Krzysztof FRĄCZEK[1*], Dariusz ROPEK[2],
Anna LENART-BOROŃ[1] and Jacek STROJNY[3]

MICROBIOLOGICAL AND PHYSICOCHEMICAL QUALITY OF LEACHATE AND WATER IN THE VICINITY OF A MUNICIPAL LANDFILL

JAKOŚĆ MIKROBIOLOGICZNA I FIZYKOCHEMICZNA ODCIEKÓW I WÓD W REJONIE SKŁADOWISKA ODPADÓW KOMUNALNYCH

Abstract: This study aimed to assess microbiological and physicochemical quality of landfill leachate and water in the landfill's vicinity. Nine samples consisting of groundwater, surface water and leachate were collected within and in the vicinity of a municipal landfill site in Tarnow. Physicochemical analyses of groundwater and leachate included: determination of pH, electric conductivity, heavy metal concentration (Pb, Cd, Cu, Zn, Cr VI and Hg) and sum of policyclic aromatic hydrocarbons. Surface water analyzes were complemented with the determination of Ni, As, Ag, V, volatile phenols concentration, content of total nitrogen and phosphorus, as well as COD_{Cr} and BOD_5 Microbiological analyzes consisted of determination of total mesophilic and psychrophilic bacteria, *Staphylococcus* spp., *Salmonella* spp., the number of coliforms and fecal coliforms, *Enterococcus faecalis*, *Clostridium perfringens*, yeast and mold fungi. No threshold values concerning the examined chemical contaminants were exceeded in any of the water or leachate samples. However, the landfill vicinity resulted in severe microbiological contamination of surface and groundwater, which contained high concentrations of not only mesophilic bacteria but also fecal and pathogenic microorganisms. The results of this study revealed that waste and leachates are a major source of microbial emissions. Therefore, there is a need to conduct both physico-chemical and microbiological analyzes of the landfill-surrounding environment and this necessity should be legally enforced.

Keywords: municipal landfill, groundwater, leachate, surface water

Despite the fact that the selective waste collection has been conducted in growing number of municipalities, landfilling is still the most common method of solid waste

[1] Department of Microbiology, University of Agriculture in Krakow, al. A. Mickiewicza 24/28, 30-059 Kraków, Poland.

[2] Department of Agricultural Environment Protection, University of Agriculture in Krakow, al. A. Mickiewicza 21, 31-120 Kraków, Poland.

[3] Department of Mathematical Statistics, University of Agriculture in Krakow, al. A. Mickiewicza 21, 31-120 Kraków, Poland.

* Corresponding author: rrfracze@cyf-kr.edu.pl

disposal in Poland, where 527 active, controlled landfills were in operation at the end of 2012, occupying a total area of 2198 ha [1]. The amount of municipal waste produced in Poland has been continuously increasing with over 12 Gg (thousand tons) of waste produced in 2012 [1], 74.7% of which has been deposited in landfills [1]. In contrast, in the USA 54.2% of the produced municipal waste went to landfills in 2010 [2]. On average each Polish citizen produced c.a. 314 kg of municipal waste in 2012, with slightly lower value recorded in the Lesser Poland voivodeship, i.e. 300 kg of municipal waste per citizen [1]. Despite using the best protection, waste disposal is always troublesome for the environment, but at the same time it is inevitable part of the waste management system. The environmental problems related to waste landfilling include the pollution of air, soil and groundwater, however the issues related to costs of landfill operation, closing and remediation are also important [3]. Waste disposal sites also pose a serious health risk not just in terms of deterioration of groundwater quality, thus affecting drinking water intakes, but also because of the problems associated with vicinity of garbage, wild animals, scavenging birds and airborne contamination caused by mobilization of fine particulate matter [4]. This is particularly significant, as municipal objects, such as waste landfills are often located in the direct vicinity of cities, and they raise many concerns, not only because they are esthetically inconvenient [5].

One of the significant problems related to waste storage is the formation of leachate which consists of liquid generated by waste decomposition and infiltrating precipitation and is both chemically and microbiologically contaminated [6]. Municipal landfill leachate are highly concentrated complex sewage, containing dissolved organic matter, inorganic compounds (e.g. calcium, magnesium, potassium, iron, sulphates, chlorides) and heavy metals (cadmium, chromium, copper, lead, zinc, nickel) [7]. Landfill leachate can also contain xenobiotic organic substances and products of their decomposition, for example benzenes, naphtalenes, chlorinates aliphatics, phenols, pesticides and phthalates in varying concentrations [8]. Some of these organic compounds proved to be highly toxic to model organisms in biological tests [8]. Another concern is related to the fact that landfills and landfill leachate contain large numbers of pathogenic and opportunistic bacteria, due to the presence of used disposable napkins and sanitary towels, clinical waste and domestic human origin waste, such as hypodermic needles and syringes [9]. Moreover, according to Palmisano and Barlaz [10], the presence of large amount of organic matter in landfills results in an increase in the number of some types of enteric bacteria. Often, the pollution load in leachate is greater than in municipal sewage [5]. The quality of leachate depends on four basic factors: material composition and size distribution of deposited waste, the age of the landfill, mode of operation as well as geometric parameters of the landfill [11]. Leachate composition depends primarily on the age of the landfilland and the degree of waste stabilization. The progress of waste stabilization largely depends on the physical, chemical and microbiological conditions developed within the landfill over time [12]. Consequently, municipal landfill sites may have significant harmful effect on surface water and groundwater in their vicinity. In general, landfills are considered to be one of the major threats to groundwater, which is one of the most important sources of potable water in Poland. Microbiological contamination of groundwater by landfills depends on the waste composition and its load, technological infrastructure of waste intakes and isolation properties of the ground, as well as on the self-purification properties of the environment [13]. Even landfills with modern systems applied have been reported to leak leachate into the ground and pollute groundwater [14]. When such contamination occurs, it persists in the environment for dozen years. Water needs at least several years before its natural properties can be restored [15]. This prolonged danger is caused, among others, by the degradation of membranes that seal landfill bases, thus resulting in pollutant infiltration into the ground [16]. Additionally, floods and intensive downpours, more and more frequently occurring in recent years in Poland, increase the risk of leachate release to the environment. Once groundwater is polluted, such pollution may be very difficult not only to remove, but also to detect. Montgomery [17] predicted that within the next few decades the number of contaminated aquifers will be discovered and new contaminants will be identified. By the time the groundwater pollution is detected, it may be very widespread, therefore in such case the extent of the problem may be difficult to assess as well as the source of the contamination may be hard to identify.

The abundance, type and distribution of waterborne microorganisms depends on numerous physical and chemical factors, including environmental conditions, season, the quality or depth of water, and many others. These factors also affect the physiology and morphology of bacteria, fungi or cyanobacteria. Too high concentrations of some nutrients, as well as extreme temperature and pH, negatively affect the proliferation of almost all microorganisms, which have a narrow range of tolerance [3]. In contrast to numerous studies concerning the impact of waste landfills on the quality of atmospheric air, there have been quite little analyses concerning the contamination of water related to leachate release into the environment with particularly few studies related to the microbiological contamination of the landfill surroundings. Nevertheless, the public awareness of the significance of these problems has raised in recent years, which has been reflected in the development of proper legislation addressing sustainable waste management [18, 19]. Moreover, pathogenic bacteria may contaminate groundwater and thus drinking water so their presence must be monitored to prevent the potential health hazards. Also, a direct contact of leachates and surface water poses the significant threat to human health. The most frequently used indicator of water contamination includes the number of total and fecal coliforms. Total coliforms can proliferat under normal environmental conditions, but their presence may indicate the occurrence of fecal coliforms, which in turn indicate rather recent fecal contamination [20]. *Enterococcus* spp. are found in varied environments, particularly in wastewater. They are more durable than coliforms and are a reliable indicators of fecal contamination but also the indicators of the occurrence of viruses. Another pollution indicator includes *Salmonella* spp., that are widespread environmental bacteria able to survive for several months in water [21]. There is a growing need to establish effective and inexpensive methods for the treatment of landfill-related environmental pollution, including leachates. Prior to this, thorough studies need to be conducted in order to understand the extent of the landfill impact on the surrounding environment.

Having regard to the above, this study was undertaken with the aim to assess microbiological and physicochemical quality of landfill leachate and water (both groundwater and surface water) in the vicinity of a municipal landfill site.

Material and methods

Field studies were conducted within and in the vicinity of a municipal landfill in Tarnow, a large landfill site, which was launched in 1985. It needs to be stressed that this landfill site may be considered as one of the best organized municipal landfills in Lesser Poland due to its mode of operation and consistently implemented modern system of waste storage. The landfill sections are in the form of troughs with embankments and drainage. The landfill consists of 4 closed sectors with a total area of 6.5 ha and 1 active sector of 2.6 ha. In recent years the landfill has received almost 50 thousand tons of unsorted waste.

The study included nine samples (three samples of surface water, four – groundwater and two – leachate), which were collected within and in the vicinity of the landfill. The location of sampling sites was designated based on the emissions from the landfill due to natural topography and groundwater flow direction. Table 1 presents the exact location and the description of water and leachate samples.

Table 1

Location and description of the sampling sites within and in the vicinity of the municipal landfill in Tarnow

Sample No. (Symbol)	Description	GPS coordinates	pH [-]	Details
1 (L1)	Leachate 1	N 50°2′35.83″ E 21°1′59.34″	7.99	Leachate tank No. 1 (new), nearby the active sector, to the east
2 (L2)	Leachate 2	N 50°2′26.52″ E 21°1′59.34″	8.08	Leachate tank No. 2 (old), below the reclaimed sectors, to the south-east
3 (G1)	Groundwater 1	N 50°2′42.18″ E 21°1′55.13″	7.26	Piezometer within the landfill, above the active sector, to the north
4 (G2)	Groundwater 2	N 50°2′32.94″ E 21°2′0.16″	7.36	Piezometer within the landfill, below the active sector, to the east
5 (G3)	Groundwater 3	N 50°2′29.54″ E 21°2′0.25″	7.12	Piezometer within the landfill, below the reclaimed sectors, to the south
6 (G4)	Groundwater 4	N 50°2′26.13″ E 21°1′58.46″	7.13	Piezometer outside the landfill, nearby the drainage ditch, to the south-east
7 (S1)	Surface water 1	N 50°2′34.66″ E 21°1′25.34″	6.93	Water ditch, approx. 100 m. before the landfill, to the south
8 (S2)	Surface water 2	N 50°2′29.56″ E 21°1′47.83″	7.85	Water ditch, at the height of the reclaimed sector, to the south
9 (S3)	Surface water 3	N 50°2′24.3″ E 21°2′1.99″	8.02	Water ditch, approx. 200 m below the landfill, to the south

The samples were collected into sterile containers, once per each season over a period of two years (2010 and 2011) to spot seasonal variations in microbial contamination. Physicochemical analyses of groundwater and leachates included: determination of pH [22], electrical conductivity [23], heavy metal concentration (Pb, Cd, Cu, Zn, Cr VI and Hg) and the sum of polycyclic aromatic hydrocarbons. The concentration of Pb, Cd, Cu and Zn was determined using the Inductively Coupled Plasma Mass Spectrometry [24], Cr(VI) was determined spectrophotometrically [25], while Hg was determined using AAS [26]. The sum of polycyclic aromatic hydrocarbons was evaluated using HPLC with fluorescence detection [27]. Surface water analyzes were complemented with the determination of Ni, As, Ag, V, which were assessed using the Inductively Coupled Plasma Mass Spectrometry [24], volatile phenols concentration [28], content of total nitrogen [29] and phosphorus [30], as well as COD_{Cr} [31] and BOD_5 [32]. Microbiological analyzes included the determination of total mesophilic and psychrophilic bacteria, *Staphylococcus* spp., *Salmonella* spp., the number of coliforms and fecal coliforms, *Enterococcus faecalis*, *Clostridium perfringens*, yeast and mold fungi. The water samples were analyzed using the plate dilution method to determine the abundance of mesophilic and psychrophilic bacteria (Nutrient agar, 48 h at 37°C or 72 h at 22°C, respectively), *Staphylococcus* spp. (Chapman agar, 48h at 35°C) *Salmonella* spp. (SS agar, 48 h at 37°C), *Clostridium perfringens* (Wilson-Blair agar, 36 h at 35°C in anaerobic conditions) and yeast and mold fungi (malt agar, 3 days at 28°C). The filtration method was applied to determine the number of coliforms and fecal coliforms (Endo agar, 48 h at 37°C or 48 h at 44°C, respectively) as well as the number of *Enterococcus faecalis* (Slanetz-Bartley agar, 72 h at 37°C). The results were presented as mean values of three replicates (CFU per 1 cm^3 of water or leachate and in the case of coliforms, fecal coliforms and *E. faecalis* – CFU per 100 cm^3). The predominant genera of mesophilic bacteria and fungi were identified based on macroscopic and microscopic observations. The bacterial isolates were differentiated using microscopic observations of Gram stained smears, as well as using metabolic characteristics using Bergey's Manual of Determinative Bacteriology [33]. Fungal genera were determined by comparing the macroscopic and microscopic observations with data from the taxonomic manuals [34, 35].

Data were analyzed using Statistica v. 10 (StatSoft). Correlations between microbial abundances and pH, as well as concentrations of various pollutants contained in surface water, groundwater and leachate samples were calculated. To test the null hypothesis that the distribution of the dependent variable does not differ among juxtaposed classes, Jonckheere-Terpstra test was employed. Jonckheere-Terpstra test enables to verify a hypothesis that populations under investigation are identically distributed. It is a nonparametric test for ordered differences among categories. The test procedure is a manner of class differences detection among ordered alternatives. Jonckheere-Terpstra test shows some advantages compared to more general research approaches, such as the Kruskal-Wallis test, for its higher ability to detect class differences [36]. Because of sparse data available in the study, the results verified with asymptotic statistics could be unreliable. The exact or Monte Carlo method was employed for p-values assessment. This makes inferences more reliable. P-values are one sided for reason of the alternative hypotheses nature.

Results and discussion

Chemical elements, including heavy metals and policyclic aromatic hydrocarbons are considered to be one of the most serious environmental threats from landfills [37]. Nevertheless, contamination with these compounds was not detected in surface or groundwater samples collected nearby the landfill. Similarly, landfill leachates did not contain heavy metal or PAH contamination. Water pH was neutral, with one exception – the sample of surface water collected southwards of the landfill was alkaline, as well as landfill leachates (Table 2). There was no transgression of the admissible values recommended in the Regulation of the Minister of Environment [38], for the classification of bodies of surface water and environmental quality standards for priority substances.

According to Dlugosz [39] the average composition of landfill leachate may be very variable and changes not only depending on the composition of deposited waste, their compaction, water content, but it also changes over time. The highest heavy metal concentration occurs in "young" landfills with acid stage of fermentation. At a later stage of operation, when pH becomes neutral, the solubility of heavy metals decreases gradually [40]. According to the literature the amount of heavy metals deposited in landfills, that enters leachate is less than 0.5% [41].

In contrast to chemical analyzes, the results of the conducted microbiological examinations of surface water, groundwater and leachate samples revealed that the studied landfill poses a potential hazard to the environment by emissions of large amounts of microorganisms, sometimes the pathogenic ones, such as *Salmonella* spp. or *C. perfringens*. Microbiological analyzes of three surface water samples revealed that after flowing along the landfill, water became contaminated. Nevertheless, it needs to be mentioned, that surface water in the stream was already contaminated when it flowed into the landfill. The sample collected before the landfill (S1) contained a considerable amount of mesophilic bacteria, as well as coliforms, fecal coliforms and other indicators of recent fecal contamination (Table 3). The presence of thermotolerant coliforms proves recent contamination of water with feces, sewage, soil or decaying plant material [42]. The sample collected after passing the landfill (S3) contained the highest concentration of mesophilic and coliform bacteria while the one collected at the height of the landfill was characterized by the highest concentration of *E. faecalis, C. perfringens* and *Salmonella* spp.. According to the Regulation of the Minister of Environment [43] the abundance of total coliforms and fecal coliforms divides surface waters into 5 classes. Therefore, regarding the mean number of total and fecal coliforms throughout the study period, the surface water samples qualify as 2nd class of purity, which means that they are of good quality and the values of biological water quality indicators show low anthropogenic impact. The abundance of psychrophilic bacteria (typical representatives of indigenous waterborne microflora) decreased with the stream course along the landfill and was outnumbered by mesophilic bacteria. The group of mesophilic bacteria was dominated by species belonging to the genus *Bacillus*. The highest numbers of fungi in surface water were detected in the sample below the landfill (S3). Fungi of the genera: *Alternaria*, *Aspergillus*, *Candida*, *Cladosporium, Geotrichum*, *Helicosporina*,

Table 2

The concentration of chemical contaminants in the analyzed water samples
(heavy metals, volatile phenols, total nitrogen and phosphorus, CODCr and BOD5; ΣPAH)

Sample	Parameter								
	pH [-]	EC [μS/cm^3]	Pb [mg/dm^3]	Cd [mg/dm^3]	Cu [mg/dm^3]	Zn [mg/dm^3]	Cr (VI) [mg/dm^3]	Hg [mg/dm^3]	ΣPAH [μg/dm^3]
L1	7.99	11 658	0.10	0.018	0.03	0.16	0.015	< 0.0005	0.10
L2	8.08	10 455	0.07	0.010	0.03	0.12	0.12	< 0.0005	< 0.06
G1	7.26	610	< 0.004	< 0.0003	< 0.002	< 0.05	< 0.01	< 0.00005	< 0.06
G2	7.36	647	< 0.004	< 0.0003	< 0.002	< 0.05	< 0.01	< 0.00005	< 0.06
G3	7.12	1 484	< 0.004	< 0.0003	0.003	< 0.05	< 0.01	< 0.00005	< 0.06
G4	7.13	1 005	< 0.004	< 0.0003	< 0.002	< 0.05	< 0.01	< 0.00005	< 0.06
S1	6.93	n/a	< 0.004	< 0.0003	< 0.002	< 0.05	0.005	< 0.00005	< 0.06
S2	7.85	n/a	< 0.004	< 0.0003	0.005	< 0.05	< 0.004	< 0.00005	< 0.06
S3	8.02	n/a	< 0.004	< 0.0003	0.003	< 0.05	< 0.004	< 0.00005	< 0.06
Sample	Parameter								
	Ni [mg/dm^3]	As [mg/dm^3]	Ag [mg/dm^3]	V [mg/dm^3]	Volatile phenols [mg/dm^3]	Total nitrogen [mg/dm^3]	Total phosphorus [mg/dm^3]	CODCr [mg/dm^3]	BOD_5 [mg/dm^3]
S1	0.009	0.003	< 0.002	< 0.005	< 0.002	1.68	11.1	136	50.4
S2	0.005	< 0.001	< 0.002	< 0.005	< 0.002	5.35	0.07	33.5	3.5
S3	< 0.005	< 0.001	< 0.002	< 0.005	< 0.002	4.91	0.04	24	2.4

Table 3

Mean prevalence of the analyzed microbial groups in leachate (L1–L2), groundwater (G1–G4) and surface water (S1–S3) samples over the whole study period (CFU/cm^3, CFU/100 cm^3 for coliforms, fecal coliforms and E. faecalis). The highest values within each group of samples are given in bold type. The site description is given in Table 1

Microorganisms	Water and leachate samples								
	L1	L2	G1	G2	G3	G4	S1	S2	S3
Mesophilic bacteria [CFU/cm^3]	231 675	650 300	12 193	3 952	8 264	12 488	14 136	14 061	18 228
Psychrophilic bacteria [CFU/cm^3]	176 462	188 470	7 336	7 201	8 130	3 209	15 687	14 027	8 218
Staphylococcus spp. [CFU/cm^3]	1 533	2 382	81	46	61	84	128	68	97
Fungi [CFU/cm^3]	738	303	205	243	295	243	395	312	425
Coliforms [CFU/100 cm^3]	1 313	982	20	61	29	34	172	340	386
Fecal coliforms [CFU/100 cm^3]	402	309	7	12	14	11	37	28	39
E. faecalis [CFU/100 cm^3]	430	248	0	4	41	12	5	34	23
C. perfringens [CFU/100 cm^3]	46	203	2	6	7	27	13	23	10
Salmonella spp. [CFU/cm^3]	297	276	0	13	5	15	2	15	0

Mucor, *Penicillium*, *Pichia*, *Rhizopus*, *Trichoderma* and *Tricladium* were the most frequent in the examined surface water samples.

The exact one-sided *p*-value of 0.0330 for coliforms (Table 4) reveals that there is a statistically significant correlation between S-y (the collection site) and the number of coliforms. The positive sign of the standardized test statistic $t^* = 1.903$ implies that the shift from S1 to subsequent sampling sites is associated with higher coliforms variable values.

Groundwater contained high concentrations of mesophilic bacteria, but other bacterial indicators of bad sanitary condition, such as coliforms and fecal coliforms or *Salmonella* spp. were also abundant. Water collected from the first piezometer contained the smallest number of all examined microbial groups. The samples no. G3 and G4 – collected after passing through the landfill – were characterized by the highest numbers of all microbial indicators of bad sanitary quality, except for the total number of coliforms, which was the highest in the sample No. G2. It is noteworthy that the water sample collected above the active sector of the landfill (G1) did not contain *E. faecalis* or *Salmonella* spp. throughout the study period and this was the only sample, where these contamination indicators were not detected. The following fungal genera were isolated from the analyzed groundwater samples: *Aspergillus*, *Candida*, *Penicillium* and *Torulopsis*.

Table 4

Jonckheere-Terpstra test results – the populations of S1–S3 samples are identically distributed

Microorganisms	Observed JT statistic	Standardized JT statistic (t^*)	Exact *p*-value (One-sided)
Coliforms	46.00	1.903	0.0330
Fecal coliforms	33.50	0.147	0.4510
E. faecalis	41.50	1.475	0.0813
C. perfringens	28.00	0.3914	0.3667
Salmonella spp.	7.000	–0.7911	0.3333

The exact one-sided *p*-values of 0.0279 and 0.0001 for *E. faecalis* and *C. perfringens*, respectively (Table 5) indicate that there is a statistically significant correlation between the sampling sites and the number of these microbial indicators of water contamination. The positive sign of the standardized test statistics (t^*) = 1.952 and (t^*) = 3.196, respectively implies that the shift from G1 to subsequent sampling sites is associated with higher variable values of *E. faecalis* and *C. perfringens*.

The presented results concerning the prevalence of microbial indicators of sanitary quality in surface and groundwater samples indicated that there is a significant problem related to the impact of neighboring landfill on the quality of surrounding waters. Similar observations were presented by Mor et al. [13], who examined leachate and groundwater nearby Gazipur landfill site and detected considerable amounts of total coliforms and fecal coliforms in groundwater samples. Uzoigwe and Agwa [44] detected large numbers of fecal coliforms and pathogens such as Salmonella or Shigella in water samples collected in the vicinity of a landfill site in Port Harcourt.

Table 5

Jonckheere-Terpstra test results – the populations of G1–G4 are identically distributed

Microorganisms	Observed JT statistic	Standardized JT statistic (t*)	Monte Carlo estimate of p-value (One-sided)
Coliforms	68.00	0.7945	0.2294
Fecal coliforms	66.00	0.7497	0.2267
E. faecalis	65.00	1.952	0.0279
C. perfringens	91.00	3.196	0.0001
Salmonella spp.	66.00	1.612	0.0542

The analyzed leachate samples contained large amounts of all microbial indicators of contamination, including pathogenic microorganisms such as *Salmonella* spp., *C. perfringens* or fecal coliforms. The differences in microbial abundances between the two samples of leachate (collected from the active sector – L1 and the reclaimed sector – L2) were insignificant, except for the number of *E. faecalis* (p = 0.0209). The improvement in leachate quality was observed usually after securing of the waste heap by e.g. reinforced soil, sealing of the ground and surrounding the heap by a screen reaching to the impermeable layer [45]. Microbiological contamination of groundwater by municipal landfills is the constant threat and depends on the waste composition and the load of waste, technological infrastructure, insulating properties of the ground and the self-purification capabilities of the environment [43]. The analysis of correlation between the abundance of the examined microbial groups and pH as well as the concentration of different water contaminants revealed that there was a strong significant negative correlation between the number of coliforms and nickel concentration (–0.99), the number of *Staphylococcus* spp. and the concentration of copper (–0.99), as well as a significant positive correlation between the number of coliforms and pH of water samples (0.99, $p < 0.05$).

Concerning the seasonal variation of mean abundance of the analyzed microbial groups in surface water samples, the highest values were recorded in warm seasons (mostly in summer), while in general the lowest mean values were observed in winter (Fig. 1). Similar regularity was observed in the case of microbial abundance in groundwater and leachate samples (Fig. 2 and 3 a–i). This result is not uncommon, as summer months, characterized by higher temperatures, promote proliferation of different bacterial genera [9].

Mean values of total coliforms qualified surface water samples into 2nd class purity in all study periods. Over the whole study period, the sample S1 two times was qualified as 1st class purity (winter 2010 and 2011), once as 3rd class (autumn 2010) and as 2nd class purity in the remaining seasons (data not shown). The sample S2 was once qualified as 3rd class purity (summer 2010) and as 2nd class in the remaining seasons. The sample S3 once was qualified as 1st class (winter 2010), 4 times as 2nd class and three times as 3rd class purity water 9autumn 2010 and spring–autumn 2011). Mean values of fecal coliforms once qualified surface water samples into 1st class purity (winter) and 2nd class purity. Half of the unit recorded values of fecal coliforms enabled to qualify all surface water samples (S1–S3) as 1st class purity (four measurement

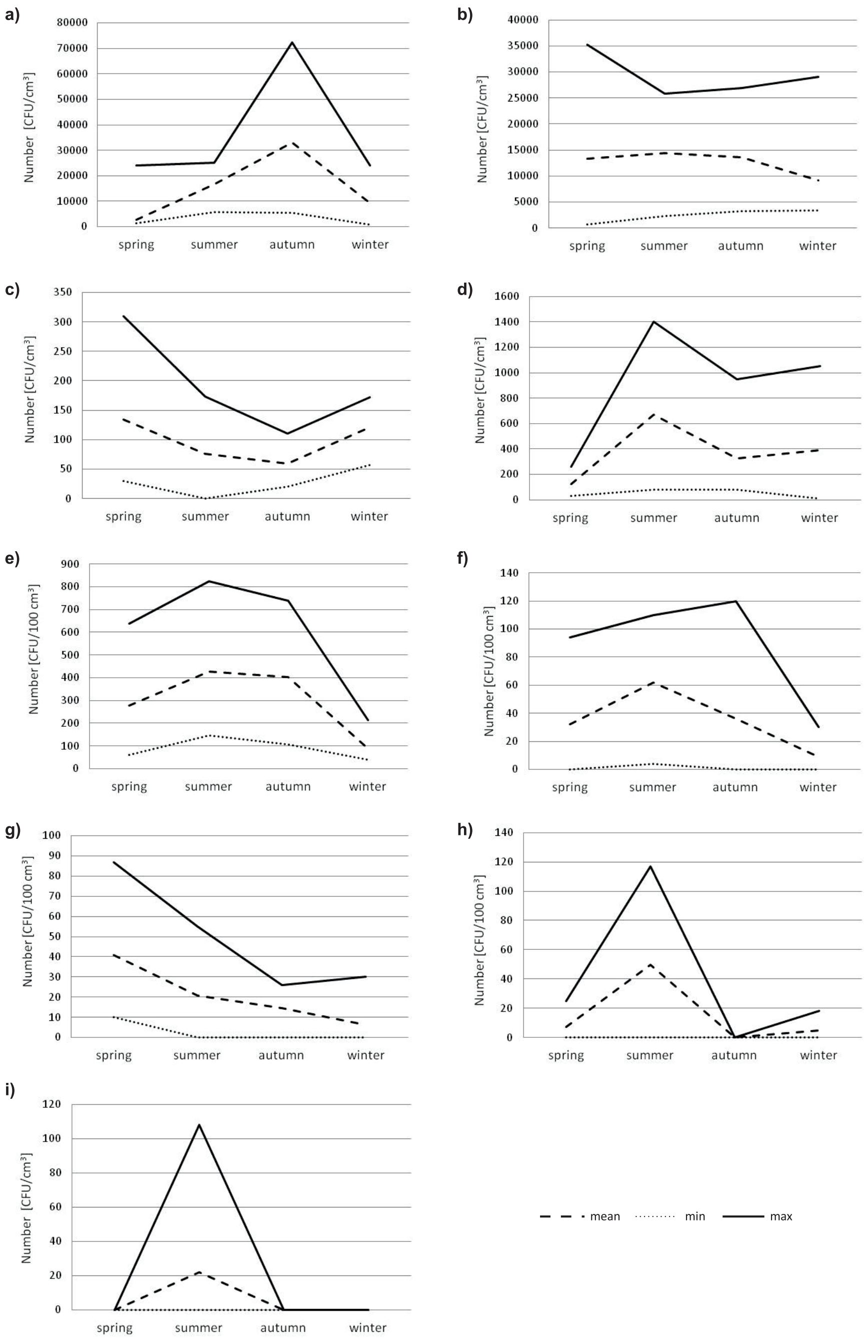

Fig. 1. Mean, minimum and maximum abundances of the analyzed microbial groups in surface water samples: a) mesophilic bacteria, b) psychrophilic bacteria, c) *Staphylococcus* spp., d) fungi, e) coliforms, f) fecal coliforms, g) *E. faecalis*, h) *C. perfringens*, i) *Salmonella* spp.

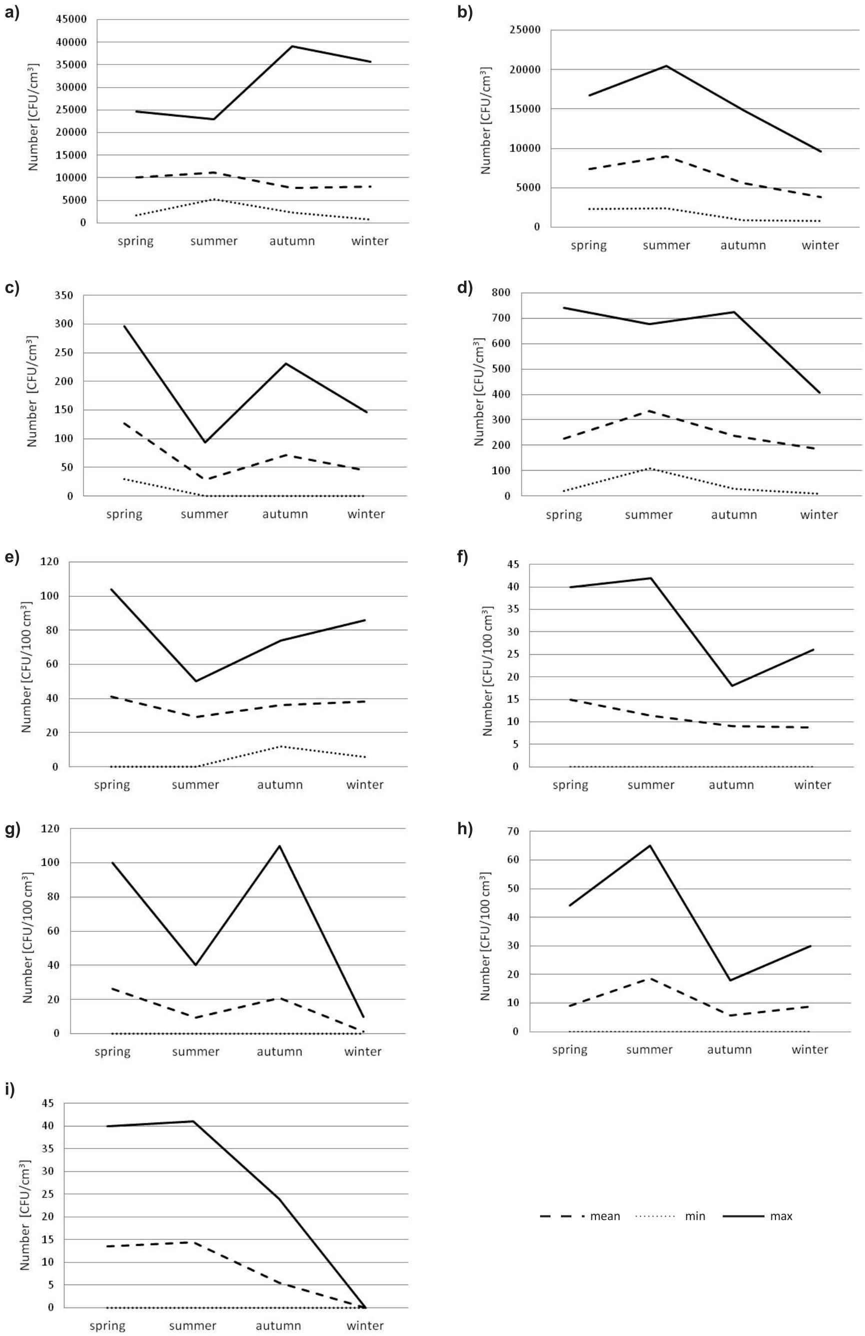

Fig. 2. Mean, minimum and maximum abundances of the analyzed microbial groups in groundwater samples: a) mesophilic bacteria, b) psychrophilic bacteria, c) *Staphylococcus* spp., d) fungi, e) coliforms, f) fecal coliforms, g) *E. faecalis*, h) *C. perfringens*, i) *Salmonella* spp.

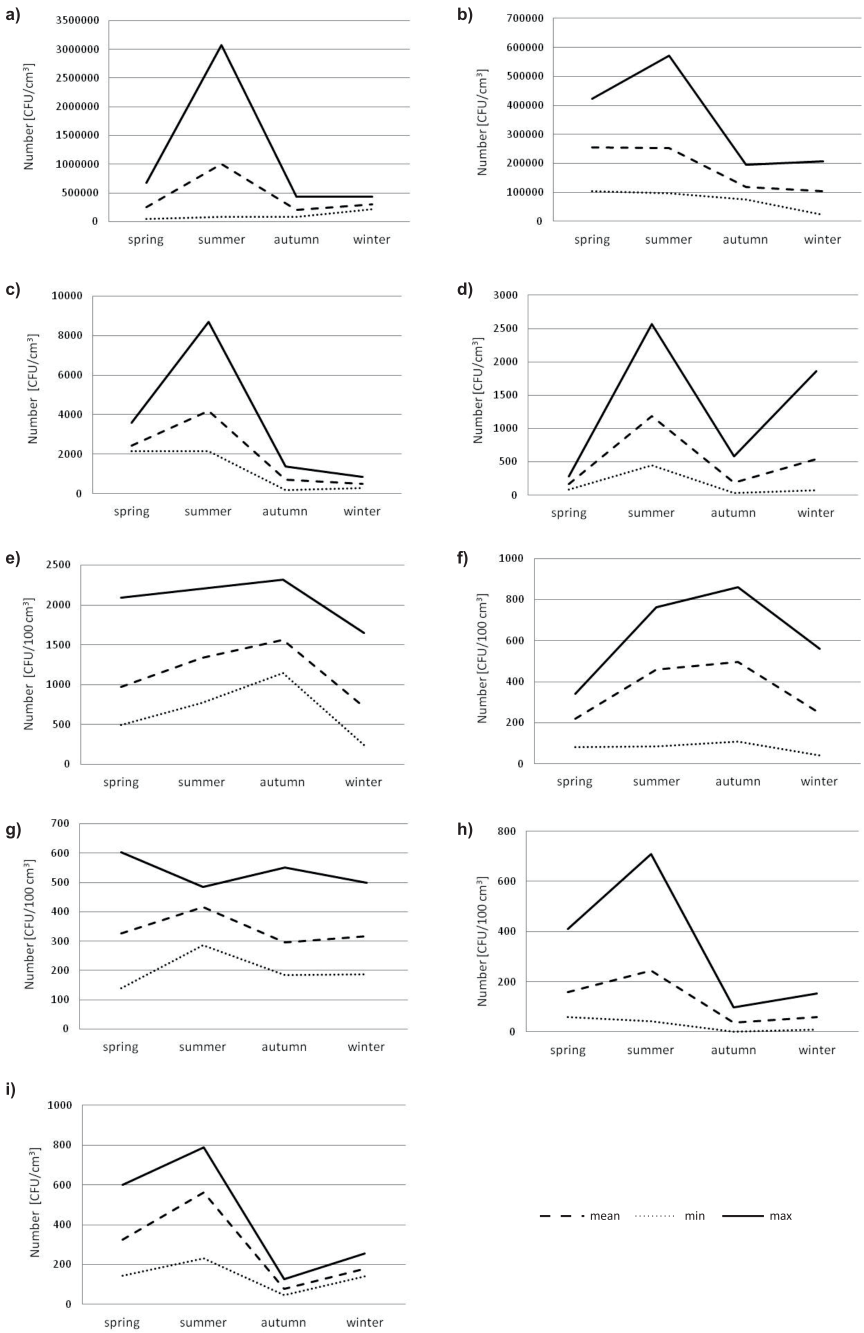

Fig. 3. Mean, minimum and maximum abundances of the analyzed microbial groups in leachate samples: a) mesophilic bacteria, b) psychrophilic bacteria, c) *Staphylococcus* spp., d) fungi, e) coliforms, f) fecal coliforms, g) *E. faecalis*, h) *C. perfringens*, i) *Salmonella* spp.

seasons) and the other half of the recorded values qualified the samples as 2nd class (the remaining four measurement seasons) [38].

Conclusions

The results of the presented research revealed that the close vicinity of the studied landfill has significant negative impact on the surrounding environment. Such adverse effect of landfills is strongly determined by the quality of collected waste. Although the threshold values for the examined chemical contaminants were not exceeded, it was found that waste and leachates are the major source of microbial emissions, including pathogenic bacteria. The abundance of bacteria is correlated with the distance from the landfill and direction of groundwater flow. Therefore, it can be concluded that the modern operation system applied in the landfill site is sufficient to prevent the chemical contamination of the close neighborhood. Nevertheless, the microbiological contamination may pose a serious threat to health of those who have direct contact with leachates or surface water. Finally, it can be stated that it is crucial to develop the proper methods of the risk evaluation related to the municipal landfills' operation. The necessity of conducting not only physico-chemical but also microbiological analyzes within and in the vicinity of landfills should be legally enforced.

Acknowledgement

The study was supported by the Ministry of Science and Higher Education in Poland (Project no. N N305 227237).

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JAKOŚĆ MIKROBIOLOGICZNA I FIZYKOCHEMICZNA ODCIEKÓW I WÓD W REJONIE SKŁADOWISKA ODPADÓW KOMUNALNYCH

[1] Katedra Mikrobiologii, Uniwersytet Rolniczy im. Hugona Kołłątaja w Krakowie
[2] Katedra Ochrony Środowiska Rolniczego, Uniwersytet Rolniczy im. Hugona Kołłątaja w Krakowie
[3] Katedra Statystyki Matematycznej, Uniwersytet Rolniczy im. Hugona Kołłątaja w Krakowie

Abstrakt: Celem badań była ocena mikrobiologicznej i fizykochemicznej jakości odcieków oraz wód w rejonie składowiska odpadów komunalnych. Przebadano 9 próbek wód podziemnych, wód powierzchniowych i odcieków zebranych na terenie oraz w rejonie składowiska odpadów komunalnych w Tarnowie. Analizy fizykochemiczne wód podziemnych i odcieków obejmowały: oznaczenie pH, przewodności elektrolitycznej, stężenia metali ciężkich (Pb, Cd, Cu, Zn, Cr VI i Hg) oraz sumy wielopierścieniowych węglowodorów aromatycznych. Analizy wód powierzchniowych uzupełniono o oznaczenie stężeń Ni, As, Ag, V, lotnych fenoli, całkowitego azotu i fosforu, a także $ChZT_r$ i BZT_5 Wykonano również analizy mikrobiologiczne: oznaczenie ogólnej liczby bakterii mezofilnych i psychrofilnych, *Staphylococcus* spp., *Salmonella* spp., bakterii grupy coli, bakterii grupy coli typu kałowego, *Enterococcus faecalis*, *Clostridium perfringens*, drożdży i pleśni. Zarówno w próbkach wód, jak i odcieków nie stwierdzono przekroczenia wartości granicznych dla żadnych z oznaczanych składników chemicznych. Zauważono jednak, że bliskie sąsiedztwo składowiska przyczynia się do znacznego skażenia mikrobiologicznego wód powierzchniowych i podziemnych, w których stwierdzono duże ilości nie tylko bakterii mezofilnych, lecz również wskaźników zanieczyszczenia kałowego, a także bakterii chorobotwórczych. Wyniki niniejszych badań wykazały, że odpady i odcieki ze składowisk są istotnym źródłem emisji drobnoustrojów do środowiska. W związku z tym ważne jest, aby na terenie i w bliskim sąsiedztwie składowisk prowadzone były nie tylko analizy fizykochemiczne, lecz również oznaczenia mikrobiologiczne, a także aby wprowadzić odpowiednie przepisy, regulujące konieczność i częstotliwość wykonywania wymienionych badań.

Słowa kluczowe: składowisko odpadów komunalnych, wody podziemne, odcieki, wody powierzchniowe