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Impact of a Small Wastewater Treatment Plant on the Sanitary State of Atmospheric Air

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1. Introduction

Wastewater treatment plants are a source of odours and microorganism emissions to the atmospheric air (Kołwzan et al. 2010, Sówka et al. 2015, Szyłak-Szydłowski et al. 2016, Sówka et al. 2017). The high density of buildings and errors in spatial planning cause that residents of buildings adjacent to municipal wastewater treatment plants are exposed to the emissions of chemical and microbial atmospheric air pollutants (Byliński et al. 2019, Paśmionka 2020). It may cause discomfort and fear of the health effects of exposure resulting from the treatment plant activities.

Bioaerosol emitted to the atmospheric air by opened wastewater treatment plants, especially municipal ones, may contain pathogenic and potentially pathogenic microorganisms for humans and livestock causing among others allergic reactions (Michalak & Pawlas 2012, Budzińska et al. 2013, Michałkiewicz 2018). Municipal wastewater is also a reservoir for antibiotic-resistant microorganisms (Huang et al. 2012, Osińska et al. 2019, Savin et al. 2019). The volume of bioaerosol emissions, and thus also the potential health risk, shows a dependence on the size of the treatment plant and the wastewater treatment technology used in it (Breza-Boruta 2010, Kołwzan et al. 2012, Rizzo et al. 2013). This justifies researching the health threat caused by the emission of bioaerosol into the atmospheric air by wastewater treatment plants and the dispersion of this type of pollution (Michalak & Pawlas 2012, Michałkiewicz 2018).

The aim of the study was to assess the impact of the new, just opend, small municipal wastewater treatment plant, located 300 m east of the nearest residential buildings on the sanitary condition of atmospheric air. In the vicinity of the investigated wastewater treatment plant, natural sources of microorganism emissions to the atmospheric air were located, including drainage channels filled with water and natural terrain obstacles (trees and forests), affecting the dispertion of pollutants emitted by the wastewater treatment plant.

2. Study object

The subject of the study was a municipal wastewater treatment plant (WWTP) serving approx. 20,000 PE (population equiwalent), with an average daily flow of approx. 2,300 m^3 located among arable fields. There is the forest on the south-west of WWTP. In the area of the investigated wastewater treatment plant, there are predenitrification chamber (67 m^3), 2 dephosphatation chambers (112 m^3 and 168 m^3), 3 denitrification chambers (343 m^3, 112.5 m^3 and 331 m^3), optional chamber (142 m^3), nitrification chamber (1432 m^3), and secondary settling tank (610 m^3). Treated wastewater is discharged into a drainage ditch. The wastewater treatment plant is equipped with a sludge dewatering station with a capacity of 10-12 m^3/h, working 6 days a week for 10 hours a day.

3. Materials and methods

The number of microorganisms suspended in the atmospheric air was determined by the sedimentation method, accordance with Polish standards no PN-89/Z-04111/01, PN-89/Z-04111/02, PN-89/Z-04111/03, and PN-89/Z-04111/08. Measuring stands 1-10 were located in the wind trail every 50 m, taking into account field conditions on the leeward side of the treatment plant. Control stands 11-13 were situated on the windward side (Fig. 1).

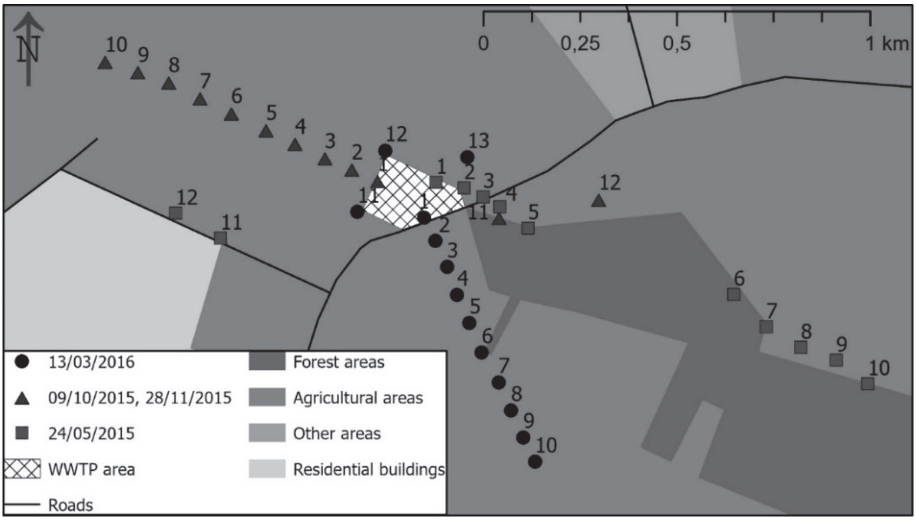

Fig. 1. Location of measuring stands

Four series of tests were carried out in the transitional periods of the year (spring and autumn), field tests were carried out between 9.00-12.00. Agarized microbiological media (BTL Polska LTD., Łódź, Poland) in Petri dishes (3 tiles with each substrate) with a diameter of 0.09 m were exposed to free-falling microorganisms for 15 min (media for psychro- and mesophilic bacteria and mold fungi) and 30 min (for actinomycetes) 1.30 m above the ground. Subsequently, the dishes with media were incubated at the temperatures indicated in Table 1.

Table 1. Microorganisms incubation conditions

Group of microorganisms	Microbiological medium	Incubation temperature [°C]	Incubation time [24 h]
psychrophilic bacteria	nutrient agar	22	3
mesophilic bacteria	nutrient agar	37	1
mold fungi	Sabouraud with chloramphenicol	26	3-5
actinomycetes	Pochon	26	3-5

After incubation, colonies grown on media were counted. The number of colony-forming units (CFU) in the unit of air volume was calculated according to the Omelian formula in the Gogoberidze modification (Polish standards – PN-89/Z-04111/02, PN-89/Z0411/3). Bioaerosol samples were taken in triplicate. The results are presented as the arithmetic mean for three replications. Standard deviation is also provided. During the tests, temperature and humidity of the air, wind direction and speed were determined (Table 2). The assessment of the sanitary state of the air around the tested wastewater treatment plant was made by comparing the concentration of microorganisms with the criteria recommended by PN-89/Z-04111/02 (Table 3), PN-89/Z0411/03 (Table 4) and the proposals of the Team of Experts on Biological Factors (Table 5).

Table 2. Meteorological conditions in the research area at 9 am

Atmospheric factor	24.04.2015	9.10.2015	28.11.2015	13.03.2016
air temperature [°C]	+18	+2	-3	+3
air humidity [%]	65	65	90	90
wind speed [m/s]	1.5	2.4	3.0	2-3
wind direction	NW	SW	SE	NNW

Table 3. Criteria for classification of atmospheric air pollution by bacteria according to PN-89/Z-04111/02 - in the scope related to the results of tests obtained in this work

Total number of mesophilic bacteria	Number of actinomycetes	Degree of atmospheric air pollution
<1000	<10	uncontaminated
1000-3000	10-100	moderately polluted
>3000	>100	heavily contaminated

Table 4. Classification criteria for atmospheric air pollution by fungi according to PN-89/Z-04111/03

Total number of fungi in 1 m^3 of atmospheric air	Degree of atmospheric air pollution
3000-5000	average clean atmospheric air, especially in the late spring and early autumn
5000-10000	pollution that may have a negative impact on the natural environment
>10000	pollution threatening the natural human environment

Table 5. Proposals for assessing the degree of microbial contamination of atmospheric air developed by the Team of Experts on Biological Factors (Górny 2010) – to the extent related to the results of research obtained in this work

Bioaerosol component	Degree of atmospheric air pollution	
	acceptable	unacceptable
mesophilic bacteria	≤5000 cuf/m^3	>5000 cuf/m^3
thermophilic actinomycetes	≤200 cuf/m^3	>200 cuf/m^3
Fungi	≤5000 cuf/m^3	>5000 cuf/m^3

4. Results and discussion

The research shows that the concentration of psychrophilic bacteria on the leeward side of the treatment plant varied in the range from 156±85 to 6587±1286 cfu/m^3, depending on the position and day of the inspection. Their concentration was higher than in control (average of all positions on the windward side of the treatment plant) at positions 1-10 on 24/04/2015, 7 and 9 o 9/10/2015, 1-2, and 4-10 on 28/11/2015, 2, 6, 8-10 on 13.03.2016 (Table 6).

Table 6. Concentrations of microorganisms at individual research stands (mean value for 3 repetitions with standard deviation)

Group of microorganisms	Number of measuring stand	Date of control			
		24.04.2015	09.10.2015	28.11.2015	13.03.2016
psychrophilic bacteria	1	1647±401	1577±88	4143±130	653±226
	2	1265±107	1543±214	329±149	1139±383
	3	2617±554	1877±270	156±85	224±91
	4	3675±946	1473±136	589±330	336±91
	5	1127±130	1993±425	572±42	1300±518
	6	1387±276	1872±278	1039±83	1792±436
	7	1300±147	6587±1287	729±184	989±778
	8	1851±70	2028±377	676±258	1531±161
	9	1647±249	6500±332	399±65	3453±2315
	10	4108±883	1300±85	555±98	597±185
	11	1005±65	2877±177	121±65	915±297
	12	919±191	2357±149	416±236	1773±140
	13	not tested	not tested	not tested	1344±992
mesophilic bacteria	1	763±214	1248±153	5997±978	87±25
	2	763±88	1144±112	1092±363	121±65
	3	953±498	1647±259	607±65	87±88
	4	1629±49	1317±201	1040±153	381±88
	5	416±185	2115±534	555±385	1300±42
	6	399±65	1491±161	624±112	1109±298
	7	659±209	6309±1349	676±195	399±107
	8	589±123	2357±107	451±172	693±356
	9	555±65	4628±663	121±49	1127±354
	10	1283±172	1473±65	347±49	243±149
	11	433±161	1421±25	399±25	225±172
	12	416±74	1577±177	364±42	797±307
	13	not tested	not tested	not tested	277±149

Table 6. cont.

Group of microorganisms	Number of measuring stand	Date of control			
		24.04.2015	09.10.2015	28.11.2015	13.03.2016
actinomycetes	1	104±56	165±65	9±12	9±12
	2	87±12	87±25	0±0	0±0
	3	225±80	520±21	43±25	43±25
	4	191±65	225±96	0±0	0±0
	5	130±0	295±12	26±21	26±21
	6	26±21	321±117	9±12	9±12
	7	69±49	849±96	17±12	17±12
	8	243±25	702±21	26±21	26±21
	9	182±56	702±21	17±25	17±25
	10	113±44	719±12	0±0	0±0
	11	113±12	745±107	0±0	0±0
	12	104±21	425±32	43±25	43±25
	13	not tested	not tested	not tested	9±12
Fungi	1	589±218	2704±321	52±42	205±140
	2	104±112	3155±283	52±42	485±132
	3	659±201	4632±410	69±65	355±115
	4	173±136	3744±405	284±21	411±115
	5	87±49	3744±258	451±218	317±132
	6	676±42	3380±195	607±177	672±229
	7	589±25	3033±298	1041±44	205±70
	8	1057±354	3397±172	711±123	1027±161
	9	555±218	4403±519	364±127	2150±454
	10	867±25	4039±177	485±49	3211±588
	11	295±49	3969±65	225±130	429±115
	12	277±25	3068±42	69±65	1045±53
	13	not tested	not tested	not tested	2949±294

The concentration of mesophilic bacteria on the leeward side of the wastewater treatment plant varied from 87±24 to 6309±1349 cfu/m^3, depending on the position and the day of the inspection. Their concentration was higher than in control (average of all positions on the windward side of the treatment plant) at positions 1-4 5 and 7-10 on 24/04/2015, 3, 5, 7-9 on 9/10/2015, 1- On November 8 28, 2015, 5-6 and 8-9 on March 13, 2016 (Table 6).

Concentrations of actinomycetes on the leeward side of the treatment plant varied from 0±0 to 719±12 cfu/m^3, depending on the position and day of the inspection. Their concentration was higher than in control (average of all sites on the windward side of the treatment plant) on sites 3-5 and 8-10 on 24/04/2015, 3, 7-10 on 9/10/2015, 3, 5 and 8 on November 28, 2015, 3 and 8 on March 13, 2016 (Table 6).

The concentration of mold fungi on the leeward side of the wastewater treatment plant varied from 52±42 to 4645±425 cfu/m^3, depending on the stand and the day of the inspection. Their concentration was higher than in control (average of all positions on the windward side of the treatment plant) at locations 1, 3, and 6-10 on 24/04/2015, 3-5, and 9-10 on 9/10/2015, 4-10 on 28.11.2015, 9-10 on 13.03.2016 (Table 6).

The concentration of microorganisms in the area and in the vicinity of wastewater treatment plants examined by other authors, serving from tens to hundreds of thousands of inhabitants were similar to those found in this work and were in the following ranges: 10^2-10^4 for psychrophilic and mesophilic bacteria, 10^1-10^2 for actinomycetes and 10^1-10^4 for mold fungi (Filipkowska et al. 2000, Breza-Boruta 2010, Kołwzan et al. 2012, Li et al. 2016, Paśmionka 2019, Paśmionka 2020). The authors of these studies also found that the concentrations of microorganisms at measuring points differed by the distance from the wastewater treatment plant as a whole and its individual elements, and depending on the day of the inspection. This phenomenon is seasonal in nature (Szyłak-Szydłowski et al. 2016). However, the formation of bioaerosol in a wastewater treatment plant and its distribution in the atmosphere as well as the survival of microorganisms in the atmospheric air depend on many factors, including:

- wastewater treatment technology used in a given treatment plant and its parameters, including: the intensity of wastewater mixing and aeration,
- variable meteorological conditions: wind speed and direction, solar radiation intensity, precipitation, air temperature and humidity
- topography around the wastewater treatment plant and the presence and distribution terrain barrier,
- the duration of the treatment plant's operation – its long-term operation may cause microbiological contamination of the soil and cause the secondary transport of microbial contamination from the soil (Korzeniewska 2011, Kołwzan et al. 2012, Michałkiewicz 2018).

In terms of the concentration of mold fungi, the air around the wastewater treatment plant was on average clean air according to PN-89/Z-04111/02, according to the classification proposed by the Team of Experts on Biological Factors, the degree of atmospheric air pollution around the treatment plant was acceptable (Górny 2010).

In terms of the concentration of mesophilic bacteria, the air was uncontaminated according to PN-89/Z-04111/02 at 23 sites on the leeward side of the treatment plant, moderately contaminated at 14 sites and heavily contaminated at 3 test sites during all four series of field tests (total 40 research positions). In terms of the classification proposed by the Panel of Experts on Biological Factors, the degree of air pollution with mesophilic bacteria was acceptable for 39 out of 40 test stands on the leeward side of the power plant (all series of field tests). The exception was the stand no. 1 located at the wastewater treatment plant fence on November 28, 2015.

In terms of concentration of actinomycetes, the air was uncontaminated according to PN-89/Z-04111/02 at 8 test stands on the leeward side of the treatment plant, moderately polluted at 16 stands and heavily contaminated at 16 stands. Concentrations of actinomycetes on 24/04/2015 and 9/10/2015 were higher than on 28/11/2015 and 13/03/2015. In the presented work, actinomycetes were incubated at 26ºC, in accordance with PN-89/Z-04111/02. At the same time, the Expert Team on Biological Factors (Górny 2010) concluded that air pollution by actinomycetes is acceptable when the concentration of thermophilic actinomycetes exceeds 200 cfu/m^3. This number of actinomycetes was found at 11 positions during the first two field tests, but it was not found during the last two field tests. It is not known, however, how many of these actinomycetes would be thermophilic actinomycetes.

The diversity of microorganism concentrations around the tested wastewater treatment plant did not decrease as a function of the distance from the emission source. It was similar in the case of the previously tested large wastewater treatment plant (Strzelecka et al. 2004). In both cases, this could be due to the presence of other sources of microorganism emissions to atmospheric air in the vicinity of the treatment plant. In the case of the small wastewater treatment plant currently under study, these were arable land without vegetation or scantily covered with emerging winter crops and numerous drainage channels filled with water and water collected in ground depressions. The plant was surrounded by obstacles such as mid-field tree stands, a forest with a dense undercoat, and a railway embankment about 1 m high. They could have changed the direction of air masses displacement from the plant together with bioaerosol lifted from its facilities.

5. Conclusion

The obtained research results indicate that the emission of bioaerosol from a small wastewater treatment plant, may cause changes in the concentration of microorganisms in the atmospheric air at a level close to natural sources. The threat to human health associated with this emission is, in such cases, the presence of pathogens in bioaerosol emitted by wastewater treatment plants (Korzeniewska 2011, Kołwzan et al. 2012, Michalak & Pawlas 2012) and microorganisms that show resistance to antibiotics (Rizzo et al. 2013). An effective solution to the problem is hermetization of the wastewater treatment plant (Michałkiewicz et al. 2009). However, this is an expensive investment. Periodic monitoring of the sanitary state of the air around wastewater management facilities is therefore justified. However, in many countries of the world, including Poland, there is no standardized methodology for this type of monitoring and the permissible concentrations of microorganisms in the air, as well as a clear statement that such monitoring is mandatory. The authors of other works have already addressed this problem (Górny 2010, Michałkiewicz 2018). It is also necessary to conduct further research to develop a set of microbiological indicators that will be used in routine monitoring of sanitary air in the area and in the vicinity of wastewater treatment plants.

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PN-89/Z-04111/01. Ochrona czystości powietrza. Badania mikrobiologiczne. Postanowienia ogólne i zakres normy.

PN-89/Z-04111/02. Ochrona czystości powietrza. Badania mikrobiologiczne. Oznaczanie liczby bakterii w powietrzu atmosferycznym (imisja) przy pobieraniu próbek metodą aspiracyjną i sedymentacyjną.

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Abstract

Wastewater treatment plants are the source of odour and microorganism emissions to the atmospheric air. Bioaerosol emitted by treatment plants may contain pathogenic microorganisms, antibiotic resistant microorganisms and cause allergies.

The aim of the study was to assess the impact of the newly created municipal wastewater treatment plant using the activated sludge method (approx. 20,000 PE, average daily flow of 2,300 m^3) on the sanitary state of atmospheric air. Numerous field obstacles (e.g. trees) and natural sources of microorganism emissions to the atmospheric air (e.g. drainage channels) were located in the vicinity of the wastewater treatment plant.

Bioaerosol samples (3 replicates) were taken in a wind trail at 10 test stands on the leeward side of the treatment plant and two control stands on the windward side of the treatment plant. Samples were taken by sedimentation on Petri dishes with microbiological mediums. Media was incubated at a temperature appropriate for the type of microorganisms (psychrophilic bacteria, mesophilic bacteria, actinomycetes, mold fungi), and then colonies growing on media were counted. The number of microorganisms per unit volume of air was determined according to the Omelian formula in the Gogoberidze modification. Four series of tests were carried out during the transition months (spring and autumn).

The concentration of microorganisms on the leeward side of the treatment plant in the following ranges amouted: psychrophilic bacteria: 156 ± 85 - 6578 ± 1286 cfu/m^3, mesophilic bacteria: 87±24 - 6309 ± 1349 cfu/m^3, actinomycetes: 0±0 - 719±12 cfu/m^3, mold fungi: 52±42 - 4645±425 cfu/m^3. These values were similar to those found in the area and in the vicinity of wastewater treatment plants examined by other authors. The concentration of microorganisms in the vicinity of the tested wastewater treatment plant did not show a downward trend as a function of distance from the wastewater treatment plant. This could be due to the presence of other sources of bioaerosol emissions to atmospheric air in the vicinity of the treatment plant (e.g. drainage canals, uncovered soil in plowed fields) and field obstacles that could have affected the movement of air masses (e.g. in-field woodland, forest, embankment Railway).

The obtained research results indicate that the emission of bioaerosol from a small wastewater treatment plant, may cause changes in the concentration of microorganisms in the atmospheric air at a level close to natural sources. However, the threats to human health caused by bioaerosol emitted from municipal wastewater may be higher. Therefore, it is justified to monitor the sanitary state of the air and the atmosphere at the wastewater treatment plant and in its vicinity, and conduct research to develop an optimal set of indicator microorganisms of this state.

Keywords:
bioaerosol, bacteria, fungi, air pollution, wastewater treatment

Wpływ małej oczyszczalni ścieków na stan sanitarny powietrza atmosferycznego

Streszczenie

Oczyszczalnie ścieków są źródłem emisji odorów i mikroorganizmów do powietrza atmosferycznego. Bioaerozol emitowany przez oczyszczalnie może zawierać mikroorganizmy chorobotwórcze, mikroorganizmy oporne na antybiotyki oraz powodować powstawanie alergii.

Celem pracy była ocena wpływu nowo powstałej oczyszczalni ścieków komunalnych oczyszczającej je metodą osadu czynnego, (ok. 20000 RLM, średni przepływ dobowy 2300 m^3) na stan sanitarny powietrza atmosferycznego. W sąsiedztwie oczyszczalni znajdowały się liczne przeszkody terenowe (np. zadrzewienia) oraz naturalne źródła emisji mikroorganizmów do powietrza atmosferycznego (np. kanały melioracyjne).

Próbki bioaerozolu (po 3 powtórzenia) pobierano w smudze wiatru na 10 stanowiskach badawczych po stronie zawietrzenj oczyszczalni i dwóch stanowiskach kontrolnych po stronie nawietrznej oczyszczalni. Próbki pobierano metodą sedymentacyjną na płytki Petriego ze zagaryzowanymi podłożami mikrobiologicznymi. Podłoża inkubowano w temperaturze odpowiedniej dla danego rodzaju mikroorganizmów (bakterie psychrofilne, bakterie mezofilne, promieniowce, grzyby pleśniowe), a potem liczono kolonie rosnące na podłożach. Liczbę mikroorganizmów w jednostce objętości powietrza określano według wzoru Omeliańskiego w modyfikacji Gogoberidze. Wykonano 4 serie badań w miesiącach przejściowych (wiosna i jesień).

Stężenia mikroorganizmów po stronie zawietrznej oczyszczalni mieściły się w przedziałach: bakterie psychrofilne: 156±85 - 6578±1286 jtk/m^3, bakterie mezofilne: 87±24 - 6309±1349 jtk/m^3, promieniowce: 0±0 - 719±12 jtk/m^3, grzyby pleśniowe: 52±42 - 4645±425 jtk/m^3. Były to wartości zbliżone do stwierdzonych na terenie oraz w sąsiedztwie oczyszczalni ścieków badanych przez innych autorów. Stężenia mikroorganizmów w sąsiedztwie badanej oczyszczalni nie wykazywało tendencji spadkowej w funkcji odległości

od oczyszczalni ścieków. Mogło to być spowodowane obecnością w sąsiedztwie oczyszczalni innych źródeł emisji bioaerozolu do powietrza atmosferycznego (np. kanałów melioracyjnych, odkrytej gleby na zaoranych na polach) oraz przeszkód terenowych, które mogły mieć wpływ na przemieszczanie się mas powietrza (np. zadrzewienia śródpolne, las, nasyp kolejowy).

Uzyskane wyniki badań wskazują, że emisja bioaerozolu z małej oczyszczalni ścieków, w niektórych przynajmniej przypadka, może powodować zmiany stężenia mikroorganizmów w powietrzu atmosferycznym na poziomie zbliżonym do źródeł naturalnych. Zagrożenia dla zdrowia ludzkiego spowodowane przez bioaerozol emitowany ze ścieków komunalnym mogą być jednak większe. Dlatego uzasadnione jest monitorowanie stanu sanitarnego powietrza atmosferycznego na terenie oczyszczalni ścieków i w ich sąsiedztwie oraz prowadzenie badań nad opracowaniem optymalnego zestawu mikroorganizmów wskaźnikowych tego stanu.

Słowa kluczowe:
bioaerozol, bakterie, grzyby, zanieczyszczenie powietrza, oczyszczalnie ścieków