Submission ID: 27316

As a local resident I was concerned about potential health impacts of living in close proximity to a waste water treatment plant. During my research I found the following article concluding that living with 2km proximity to a waste water treatment plant favours the occurrence of gastrointestinal symptoms among local residents (Article in Polish Journal of Environmental Studies ÛÿÜ! January 2017 DOI: 10.15244/pjoes/64793) see attach
taken into account when considering the current application.

Impact of a Sewage Treatment Plant on Health of Local Residents: Gastrointestinal System Symptoms

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Original Research

Impact of a Sewage Treatment Plant on Health of Local Residents: Gastrointestinal System Symptoms

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Abstract

The aim of this study was to evaluate the impact of a sewage treatment plant on the occurrence of gastrointestinal symptoms among the local residents. A survey was conducted on two populations: one from the vicinity of the sewage treatment plant (the exposed group: 586 people), and the other from outside the impact area of the plant (the control group: 502 people). The research area was divided into distance zones from the plant (A, B, C). The questionnaire included questions about the occurrence of gastrointestinal disorders. Compared with the control group, the local residents reported more often: nausea, vomiting, and frequent diarrhea. Occurrences of gastrointestinal disorders were associated with air pollution by pathogenic staphylococci (OR~7) and odours (OR = 7.34; Cl 3.43-15.72) emitted by the plant, and also living in zone A vs. zone C (OR = 3.47; CI 1.00-12.07), use of a gas cooker in houses (OR = 2.21; CI 1.03-4.70), and the age of the respondents (0.98; CI 0.96-1.00). The study showed that as distance from the plant increased, the incidence of reported gastrointestinal disorders declined. Living in the vicinity of a sewage treatment plant favours the occurrence of gastrointestinal symptoms among the local residents.

Keywords: environmental exposure, gastrointestinal disorders, health, sewage

Introduction

Sewage treatment plants protect water resources against pollutants and constitute an important component of environmental protection. Nevertheless, the premises of such plants accumulate both chemical contaminants (including heavy metals, aromatic hydrocarbons, and aromatic solvents) as well as biological contaminants (viruses, bacteria, fungi, parasites, and protozoa), which are a common cause of diseases, including gastroin-testinal disorders [1]. This poses a serious epidemiolo-gical threat, especially to the

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employees of such plants who come in direct contact with sewage [2].

The sewage treatment process involves the emission of odours and biological agents in the form of bioaerosol. Depending on the direction and strength of the wind, the season of the year, and topography of the area where the plant is located, the emission of pollutants may extend beyond the plant premises, which also poses a risk of exposure to the residents living in the vicinity of the plant [3-4]. Pollutants can get into the gastrointestinal tract, initiating inflammatory reactions (e.g., Gram-negative bacteria, staphylococci, and endotoxins) and consequently causing disturbances such as nausea, vomiting, diarrhea, and abdominal pain [5]. Depending on individual susceptibility, odours may also cause gastrointestinal disorders, as evidenced, for example, by the studies of Aatamila et al. [6] (people with high olfactory sensitivity reported diarrhea more often than the other respondents). The impact of odours on the occurrence of gastrointestinal disorders remains a contentious issue because the underlying mechanisms behind such symptoms are not fully understood [7].

The aim of this study was to evaluate the impact of a sewage treatment plant on the occurrence of gastrointestinal disorders among the local population. So far, the issue of the impact of pollution emitted from the sewage treatment plant on the gastrointestinal tract of nearby residents has not been thoroughly analysed. Instead, the literature focuses on occupational exposure [1-2, 5]. Just a few scientists, i.e., Herr et al. [8] and Aatamila et al. [6], have conducted research on the health effects of living in the vicinity of such plants. However, nobody had previously analysed the impact of odour pollutants as well as microbial pollutants emitted from sewage treatment plants on the incidence of gastrointestinal disorders among the local population. Due to the increasing number of sewage plants operating in Poland, the problem of plant pollutant emissions may intensify, which makes the above issue very topical [9].

Material and Methods

Characteristic of the Sewage Treatment Plant

The study was conducted in the vicinity of the mechanical-biological sewage treatment plant. Wastewater treatment facilities were only partially hermetic – in the mechanical part, without clarifiers (primary and secondary) and bioreactors. In the biological treatment process the activated sludge method was used.

Survey Research

A review of the documentation on the conditions existing at the site of the examined municipal sewage treatment plant enabled the authors to draw up an original survey based on a survey used in CESAR studies (PHARE-CESAR STUDY – international studies on children's respiratory systems in the countries of Central Europe) [10]. The survey questions concerned potential symptoms and diseases of the gastrointestinal tract characteristic of the composition of bioaerosol from a sewage plant: "What are your current diseases or gastrointestinal disorders?" We asked about nausea, vomiting, and frequent diarrhea. The respondents could choose from the following answers: Yes (medical opinion) – related to diseases diagnosed by a doctor, Yes (my own opinion) – concerned ailments suffered by the respondent but undiagnosed by a doctor, and No – lack of ailments. The questionnaire also included questions on living conditions (type of residential building, source of heating, use of a gas cooker, presence of pets at home, indoor dampness, smoking of cigarettes in the flat, and exposure to car fumes).

The survey was conducted on two populations of residents from neighbouring villages, one living in the vicinity of the examined treatment plant (the exposed group) and the other belonging to the same commune but living outside the impact area of the plant and constituting the control group. Such a choice of both populations allowed for the elimination of potential confounders related to climate and weather conditions, eating habits, and general air pollution around the place of residence. The analysed populations did not differ in this regard.

The estimated size of the sample, with knowledge of the age structure of the inhabitants (approx. 5% of children aged 3-10 years and approx. 80% of adults) of both villages, with the populations of approximately 11,000 inhabitants in the impact area and 5,000 inhabitants in territory not impacted by the plant, amounted to, respectively, 590 and 504 people. The selection process for both groups was based on systematic sampling. The interviewers selected every 10th flat from an address list (from the local municipal office).

The examined populations were divided into two subgroups: adults (aged 20-65 years) and children (aged 3-10 years). The analysis excluded teenagers and the elderly due to the introduction of possible confounders (disturbances associated with adolescence and senile diseases).

Out of the 1,094 people who took part in the study, six individuals were rejected due to non-fulfilment of the age requirements. Thus, the final number of the respondents was as follows: 586 people from the exposed group and 502 people from the control group (in total 1,088 people).

Following the collection of all surveys, a computer database was established containing the information provided in the survey prepared within the framework of the present epidemiological study.

Free and informed consent of the participants or their legal representatives was obtained, and the study protocol was approved by the Bioethics Committee of the Wroclaw Medical University, Wrocław, Poland (approval no. KB 764/2012).

Olfactometric and Microbiological Tests

Olfactometric measurements were performed in summer and winter according to German VDI 3940 guidelines [11] and covered an area up to 1.5 km east of the sewage treatment plant and 2.5 km northwest of the plant. The measurement unit was the frequency of odours.

Microbiological measurements were performed in all seasons (summer, in July 2011; autumn, in November 2011; winter, in March 2012; and spring in April 2012) and covered an area up to 0.5 km from the examined sewage treatment plant (the sampling places: 100 m, 180 m, 200 m, 225 m, 250 m, 350 m, 400 m, and 500 m – distances from the sewage treatment plant). The tests included indicator microorganisms (psychrophilic and mesophilic bacteria, *Pseudomonas fluorescens*, actinomycetes, staphylococci, and moulds) in accordance with the applicable Polish Standards [12-13] and also indicator bacteria from the Enterobacteriaceae family. The examination was performed using the sedimentation method. Petri dishes (9 cm diameter) with an appropriate agar medium for 30 min were placed at a height of 130 cm above ground level. Then, depending on the type of microorganisms and the used agar medium, the samples were incubated at 10-44ºC for 1-7 days:

- Psychrophilic bacteria: agar PCA with cycloheximide, 22ºC, 3 days.
- Mesophilic bacteria: agar PCA with cycloheximide, 37ºC, 1 day.
- Yeast-like: Sabouraud with TTC, 26ºC, 3-5 days.
- Molds: Sabouraud with chloramphenicol, 26ºC, 3-5 days.
- Actinomycetes: Pochon, 26ºC, 3-5 days.
- *Pseudomonas fluorescens*: King B cykloheksamidem, 4ºC, 7 days or 26°C, 3-5 days.
- α- and ß-haemolytic staphylococci: Columbia + 5% sheep blood, 37ºC, 2 days.
- Mannitol-positive and mannitol-negative staphylococci: Chapman, 37ºC, 1-2 days.
- Coliforms, Escherichia coli: Endo-LES, 37/44ºC, 1 day.

After this time the colonies were counted and identified. Concentrations of microorganisms were calculated according to Omelianski's formula, modified by Gogoberidze [13]:

$$x = \frac{a \cdot 5 \cdot 10^4}{\pi r^2 \cdot t}$$

…where x is the average number of microorganisms per 1 m^3 air [CFU/m^3] (from three repeated measurements), a is the number of microorganisms per plate, πr^2 is the plate surface (cm^2), and t is exposure time (min). The above formula is based on the assumption that within 5 minutes the same number of microorganisms settles on the surface of 100 cm^2 as in the air volume: 10 m^3.

The obtained data were entered into the computer database, assigning their location to the nearest place of residence of the respondents (address data).

Olfactometric tests showed that the impact area of the examined sewage treatment plant extended up to 1.5 km from the plant, with the highest air pollution rates recorded within 0.5 km of its boundary (according to olfactometric and microbiological tests). On the basis of these findings, the area around the sewage treatment plant was divided into three zones: A, B, and C. Zone A (highest air pollution) extended up to 0.5 km from the plant, zone B (average air pollution) extended from 0.5 km to 1.5 km from the plant, and zone C (control group) covered an area outside the impact rage of the plant (more than 2 km away).

At the time of conducting the surveys, neither the respondents nor the interviewers knew which zones corresponded to individual participants.

Statistical Analysis

Statistical analysis was performed using Statistica 10.0 for Windows software. The incidence of gastrointestinal disorders among children and adults was compared between the examined populations (the controls/the exposed) and with respect to the distance from the sewage treatment plant (divided into zones: A, B, and C). For this purpose, Pearson's chi-squared test was performed. The impact of risk factors on the incidence of gastrointestinal disorders (confirmed by medical opinion) was assessed using logistic regression analysis (single-factor model – microorganisms and odours; multi-factor model – other risk factors). The odds ratios (OR) were also calculated with the corresponding 95% confidence intervals (CI). The following were classified as risk factors: living in zone A as opposed to zone C (A vs. C), living in zone B as opposed to zone C (B vs C), age, period of residence, type of residential building, exposure to tobacco smoke, use of a gas cooker, type of heating, indoor dampness, ownership of pets, exposure to car exhaust fumes (number of cars passing by the house), high concentrations of microorganisms in the air, and odours (frequency of odours in summer and winter). The adopted level of statistical significance was $p<0.05$ for all analyses.

Results

Characteristics of Air Pollution (Microorganisms and Odours) around the Examined Sewage Treatment Plant

Within 0.5 km of the examined sewage treatment plant we found pathogenic staphylococci (α-haemolytic, β-haemolytic, mannitol-positive, and mannitol-negative; Table 1). The highest concentrations were recorded for β-haemolytic staphylococci (1180 CFU/m^3) and α-haemolytic staphylococci (826 CFU/m^3). At most measurement points the recorded staphylococci concentrations exceeded Polish safe air quality standards (respectively >50 and >25 CFU/m^3 [13]).

By contrast, concentrations of microorganisms commonly found in the environment (*Pseudomonas*

Table 1. Concentrations of microorganisims[a] (minimum/maximum) in the air in the vicinity of a sewage treatment plant (up to 0.5 km from the plant).

Microorganisms	Concentrations in the air [CFU/m³]		
	Mean	Min.	Max.
psychrophilic bacteria	2076	576	4087
mesophilic bacteria	1005	52	3354
actinomycetes	56	0	183
α-haemolytic staphylococci	252	26	826
β-haemolytic staphylococci	98	0	1180
mannitol-positive staphylococci	101	0	288
mannitol-negative staphylococci	59	0	354
molds	4148	217	9432
yeast-like fungi	177	0	524

[a]concentrations of microorganisms determined in three repeated measurements
Measurement periods: summer, July 2011; autumn, November 2011; winter, March 2012; and spring, April 2012

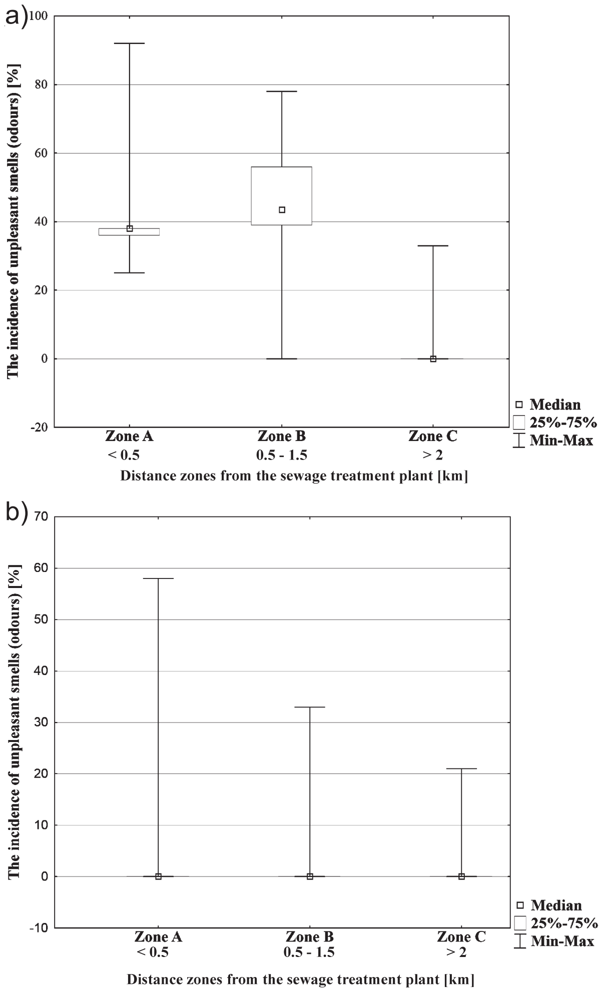

Fig. 1. The incidence of odours in distance zones in the summer a) and in the winter b).

fluorescens, psychrophilic and mesophilic bacteria, actinomycetes, molds) indicated mostly low or medium levels of air pollution according to Polish standards (respectively: lack, <3,000, <100, <5,000 CFU/m³) [12-13].

Concentrations of yeast-like fungi remained at a level of 0-524 CFU/m³.

No bacteria of faecal origin were found in the air of the area covered by microbiological analysis.

According to olfactometric tests, the odours emitted from the sewage treatment plant were perceptible even at a distance of approx. 2 km from the plant. The recorded frequency of odours was significantly higher in summer (Fig. 1a) than in winter (Fig. 1b). The frequency of odours coming from the plant in zone A (closest proximity to the plant) reached up to 92% (in summer). In zone B the measured frequency of odours ranged from 0% at the end of zone B to 78% (in summer) at the boundary of exposure zones A and B. In the area of residence of the control group, the frequency of odours reached up to 33%. The measured odour rates correlated with distance from the sewage treatment plant: the frequency of odours decreased as the distance from the plant increased (Fig. 1).

Study Population

The characteristics of the examined population, divided into the control group and the exposed group, are shown in Table 2. In both subpopulations there is a similar number of men and women. In the control group and the exposed group the children account for, respectively, 25.5% and 28.8%, whereas the adults account for 74.5% and 71.2%. Among people classified to the individual zones, the smallest percentage of respondents consisted of inhabitants of zone A: 8.1% (zone B: 43.6% and zone C: 46.1%).

Most people from the exposed group live in blocks of flats with central heating, whereas the control group is dominated by residents of single-family houses, who use different types of heating (gas stove, coal stove, and fireplace). Compared to the control group, a predominant percentage of people from the exposed group smoke at home. On the other hand, pet owners were mostly people from outside the area impacted by the sewage treatment plant (control group). No differences were found between the examined populations in terms of indoor dampness and exposure to car exhaust fumes.

Group Division: Control/Exposed

Compared to the control group, a predominant percentage of children from the exposed group reported nausea and vomiting. Also, among adult inhabitants of the impact area there were significantly more occurrences of nausea and frequent diarrhoea compared to the control

Table 2. Characteristics of the study population.

Characteristics			Control (N[a] = 502) CH: 128 A: 374		Exposed (N = 586) CH: 169 A: 417	
			n[b]	%[c]	n	%
Sex	Female	CH[d]	72	56.2	80	47.3
	Male		56	43.8	89	52.7
	Female	A[e]	207	55.3	232	55.6
	Male		167	44.7	185	44.4
Exposure to tobacco smoke in the flat (missing 1)		CH	21	16.4	38	22.6
		A	69	18.5	146	35.0
Living in blocks of flats		CH	17	13.3	150	88.8
		A	82	21.9	407	97.6
Use of gas cooker		CH	115	89.8	93	55.0
		A	309	82.6	298	71.5
Heating (central heating) (missing 15)		CH	69	53.9	167	98.8
		A	248	66.3	411	98.6
Dampness in the flat (missing 2)		CH	17	13.3	28	16.8
		A	32	8.6	46	11.0
Ownership of pets (missing 5)		CH	70	54.7	64	38.8
		A	220	58.8	152	36.5
Exposure to car fumes (missing 3)		CH	39	30.5	54	32.3
		A	133	35.6	147	35.3
Zone A		CH	-	-	43	49.4
		A	-	-	44	50.6
Zone B		CH	-	-	120	25.3
		A	-	-	354	74.7
Zone C		CH	128	25.5	-	-
		A	374	74.5	-	-

[a]all respondents from studied population, [b]number of respondents, [c]proportion of respondents, [d]children (3-10 years) [e]adults (20-65 years)

group. The indicated symptoms were confirmed by medical diagnosis as well as independent opinion of the respondents (Figs 2a-b).

Zone Division: A, B, and C

Among children, significant differences between the zones concerned the prevalence of nausea, vomiting, and frequent diarrhoea. The above-mentioned symptoms, confirmed by medical diagnosis, dominated in zone A, and their reportability decreased as the distance from sewage treatment plant increased (Fig. 3a). The situation was similar with regard to adults, but only in the case of vomiting were there no significant differences reported between the examined zones.

However, according to an independent opinion of the respondents, symptoms such as nausea and vomiting in children, and only nausea in adults, appeared most frequently in zone B (Fig. 3b).

The Impact of Microbial and Odorous Pollution on the Incidence of Gastrointestinal Disorders

In order to examine the effects of microbial air pollution on the reported gastrointestinal disorders in t he immediate vicinity of the sewage treatment plant (zone A), the occurrence of such disturbances was compared between respondents exposed to concentrations of microorganisms exceeding Polish air quality standards (total bacteria >3,000 CFU/m^3; actinomycetes

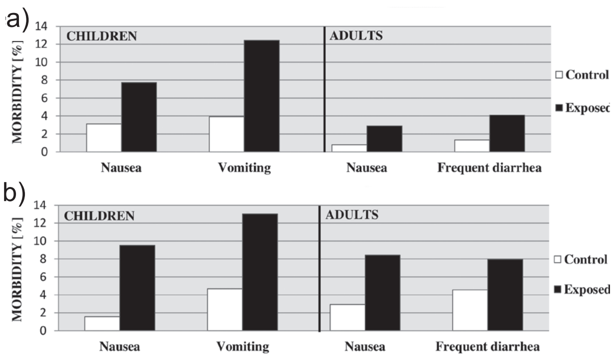

Fig. 2. Statistically significant differences of gastrointestinal disorders in children and adults between the control and the exposed group (a) – "Yes (medical opinion)", b) – "Yes (my own opinion)". All presented data: $p<0.05$.

>100 CFU/m³; α-haemolytic staphylococci and mannitol-positive staphylococci >25 CFU/m³; β-haemolytic staphylococci and mannitol-negative staphylococci >50 CFU/m³) and the control group.

Among the analysed microorganisms, only α-haemolytic staphylococci (OR = 6.76; CI 3.17-14.45) and mannitol-positive staphylococci (OR = 7.22; CI 3.37-15.45) had a significant impact on the incidence of gastrointestinal disorders among inhabitants of zone A.

The research has also shown that the incidence of gastrointestinal disorders in the immediate vicinity of the sewage treatment plant (zone A) was closely associated with exposure to odours, issued by the plant in summer (OR = 7.34; CI 3.43-15.72). By contrast, odour emissions in winter had no impact on the incidence of the indicated symptoms among the respondents. Similarly, in the case of zone B inhabitants no correlation was found between the reported gastrointestinal disorders and odour emissions (either in summer or winter) from the plant.

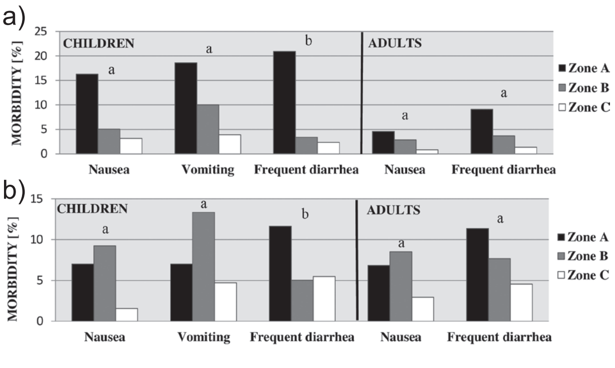

Fig. 3. Statistically significant differences of gastrointestinal disorders in children and adults by distance zone (a) – "Yes (medical opinion)", b) – "Yes (my own opinion)"). $p<0.05$ zone A vs zone B vs zone C (marked as "a"); $p < 0.05$ zone A vs zone B and zone A vs zone C (marked as "b").

The Impact of Different Risk Factors on the Incidence of Gastrointestinal Disorders Among the Respondents

The model shown in Table 3 was used to analyse the impact of coexisting, potential health risks on the incidence of gastrointestinal conditions among all respondents (multifactorial analysis). The reported gastrointestinal disorders depended to a significant degree on: place of residence in zone A relative to zone C (on the border of statistical significance), age of the respondents, and use of a gas cooker. In the case of other factors, no correlation was found with the reported gastrointestinal disorders.

A stratified model for children is presented in Table 4 and for adults in Table 5. The occurrence of gastrointestinal disorders among children was significantly associated with the use of a gas cooker and having pets. For adults, the type of a residential building had a significant impact on reported symptoms.

Discussion

Both microbiological and olfactometric tests show that the area of greatest air pollution extended to 0.5 km from the examined sewage treatment plant. This is consistent with the results of studies published by German researchers, who reported high concentrations of microorganisms (>10^5 CFU/m³) as far as 0.55 km away from the analysed composting plant [8]. On the other hand, Albrecht et al. [3] demonstrated that emissions of microbiological pollutants may also extend beyond 0.5 km (even up to 0.8-1.4 km) from the plant depending on the weather conditions, topography, process technology of the plant, and the methods of control of pollutant emissions. The highest concentrations of microorganisms reported by them concerned actinomycetes and thermotolerant fungi. By contrast, the results of our research indicate that the most dangerous air contaminants were staphylococci (α-haemolytic and mannitol-positive), whose concentrations significantly exceeded safe air quality standards [12-13]. The presence of staphylococci in outdoor air samples is a natural phenomenon because they belong to environmental bacteria; however, their elevated concentrations are dangerous to human health and may indicate the presence of an anthropogenic emitter (e.g., a sewage treatment plant) [14]. On the other hand, the microorganisms commonly found in the environment did not constitute a health risk for the examined population because their concentrations were within the range showing low or medium air pollution. Compared with literature data, their number was lower than in the vicinity of similar sewage treatment plants [15].

In the literature there are few studies that analyse the frequency of odours around such plants. According to our research, the emission of odours extended up to approx. 2 km from the plant, covering a range from 92% in the zone adjacent to the plant (zone A) to 0% at the end of zone B. Odours were also perceived in the zone inhabited

Table 3. Odds ratios (OR) and 95% confidence intervals (CI) for reported gastrointestinal disorders relative to the risk factors – the whole population (N[a] = 1,088); $R^2_{Negelkerke'a}$ [b] = 0.11.

Risk factors	OR	95% CI	p[c]
Zone B vs. Zone C	1.53	0.54-4.36	n.s[d]
Zone A vs. Zone C	3.47	1.00-12.07	0.050
Female	1.10	0.64-1.87	n.s
Age	0.98	0.96-1.00	0.040
Period of residence	0.99	0.95-1.03	n.s
Type of residential building: block of flats	2.05	0.83-5.04	n.s
Exposure to tobacco smoke	0.64	0.33-1.28	n.s
Using a gas cooker	2.21	1.03-4.70	0.040
Type of heating in the house	0.76	0.25-2.30	n.s
Presence of moisture in the house	1.22	0.58-2.58	n.s
Owner of pets	0.74	0.42-1.28	n.s
Exposure to car fumes	0.72	0.39-1.36	n.s
Odours	0.95	0.39-2.28	n.s

[a]all respondents from studied population
[b]generalized coefficient of determination
[c]level of statistical significance
[d]not significant

Table 4. Odds ratios (OR) and 95% confidence intervals (CI) for reported gastrointestinal disorders relative to the risk factors – children (N[a] = 297); $R^2_{Nagelkerke'a}$ [b] = 0.19.

Risk factors	OR	95% CI	p[c]
Zone B vs. Zone C	3.15	0.64-15.49	n.s[d]
Zone A vs. Zone C	4.50	0.69-29.30	n.s
Female	1.12	0.50-2.50	n.s
Age	1.01	0.83-1.24	n.s
Period of residence	0.92	0.76-1.10	n.s
Type of residential building: block of flats	1.18	0.37-3.73	n.s
Exposure to tobacco smoke	0.44	0.13-1.52	n.s
Using a gas cooker	5.36	1.45-19.74	0.011
Type of heating in the house	0.70	0.15-3.14	n.s
Presence of moisture in the house	0.85	0.28-2.59	n.s
Owner of pets	0.34	0.13-0.87	0.024
Exposure to car fumes	0.96	0.37-2.46	n.s
Odours	1.04	0.25-4.25	n.s

[a]number of children from studied population
[b]generalized coefficient of determination
[c]level of statistical significance
[d]not significant

by the control group, where their frequency reached up to 33%. Their source could be local livestock farms. By way of comparison, German test results of air pollution in the vicinity of a composting plant demonstrate that odour was perceptible up to approx. 870 m from the plant. At this distance, the frequency of odour perception was 10-30% [4].

In this study there was an increase in the incidence of gastrointestinal disorders in the exposed group compared to the control group. In the group of children this concerned nausea and vomiting, whereas in adults it concerned nausea and frequent diarrhoea. All of the reported ailments, confirmed by medical diagnosis, correlated with the distance from the sewage treatment plant. They appeared most frequently in zone A, gradually decreasing with increasing distance from the plant. Only in the case of independent opinion of the respondents did nausea and vomiting dominate in zone B. The resulting differences may arise from the fact that not all gastrointestinal disorders were diagnosed by a medical professional; some of the symptoms were treated with home remedies. A correlation between the incidence of gastrointestinal symptoms and the distance from the treatment plant was confirmed by German studies [8], which analysed the impact of pollutants emitted from a composting plant on the health of nearby residents. On the other hand, according to Finnish researchers, due to technical diversity of the five analysed sewage treatment plants, no correlation was found between the reported gastrointestinal disorders and the distance from the plant [6].

The symptoms reported by the respondents are consistent with gastrointestinal disorders also occurring among employees of sewage treatment plants. According to a study by Abd El-Wahab et al., compared to the unexposed group, the employees reported significantly more frequently: diarrhoea, vomiting, abdominal colics, and dyspepsia (in our study we did not ask the respondents about abdominal colics, dyspepsia) [2]. Abdominal pain may be the result of direct contact with sewage, and therefore exposure to adenoviruses, rotaviruses, noroviruses, enteroviruses, and the *Helicobacter pylori* bacterium [16]. Similar results were also obtained by Dutch researchers, according to whom sewage plant employees reported gastrointestinal symptoms (nausea, vomiting, diarrhoea, and loss of appetite) approx. twice as often as office workers [17]. The similarity of reported symptoms between residents of areas adjacent to the sewage plant and the employees of such plants demonstrates comparable exposure to sewage pollution. This is all the more important since the employees come in direct contact with sewage, therefore microbes most commonly spread via the gastrointestinal tract while the health risks of people living in the vicinity of the sewage

Table 5. Odds ratios (OR) and 95% confidence intervals (CI) for reported gastrointestinal disorders relative to the risk factors – adults (N[a] = 791); $R^2_{Nagelkerke'a}$[b] = 0.09.

Risk factors	OR	95% CI	p[c]
Zone B vs. Zone C	0.81	0.20-3.21	n.s[d]
Zone A vs. Zone C	1.69	0.28-10.13	n.s
Female	1.24	0.58-2.64	n.s
Age	1.02	0.99-1.05	n.s
Period of residence	0.99	0.95-1.04	n.s
Type of residential building: block of flats	8.80	1.73-44.84	0.009
Exposure to tobacco smoke	0.69	0.29-1.64	n.s
Using a gas cooker	1.15	0.43-3.08	n.s
Type of heating in the house	1.34	0.22-8.07	n.s
Presence of moisture in the house	1.86	0.65-5.29	n.s
Owner of pets	1.33	0.63-2.81	n.s
Exposure to car fumes	0.53	0.22-1.29	n.s
Odours	1.05	0.31-3.49	n.s

[a]number of adults from studied population
[b]generalized coefficient of determination
[c]level of statistical significance
[d]not significant

plant are related to their exposure to bioaerosols in the air (the air droplet transmission route).

The symptoms reported by the respondents from zone A were closely associated with exposure to the highest concentration of staphylococci (α – haemolytic: OR = 6.76; CI 3.17-14.45 and mannitol-positive: OR = 7.22; CI 3.37-15.45) in the air. Of these bacteria, e.g., *Staphylococcus aureus* is responsible for the occurrence of gastrointestinal disorders (nausea, vomiting, diarrhoea, and abdominal pint) – mostly as a result of consuming contaminated food. However, sometimes the above symptoms are caused by exposure to high concentrations of staphylococci in the air. An inflammatory reaction takes place, whose main symptom is a rise in body temperature, which is typically accompanied by respiratory and/or gastrointestinal problems [18]. One US study reported a minor increase in the prevalence of drug-resistant strains of *Staphylococcus aureus* in the nasal cavity and on the skin of employees in contact with sewage compared to the control group; however, this indicates the existence of a real health risk associated with the emission of pathogens [19].

Lack of immunological testing among the residents living in the vicinity of the sewage treatment plant which would confirm the obtained relationship between exposure to pathogenic staphylococci and reported symptoms was a limitation of our study, but this is a good start to further research.

In the present study we also noticed a correlation between the reported gastrointestinal disorders among the inhabitants of the immediate vicinity of the sewage treatment plant (zone A) and the exposure to odours emitted from the plant in summer (OR = 7.34; CI 3.43-15.72). This is in line with studies carried out by Aatamila et al. [6], according to which people sensitive to unpleasant smells had a higher incidence of diarrhoea than the other respondents. On the other hand, the incidence of nausea and vomiting did not depend on either sensitivity or olfactory irritability. However, German studies confirm a correlation between a feeling of nausea and odour nuisance [20].

The mechanisms of initiation of gastrointestinal disorders by odours have not yet been fully understood. According to Herr [20], the incidence of nausea may be associated with exposure to the odour of decomposing organic material, which is explained by an associative effect between an unpleasant smell and the place of its origin (e.g., faeces, rotten leftovers, etc.). Odours may also irritate organs, resulting in abdominal pain, nausea, and diarrhoea. In people characterised by olfactory hypersensitivity (MSC - multiple chemical sensitivity), the occurrence of such symptoms can also be of psychogenic nature (fear of the effect of odours, individual symptomatic response to a stimulus) [7].

Gastrointestinal disorders may also occur as a result of exposure to endotoxins, which are often recorded within such plants. According to Rylander [5], endotoxins can be deposited in the gastrointestinal tract, thus starting an inflammatory response in the intestinal mucosa, which causes gastrointestinal symptoms such as abdominal pain and diarrhoea. The results of a Dutch research study suggest that when endotoxin concentration in the air ranged from 50-200 EU/m^3, the risk of diarrhoea among sewage plant employees was approximately 1.5 times higher than in the unexposed group [17]. Also, Danish researchers found that the risk of experiencing gastrointestinal disorders (nausea and diarrhoea) increased with increased concentration of endotoxins in the air [21]. In the present study, we did not measure the concentration of endotoxins in the air, which undoubtedly is a limitation; however, given the increased incidence of reported gastrointestinal disorders in the exposed group as compared to the control group, it can be assumed that the cause of their occurrence was also exposure to endotoxins emitted from the sewage treatment plant.

Among the co-occurring health risks, living in zone A was associated with a higher probability of gastrointestinal disorders compared to the control group. This can be explained by the results of microbiological and olfactometric measurements, according to which this was the area with the highest pollution rates. The results of studies by Herr [8] also show that living at a distance of up to approximately 0.5 km from the composting plant (bacteria concentration in the air >10^5 CFU/m^3) was associated with a significant risk of occurrence of gastrointestinal disorders.

The use of a gas cooker was another factor found to be significant in such disorders (in the whole population, especially among children). The health risks resulting from gas cooker use were connected with the emission of carbon monoxide and nitrogen dioxide. In the case of poisoning with the first of said chemicals, the victims suffer primarily from neurological and cardiac disorders, which can be accompanied by nausea and vomiting (early stage poisoning) [22]. However, prolonged exposure to high concentrations of nitrogen dioxide usually cause respiratory problems and eye irritations. At a later stage, the affected individuals may also suffer from cardiac and neurological disorders, but gastrointestinal disorders are not among characteristic symptoms of nitrogen dioxide poisoning. In one study by English researchers, a correlation was found between the incidence of diarrhoea among children and exposure to nitrogen dioxide. However, the mechanism behind the above result is not clear; therefore, researchers suggested that the obtained correlation could have been accidental [23]. Due to the small number of reports in the literature associating exposure to nitrogen dioxide with the occurrence of gastrointestinal disorders, the authors of this study agree with the presented view.

Age was another important factor associated with the occurrence of gastrointestinal disorders among the respondents. In contrast to the previously presented risk factors (residence in zone A as opposed to zone C and use of a gas cooker), a decrease in this parameter increased the probability of the appearance of gastrointestinal symptoms (OR<1). Thus, the younger the respondents were, the more often they became afflicted with gastrointestinal diseases. This may be due to the less developed immune system in children as compared to adults [24]. Besides, children are still learning proper hygienic practices, hence they are more likely than adults to make related mistakes that may cause gastrointestinal disorders, such as lack of the habit of washing hands before eating and licking and putting dirty objects (e.g., toys) as well as their hands into their mouths [25].

Our research also shows that children with pets reported gastrointestinal disorders less frequently than children who do not have contact with pets. The existence of the indicated dependence can be explained by the so-called hygiene hypothesis, according to which contact of the body with microbes has a beneficial effect on the immune system whereas excess purity leads to the development of many different diseases (not only allergic) [26].

Gastrointestinal disorders in adults occurred more often among inhabitants of blocks of flats than detached houses. It can be assumed that in smaller-area houses (i.e., blocks of flats), air pollution resulting from poor exchange of indoor air occurred more frequently (rare airing due to social reservations about the influx of pollution from the sewage treatment plant through the windows). Bad indoor air quality can cause several non-specific symptoms, including gastrointestinal disorders (nausea, vomiting, diarrhoea; sick building syndrome) [27].

Conclusion

The results of our study show that living in the vicinity of the analysed sewage treatment plant is associated with an increased risk of the occurrence of gastrointestinal disorders among the population. The health impact area of the sewage treatment plant extended up to approx. 2 km from its border, including the village where the plant was located. The study showed that as the distance from the sewage treatment plant increased, the percentage of gastrointestinal incidents decreased (zone A > zone B > zone C). Gastrointestinal disorders were reported most often at a distance of up to 0.5 km (zone A) from the examined sewage treatment plant, which was related to the highest rates of air pollution in this area (microbiological pollutants and odours). Among the microorganisms identified in the air, pathogenic α-haemolytic and mannitol-positive staphylococci had a significant effect on the reported gastrointestinal disorders in the immediate vicinity of the sewage treatment plant. The emission of odours in summer also favoured the occurrence of such disorders. Due to the prevailing morbidity rate (especially of children) among the population living in the vicinity of the sewage plant, corrective actions should be taken to limit/eliminate pollutant emissions (e.g., hermetization of clarifiers and bioreactors).

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