothing and materials after washing.

The contribution of the authors

Monika Zdeb – literature review, conducting the experiment, research, writing a manuscript – 50%
Justyna Zamorska – research, analysis of the results – 20%
Dorota Papciak – concept and objectives, analysis and presentation of the results, writing a manuscript – 30%

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