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Bacteriological health threats to water in home wells

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Abstract: Bacterial infections that are due to consumption of poor quality water are still an important threat to human health and life. The aim of the article was to investigate the bacteriological threat of water from home wells. The results of water testing from individual wells constituted research material. On their basis, the health risk of fecal streptococci, coliforms and Escherichia coli was assessed and an attempt was made to assess the impact of pollution on the health of residents. The results of water testing in private wells showed unacceptable values for bacteriological pollution. A significant health risk was found for fecal streptococci, coliforms and *Escherichia coli*. The authors pointed out the need to take extensive actions aimed at raising environmental and health awareness of the inhabitants in terms of water quality used for living purposes, in particular for consumption.

Introduction

Economic and technological development increases the number of challenges in the range of ensuring health safety of the population. Constantly changing environmental conditions may create threats, leading to an increased risk of human health threat (Kicińska 2019). Despite the gradual equalization of access to the water supply network, a significant percentage of the population still uses individual water intakes whose state of physicochemical and microbiological parameters varies highly. In the research topic undertaken, an attempt was made to estimate the bacteriological health threat resulting from the consumption of water taken from individual home wells. It is assumed that to meet a household's needs, an intake supplying up to 5 m^3 of water per day on average is sufficient annually (Water Law 2017). However, water collected using individual (household) wells is not covered by any form of control (including legal), monitoring or, in most cases, purification processes, as indicated by the results of previous scientific works (Wójcik-Jackowski et al. 2016, Wójcik-Jackowski and Bilek 2015, Żurek and Bilek 2016, Bilek et al. 2015). Therefore, there is no data available to assess the sanitary condition of the well and calculate the health risk to residents consuming these waters.

The reasons for bacteria presence in water can be both natural, because these bacteria live in waters, plants or in soils, but also their presence may be the effect of anthropogenic pollution of the environment, especially as a result of leaking septic tanks. *Escherichia coli* is a type of fecal coli group (*Enterobacteriaceae* family) and is the best known indicator of fecal contamination (Chief Sanitary Inspectorate 2018). The vitality of *E. coli* in water is short therefore its presence indicates "fresh" contamination as compared to fecal streptococci, whose occurrence is characterized by "old" or long-lasting contaminants of fecal origin (Kuczyńska and Janica 2017).

In accordance with the legal regulations in force in Poland, the construction plot intended for residential buildings has a well-established possibility of connections, among others, to the water and sewage network. If there are no conditions for connection to the water supply and sewage system, the same regulations allow for the construction of residential buildings, provided that it is possible to use an individual water intake, as well as the use of a drainless tank or a household sewage treatment plant. However, the location of water intakes, devices for collecting and treating sewage on the construction plot must meet a number of conditions and comply with the provisions on soil, water and air protection (Regulation of the Minister of Infrastructure, 2002). The distance of a well supplying water intended for human consumption should be – counting to the well axis – at least 5 m – from the plot border, 7.5 m – from the axis of the roadside ditch, 15 m – from livestock buildings and associated airtight silos, waste collection tanks, compost, etc., 30 m – from the nearest sewer pipe, 70 m – from unpaved paddocks for farm animals. Moreover, the housing of the dug well must be made of impermeable materials that do not deteriorate water quality, and the joints of the restoration elements should be properly sealed. The area around the well must be at least 1 m wide covered with hardened surface with a 2% slope outside (Regulation of the Minister of Infrastructure 2002). The above regulations apply to design, construction, reconstruction, extension, superstructure, reconstruction and when changing the method of use of buildings and structures. Household wells are usually dug in the so-called "economic system", often fast and without meeting the requirements mentioned above. This may be due to lack of awareness of risks and/or ignorance of applicable regulations. Especially dangerous items are devices used for periodic collection or disposal of domestic and household sewage, the so-called septic tanks.

Taking into account the facts quoted in the area of the municipal water and sewage enterprise, free check-ups were proposed as part of which residents had the opportunity to test the quality of water taken from their private home wells. On their basis, the potential risk resulting from the consumption of water contaminated with microbial pathogens, such as: *(a)* fecal streptococci *(Enterococcus faecalis)*, *(b) coli* group bacteria and *c) Escherichia coli (hereinafter E. coli)*. The study of the indicated groups of microorganisms is required in the monitoring of intakes used for the collective supply of drinking water (Regulation of the Minister of Health 2017).

Materials and methods

The collected research material included the results of testing water samples from individual wells with a total amount of $n = 435$ from a selected area of south-eastern Lesser Poland. For the purposes of this article, the communes where the research material was collected were marked with symbols A–J (Tab. 1), and the waters in which fecal streptococci, coliforms and *Escherichia coli* were analyzed were collected in 2015–2018.

The analyzed water samples were taken from home wells, mostly dug wells. These wells use the shallowest, Quaternary water layer, characterized by low resistance to pollution originating from the land surface. Raw water samples came from wells that:

i. are a reserve source of drinking water for households using the collective water supply system,
ii. can be a basic source of drinking water for households using the collective water supply system,
iii. are a source of drinking water for households within the range of the collective water supply system, but not using it,
iv. are a basic source of drinking water for households outside the range of the collective water supply system.

The voluntary nature of testing water from individual home wells and the related anonymity of the research results made it impossible to assign specific wells to the groups described above. However, this does not diminish the advisability of the pilot research on the water supply company and the appropriateness of further analysis.

Of the *435* samples tested, 6 came from households located outside the area of activity of the collective water supply company and 14 samples were repeated, i.e. a repeat check-up was made after the well user's report. The number of samples taken in individual communes together with the breakdown by years is presented in Table 1. Due to the fact that the samples were not collected cyclically from each of the communes over the analyzed period, and the sampling was previously a verification test, a research sample consisting of *425* samples from the communes was selected for further analysis: **A**, **B**, **C** and **D**, in which the greatest number of water samples was taken. Other sampling sites were rejected due to the negligible number of well water samples taken in 2015–2018 $(n \leq 2)$. It is mentioned that the total number of rejected samples $(n = 10)$ represents only about 2% of the total test sample $(n = 435)$. In Table 1, the rejected samples were marked grey. Further analyses were made based on a selected research material consisting of *425* samples.

Microbiological tests of water were made in the Accredited Water and Sewage Testing Laboratory, belonging to the water supply company making verification tests, based on the PN-EN ISO 7889-2:2004, PN-EN ISO 9308-1:2014 Ap1:2017 standards.

Characteristics of the study area

From the total number of tested water samples $(n = 425)$, 127 samples (areas B, C, D) came from agricultural areas, while agricultural or post-agricultural areas located on the outskirts of cities were home to:298 samples (areas A and D) (Fig. 1).

The research areas (A–D) are geographically located in the part of the Carpathian Foothills of the Outer Western Carpathians, constituting mountainous, upland and river valleys with a diversified terrain. They are located at altitudes from 270 up to 450 m above sea level (Kubal 2001). The geological structure of the area consists of tertiary formations: sandstones, shales and marls that were uplifted and folded. The area is located within the main structural unit of the Carpathians.

Table 1. Quantities of well water samples taken in 2015–2018

Commune	Number of samples taken *(n)*				
	2015	2016	2017	2018	Total
A	169	80	0	0	**249**
B	17	3	49	13	**82**
C	38	7	0	0	**45**
D	1	14	0	34	**49**
E	2	0	0	0	**2**
F	2	0	0	0	**2**
G	0	2	0	0	**2**
H	2	0	0	0	**2**
I	0	0	1	0	**1**
J	0	1	0	0	**1**

Grey coloured samples indicate rejected samples
Source: own study

The separated research areas are characterized by a dispersed farm structure or single-family housing and are relatively poorly urbanized. The forest cover of the area is varied and ranges between 10.9 and 39.9%, and the average population density of the studied area is 410 people/km^2 (according to the Central Statistical Office data (https://bdl.stat.gov.pl)). In areas marked as: C and D forest cover is relatively large and accounts for about 40% of the area, while areas: A and B have much less forests – the forest cover accounts for around 11–22% of the entire area (according to GUS data (https://bdl.stat.gov.pl)). The agricultural use of the described areas is also very diverse and ranges from 27% up to 72% of the area. The detailed characteristics of individual research areas is presented in Table 2.

Fig. 1. A–D water sampling areas in 2015–2018 with reference to the area of Poland

Source: Own study on map outlines based on: https://www.worldatlas.com/webimage/countrys/europe/outline/pl.gif oraz https://mis.rops.krakow.pl/themes/page/images/maps/nowosadecki.gif

Table 2. Characteristics of research areas

Research area Town/commune		Area [km^2]	In this area:			Number of farms*		Total number of inhabitants	Population density [person/km^2]	Number of locations in the study area	
			Forest [%]	Agricultural*							
				total [%]	land for agricultural activity [%]	Total number	Number of agricultural owners			Total	Included in the research
A	city	60	10.9	27	24	893	664	83,896	1,398	1	1
B	rural commune	107	21.6	72	57	2,312	1,887	14,500	136	16	12
C	rural commune	51	38.9	59	41	1,265	734	8,703	171	8	6
D	urban-rural commune	101	39.9	43	32	1,938	1,434	23,677	234	16	6

(data as at 31 December 2018 and * data as at 31 December 2010)
Source: own study based on CSO data (https://bdl.stat.gov.pl)

During the research, the area was partly covered by the water supply and sewage system, and the water supply and sewage system was partly built. Details of the availability of collective water supply systems and collective sewage disposal systems in individual areas during the research period were developed on the basis of CSO data and are shown in Table 3.

Some farms in the research area did not use the water supply and sewage systems due to having their own individual water well and individual equipment for periodic collection or disposal of domestic sewage. The details on the number of home appliances for periodically collecting or treating household and economic wastewater in individual areas are presented in Table 4. The observed decrease in the number of drainage tanks in 2017 compared to 2016 for areas A and C is due to the expansion of the sanitary sewerage network in this area.

Table 3. Access to the water supply and sewage system of the agglomeration of residents of the researched communes

Area/municipality total number of inhabitants*	Year	Number of people using		Network length [km]		Number of connections to residential buildings [pcs.]	
		Water supply system	Sewage System	Water supply	Sanitary and combined sewage system	Water supply	Sanitary sewage system
Area A							
83,903	2015	66,346	71,120	286.5	309.6	8,031	9,447
83,993	2016	70,000	73,000	308.3	332.6	8,501	10,262
84,041	2017	70,620	78,052	312.5	333.7	8,656	10,541
83,896	2018	71,740	78,512	314.7	335.6	8,870	10,840
Area B							
14,242	2015	4,418	2,044	103.2	50.4	836	410
14,331	2016	5,282	2,080	108.4	50.4	857	419
14,397	2017	5,498	2,124	111.1	58.1	911	430
14,500	2018	5,766	2,668	154.9	69.9	978	566
Area C							
8,489	2015	2,404	3,101	36.4	44.2	426	557
8,573	2016	2,956	3,929	36.4	44.2	564	764
8,599	2017	3,120	4,289	48.9	56.8	605	854
8,703	2018	3,432	4,973	49.6	57.0	760	942
Area D							
23,445	2015	14,495	8,113	87.5	77.3	1,906	1,113
23,532	2016	18,179	11,797	135.7	95.8	2,827	1,922
23,574	2017	18,275	12,227	144.6	97.1	2,875	2,008
23,677	2018	21,067	13,819	146	98.8	2,937	2,094

Source: own study based on data from the agglomeration water supply company and * CSO data (https://bdl.stat.gov.pl)

Table 4. Household appliances for periodic collection or treatment of wastewater in the research area

Research area/commune	Household appliances for periodic collection or treatment of wastewater	Number of devices as at 31 December of a given year			
		2015	2016	2017	2018
A	Non-drainage tanks for domestic sewage	no data	3,084	1,625	no data
	Household sewage treatment plants	no data	3	6	no data
B	Non-drainage tanks for domestic sewage	720	720	1,315	no data
	Household sewage treatment plants	5	5	5	no data
C	Non-drainage tanks for domestic sewage	1,209	1,209	1,164	no data
	Household sewage treatment plants	5	5	5	no data
D	Non-drainage tanks for domestic sewage	3,282	3,320	3,402	no data
	Household sewage treatment plants	56	59	76	no data

Where: no data – no available data
Source: own study based on CSO data (https://bdl.stat.gov.pl)

Results and discussion

Comparative analysis of bacterial groups

The quantities and periods of samples taken depended on the individual applications of residents of A–D communes (n = 425) wanting to use the verification tests made by the water and sewage company. The samples were taken for the most part during the summer months for:

- 2018: in May (n = 30 samples), June (n = 15) and in July (n = 2),
- 2017 in August (n = 49),
- 2016: in May (n = 36), in June (n = 66), July (n = 1) and August (n = 1),
- 2015: in March (n = 12), April (n = 11), in May (n = 7), June (n = 16), July (n = 60), August (n = 91) and September (n = 28).

Due to the variability of sampling and different weather periods for individual communes, the research sample, despite the greater number, was difficult to analyze, characterize and assess statistically.

A statistical analysis of microbiological parameters of obtained test results was made *(n = 425)*. Average values of indicators for individual years were calculated, which ranged accordingly: *(a)* for fecal streptococci from 21.3 [cfu/100ml] for 2016 to 84.6 [cfu/100ml] for 2017 (Fig. 2) *(b)* for coliforms from 60.4 [cfu/100ml] for 2016 to 339.8 [cfu/100ml] for 2017 (Fig. 3) *(c)* for E.coli from 1.2 [cfu/100ml] for 2015 to 142.7 [cfu/100ml] for 2018 (Fig. 4).

An unfavourable linear time trend was observed for all investigated series of average analysed pathogens, i.e. increasing the amount of bacteria in waters used for consumption and for living purposes by residents.

It was examined whether between the analyzed parameters of pathogens (fecal streptococci, coliforms and *E. coli*) there are interdependencies. To illustrate the dependencies of the obtained parameter values, correlation (scatter) diagrams were

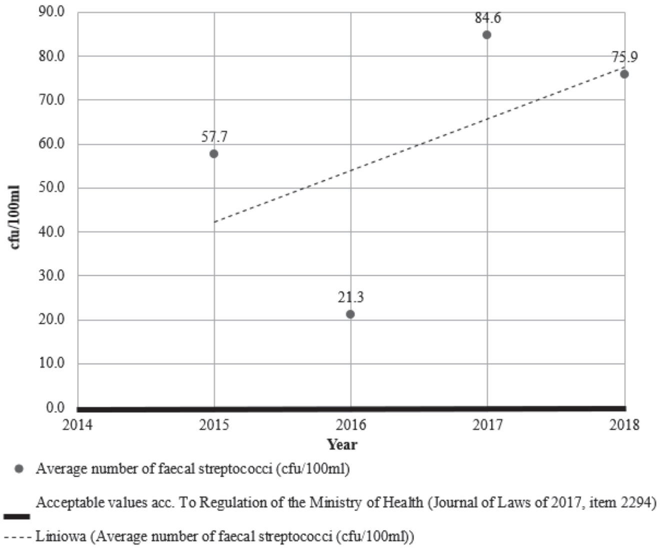

Fig. 2. The average number of *faecal streptococci* in the well water samples taken in the years 2015–2018

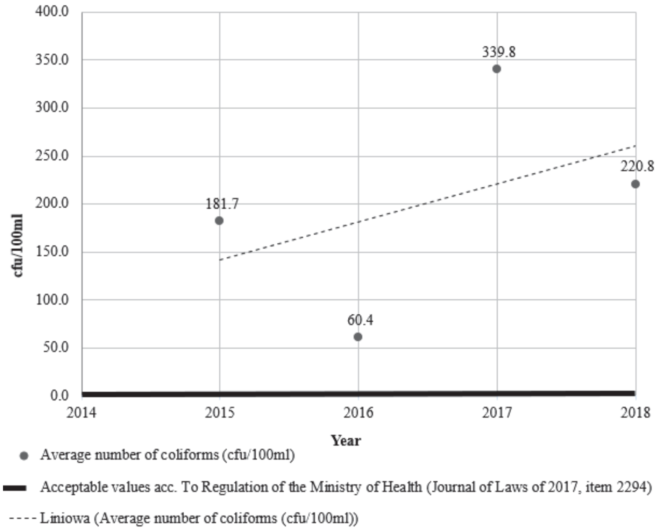

Fig. 3. The average number of *coliforms* in the well water samples taken in the years 2015–2018

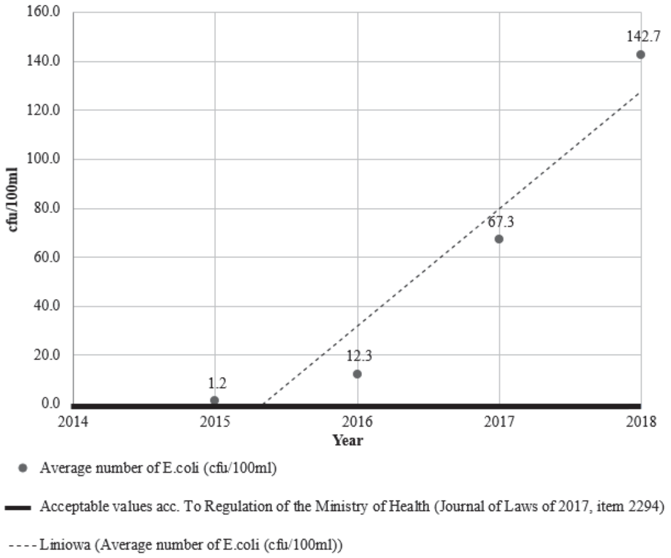

Fig. 4. The average number of *E. coli* in the well water samples taken in the years 2015–2018

made. The parameters were correlated: *(a)* fecal streptococci – coliforms, *(b)* fecal streptococci – *E. coli* , *(c)* coliforms – *E. coli*, as shown in Fig. 5a–c.

Visual assessment of the scatter diagrams showed that fecal streptococci and coli group bacteria in the range of up to about 200 [cfu] streptococci and about 600 [cfu] coli group bacteria and coliforms and *E. coli* in the range from 0 to about 500 were characterized by the largest correlation [cfu] for coliforms and up to about 250 [cfu] *E. coli*. Above the indicated ranges, weakening of the co-relation between the analyzed components was observed, as evidenced by the large distribution of points on the charts. The degree of correlation was tested using the Pearson correlation coefficient (r_p). This factor was chosen because of the measurable nature of all bacteriological factors. The obtained results of the coefficient (r_p) were, respectively, for correlations between: *(a)* fecal streptococci

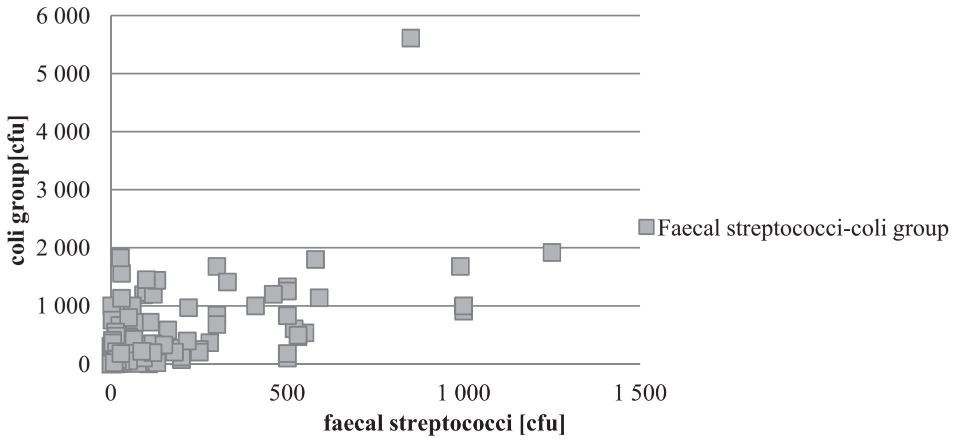

Fig. 5a. Scatter chart of faecal streptococci – a group of coli occurring in the analysed well waters

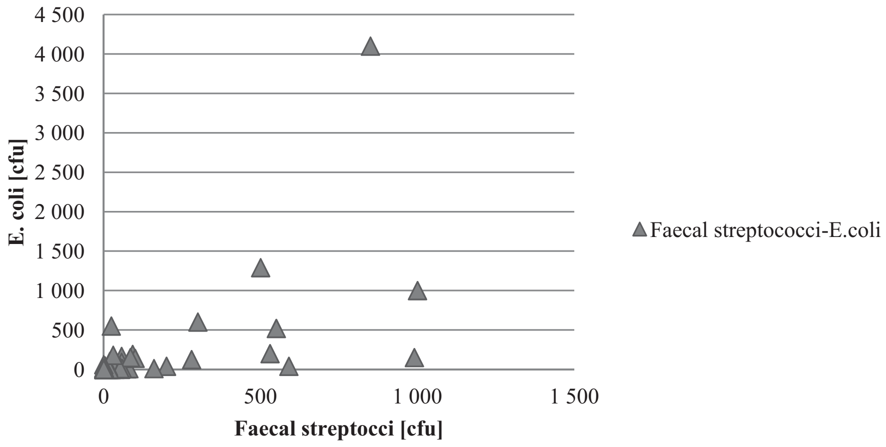

Fig. 5b. Scatter chart of faecal streptococci – E. coli occurring in the analysed well waters

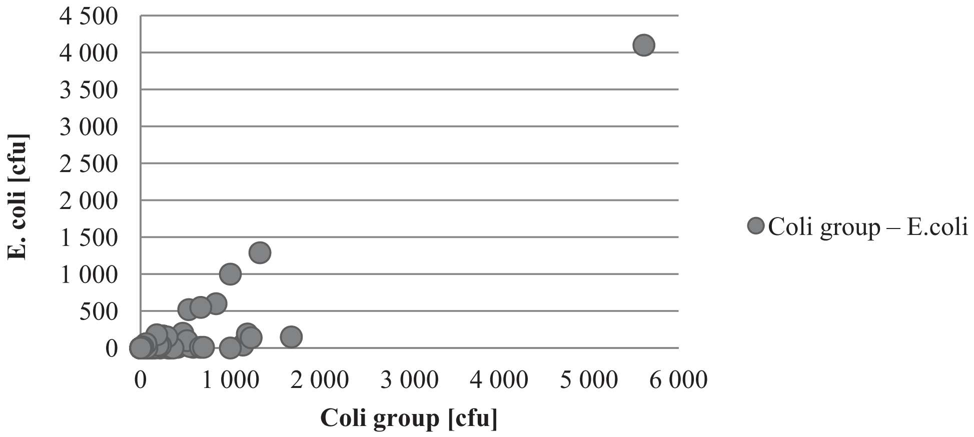

Fig. 5c. Scatter chart of Coli group – E. coli occurring in the analysed well waters

– a group of coli: 0.65; *(b)* fecal streptococci – *E. coli*: 0.63; *(c)* coliforms – *E. coli*: 0.90. Based on the results obtained, it was found that positive correlations exist for all the analyzed cases of dependencies. Then, the value of the coefficient of determination, r^2 [%] was examined, which was respectively for the correlation between: *(a)* fecal streptococci – a group of coli: 42%; *(b)* fecal streptococci – *E. coli*: 40%; *(c)* coliforms – *E. coli*: 80%. The obtained results mean that 42% of fecal streptococci results can be explained by the variability of coli group bacteria and 40% of the number of streptococci can be explained by the variability of *E. coli* bacteria. As much as 80% of the number of coliforms can be explained by the variability of *E. coli* (only 20% of the coliforms is random). The obtained compliances confirm the common, fecal outbreaks of pathogen contamination.

Bacteriological threat assessment in relation to legal requirements

The next step was to assess the potential bacteriological threat based on the current Regulation of the Minister of Health (2017). Requirements for waters intended for human consumption do not allow people to consume water in which any microbial contaminants have been found – the acceptable amount for both: *(a)* fecal streptococci, *(b)* for coliforms and *(c) E. coli* is zero [cfu/100ml]. It should be emphasized that for most pathogenic factors the occurrence of 1 unit of microbial factor carries a threat of health effects (Kowal and Świderska-Broż 2005), and according to the guidelines of the Main Sanitary Inspectorate (2018), the value of coliforms ≥ 10 CFU/NPL in 100 ml of water is an alarm level and means that water cannot be consumed.

Therefore, the results obtained were compared with the limit values resulting from the said Regulation. For each of the indicators, significant exceedances were found in relation to the requirements. Table 5 in bold indicates the maximum values of bacteria and the number of exceedances recorded in relation to legal regulations.

A comparative analysis showed that for:

- fecal streptococci, the smallest number of exceedances was found in 2015 (48% of the tested water samples in terms of the indicated parameter showed exceedances of normative values, with the number of samples of n = 225), while the highest in 2017 (**94% of the samples showed exceedances**, at n = 49),
- for coliform bacteria the smallest number of exceedances was recorded in 2016 (60% of the samples showed exceedances, at n = 104, and as many as **100%** of the tested samples showed exceedances in 2017 (n = 49),
- for *E. coli,* the smallest percentage of exceedances of 3% was found in 2015 (n = 63), while **69%** of exceedances with 49 samples of the parameter determined were found in 2017.

It should be noted that in 2017, the samples were taken only from commune B. The percentages of exceedances are presented in Figure 6.

Table 5. The number of pathogen exceedances in the analysed well water samples in 2015–2018 compared to the requirements of the Regulation of the Minister of Health (2017)

Year	*faecal streptococci*					*coli group*					*E. coli*				
	N1)	$\bar{X}$2)	MIN.	MAX.	N_p3)	N	$\bar{X}$	MIN.	MAX.	N_p	N	$\bar{X}$	MIN.	MAX.	N_p
2015	225	57.7	0	**1,250**	**107**	225	181.7	0	**1,920**	**141**	63	1.2	0	**59**	**2**
2016	104	21.3	0	**250**	**51**	104	60.4	0	**1,200**	**62**	16	12.3	0	**179**	**3**
2017	49	84.6	0	**990**	**46**	49	339.8	2	**1,680**	**49**	49	67.3	0	**1,290**	**34**
2018	47	75.9	0	**100**	**31**	47	220.8	0	**5,612**	**43**	47	142.7	0	**4,100**	**25**

1) N – the number of parameter determinations during the year
2) $\bar{X}$ – the average value of the parameter during the year
3) N_p – the number of parameter exceedences during the year
Text in bold indicates the maximum values of bacteria and the number of exceedances recorded in relation to legal regulations
Source: own study

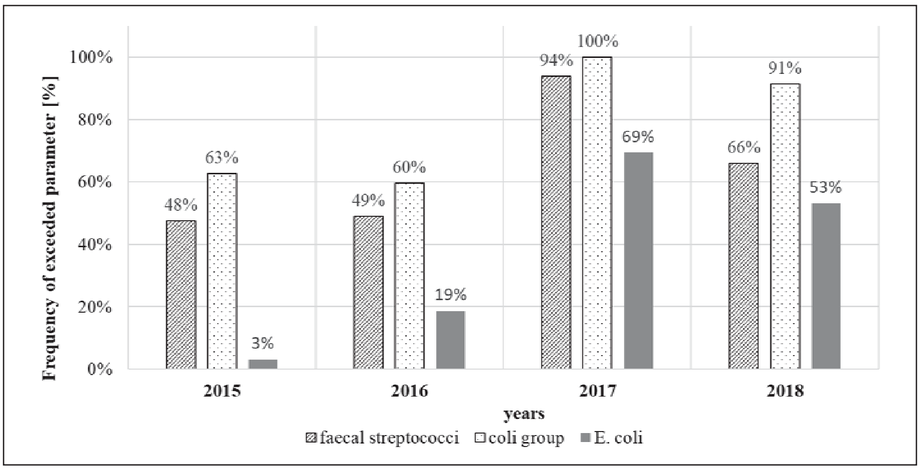

Fig. 6. Participation percentages of exceeded microbiological threats in tested well water samples

For all analyzed indicators, 2015–2016 was the most favourable period when the smallest number of exceedances was found. Whereas 2017 was the least favourable period in terms of bacteriological safety. It was found that for 2015–2016 the average number of exceedances was respectively for: *(a)* fecal streptococci 48%, for *(b)* coliforms 61% and for *(c) E. coli* 11%. While for 2017–2018 these values increased reaching the average exceedances: for *(a)* fecal streptococci 80%, for *(b)* coliforms 96% and for *(c) E. coli* 61%.

The greatest increase in exceedances was found in 2017 when compared to 2016. It was, respectively, for *(a)* fecal streptococci by 45% for *(b)* coliforms by 40% and for *E. coli* *(c)* an increase in exceedances by 51% was noted.

Analysis of bacteriological threat in relation to the season of the year

Due to the irregularity of the time distribution of sampling during the year, the seasonal variability analysis of microbial contaminants was more difficult. Nevertheless, even for samples taken in the early spring (March, April) and autumn (September), characterized by relatively unfavourable conditions for bacterial growth and development, including reduced ambient temperatures, exceeded allowable sizes of pathogens were found. 17% of 23 samples taken in March and April 2015 showed exceedances of coliforms (from 200% to 5,900% of the permissible value) and *E. coli* (up to 5,900% of the normative value), and respectively, for 28 samples collected in September, as much as 61% of the samples tested showed exceedances for fecal streptococci (from 100 – fold up to 30,000% exceedances of the normative value) and coliforms (from 100% to 68,000% of the limit value), *E. coli* was not tested in the collected series of samples (no data).

Bacteriological contamination in the examined communes

The next step of the research was a comparative analysis of the obtained research results between the indicated administrative units (A–D communes). The analysis based on fecal streptococci showed the greatest share of the observed number of exceedances of normative values in 2015–2018 for commune B (as much as 84% of exceedances with the total number of samples tested for the indicated pathogen in this commune of n = 82). The next was commune C, for which 71% of exceedances were recorded in relation to the number of 45 tests of fecal streptococci made. The smallest share of detected exceedances was characteristic of commune A, for which 41% of the results exceeded were reported in 249 tests made. For coliforms, the highest number of exceeded values was also found in commune B, where for 82 pathogen measurements as much as 93% were samples with exceeded values, while the smallest number of exceedances was for commune A = 56% (with n = 249). The values exceeded for coliform bacteria *E. coli* showed reduced quantity compared to the other two parameters. The exceedances for *E. coli* ranged in the analyzed communes in the range from 4% (for commune A) to 66% for commune B, with the total number of tests from all communes amounting to 175 measurements. The series of exceedances for coliforms and *E. coli* was as follows: ***A<C<D<B***, whereas for fecal streptococci: ***A<D<C<B*** (where commune A – the lowest number of exceedances, B – the highest recorded number of exceedances). This state is reflected in the fact that commune A is an urban commune with a significant degree of sewage and water supply system, exceeding 90%.

With the obtained results, the relationship between the size of the sewage system in a given commune and the results of bacteriological contamination was assessed. The correlation coefficient *(r)* between changes (increase) of the sewage network and the variability of bacterial content in well water (all three pathogens) for commune A was negative and amounted to -1. The strong negative relationship means that as the length of the sewage system increased, the average values of microbial contaminants decreased. A different relationship was observed for commune B, where the correlation coefficient ranged from 0.34 for coli group bacteria to 0.89 for fecal streptococci. This means that regardless of the increase in the length of the sewage system in the commune, there was an increase in the average number of the analyzed pathogens in 2015–2018. A positive correlation was also found for fecal streptococci (r = 0.95) and for coliforms for commune D (r = 0.92). The dependence assessment of the number of *E. coli* bacteria in relation to the length of the sewage system in B–D communes showed a strong positive correlation, which means that regardless of the development of the sewage system in the communes mentioned, there was still an increase in fecal contamination (which may indicate that no outbreaks have been eliminated). On the other hand, for commune A it is a negative dependence, i.e. the expansion of the water supply network in the commune contributed to the reduction of bacteriological pollution.

It was also examined whether there is a relationship between the percentage of inhabitants using collective sewage system and the average size of microbial contaminants. During this assessment, a strong negative dependence (r = -1) was found for commune A, and thus the increase in the participation of inhabitants using the sewage system was accompanied by a decrease in microbial contamination. For commune C, a strong negative correlation was also noted for fecal streptococci and coliforms. On the other hand, a positive correlation was found for *E. coli*, i.e. regardless of the increase in the percentage of inhabitants connected to the sewage system for this area, there was also an increase in the size of the contamination for this pathogen. For commune D, a positive correlation coefficient was found for all bacterial groups, which indicates an increase in the amount of contamination despite the increase in the number of people using the sewage system.

The authors conclude that correlation unevenness can be caused by: *a)* different periods of bacterial viability. Due to the fact that faecal streptococci can live in water longer than *E. coli*, the development of the collective sewage system and the use of more inhabitants over time contributes to reducing the average values of this pathogen. In contrast to *E. coli*, whose presence in water is evidence of "fresh" fecal contamination, *b)* differences in the size of parameter samples taken (no data available in some years – correlation error).

Assessment of the effect of bacteriological contamination on residents' health

An attempt to estimate the risk of a negative effect on the health of residents using water from the studied household wells for drinking purposes is the next research step. Based on research results for each of the analyzed communes (A–D), the number of exceedances was calculated by type of pathogen (fecal streptococci, coliforms and *E. coli*). Then, detailed analysis of the amount of exceeded normative values in relation to the requirements of the Regulation of the Minister of Health (2017) was made, adopting the following ranges (marked for the purposes of the article with numbers 1–6) of exceeded normative values: *(1)* by 100%, *(2)* from 100% to 1,000%, *(3)* from 1,000% to 10,000%, *(4)* from 10,000% to 100,000% *(5)* from 100,000% to 1,000,000% and *(6)* the number of exceedances above 1 million% in relation to the requirements for drinking water.

The highest amounts of exceedances in 2015–2018 for fecal streptococci and *E. coli* bacteria were characterized as being in the range of 1,000 to 10,000% *(3)*, whereas for coli group bacteria were in the range from 10,000% to 100,000% *(4)* of multiple requirements of the Regulation of the Minister of Health (2017). On average, as much as 46% of exceeded streptococci from A–D communes were in the range *(3),* 34% of exceeded results for coli group bacteria and on average 46% of exceedances for *E. coli bacteria*. There was a small percentage of exceedances in the ranges *(5)* and *(6)*, illustrating the number of exceedances from 100,000% to over 1 million times the threshold value of the Regulation (2017) – from an average of 1% for fecal streptococci to 9% of exceedances for coliforms. The obtained results are characterized by a small average percentage of exceedances in the range *(1)* to 10 [cfu] for each of the pathogens, corresponding to *a)* streptococci: 10%, *b)* coliforms: 5% and *c) E. coli* : 10%. This means that relatively small exceedances have a negligible participation in the amount of microbiological contamination of the domestic wells analyzed (Tab. 6a–c).

Table 6a. Percentages of exceedances of faecal streptococci in assumed ranges (1–6) in communes A–D in well waters in the period 2015–2018

Commune	Total samples tested	Average value [cfu]	Exceedances of normative value*		Participation in assumed exceedance ranges** [%]					
			Total	***[%]***	***(1)***	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***
A	249	24.6	102	41	1	34	37	16	0	0
B	82	55.4	69	84	9	14	65	12	0	0
C	45	106.5	32	71	3	16	38	41	3	0
D	49	36.1	32	65	16	22	44	19	0	0

Table 6b. Percentages of exceedances of coli bacteria in assumed ranges (1–6) in communes A–D in well waters in the period 2015–2018

Commune	Total samples tested	Average value [cfu]	Exceedances of normative value*		Participation in assumed exceedance ranges** [%]					
			Total	***[%]***	***(1)***	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***
A	249	74.3	140	56	11	19	38	30	2	0
B	82	149.3	76	93	1	13	29	50	7	0
C	45	375.0	37	82	3	8	22	46	22	0
D	48	125.3	42	88	7	21	48	19	5	0

Table 6c. Percentages of exceedances of E. coli in assumed ranges (1–6) in communes A–D in well waters in the period 2015–2018

Commune	Total samples tested	Average value [cfu]	Exceedances of normative value*		Participation in assumed exceedance ranges** [%]					
			Total	***[%]***	***(1)***	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***
A	69	0.7	3	4%	33	0	67	0	0	0
B	62	73.1	41	66%	7	44	29	17	2	0
C	9	49.0	2	22%	0	0	50	50	0	0
D	35	83.6	18	51%	0	33	39	22	6	0

where:
** normative values for drinking water required by the Regulation of the Minister of Health (2017)*
*** intervals of multiple exceeded normative value*
(1) by 100%,
(2) from 100% to 1,000%,
(3) from 1,000% to 10,000%,
(4) from 10,000% to 100,000%,
(5) from 100,000% to 1,000,000%,
(6) exceedances by more than 1 million%
Source: own study

The next step in the analysis was to check the variability of exceedances in given ranges *(1–6)* for each year in detail. The percentage amounts of exceedances in the assumed ranges were calculated in relation to the actual amounts of tests made separately for each parameter and time period. Thus, the obtained results were not affected by the variable quantitative composition of the research sample (different amounts of tests made for different pathogens and years).

For fecal streptococci, the highest unit quantities of exceedances recorded were obtained for all assumed ranges in 2017. The greatest number of exceedances for the indicated pathogen was recorded in the range *(3)* (from 1,000% to 10,000% of exceedance in relation to the values required for drinking water) in 2017, for which an increase from 43% in 2016 to 67% in 2017 was recorded, and a decrease to 48% in 2018. Range *(1)* had a relatively uniform character and ranged from 10% (2015) to 16% (2016). The smallest participation in the number of exceedances was in the ranges *(5)* and *(6)* and they were zero for 2016–2018, with a participation in the number of exceedances in range *(5)* in 2015 amounting to 1%. For the percentage ranges of exceedances of coliforms, the greatest variability was found for ranges *(3)*: from 30% (2015) to 50% (2017) and 49% (2018) and range *(4)* (from 10,000% to 100,000%), which changed from 38% in 2015, by 21% in the exceedances found in 2016 to as much as 59% in 2017, with a decrease to 23% for 2018. For *E. coli* bacteria, a decrease in the share of exceedances in range *(3)* from 1 to 10,000% – from 100% in 2015 to 33% in 2016 was found. However, it should be noted that the limited number of tests made during this period for this pathogen do not give representative results. An increase in the participation of exceeded *E. coli* in range *(2)* was found which amounted to 44% in 2018. Fig. 7a–c shows the variability of percentages of exceedances *(1–6)* cumulated for the analysed period of examined microbial contaminants.

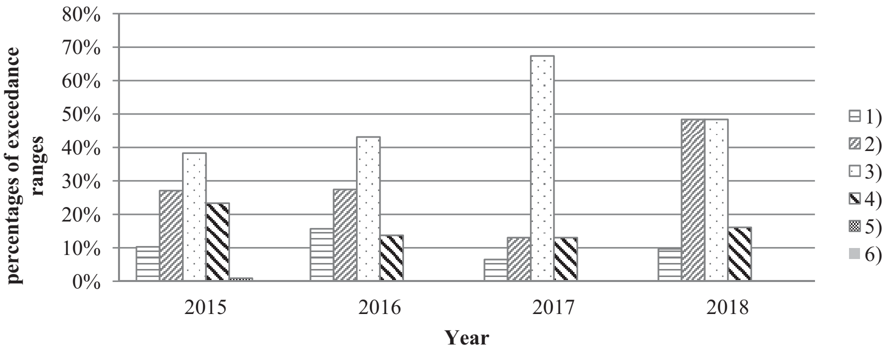

Fig. 7a. Cumulative percentages of given exceedance ranges (1–6) for faecal streptococci in well water in 2015–2018

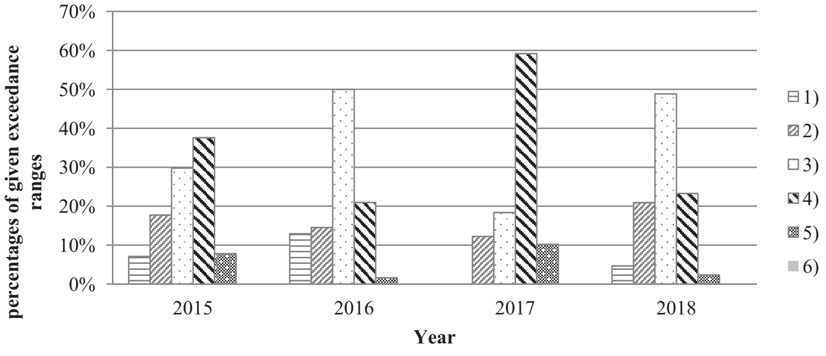

Fig. 7b. Cumulative percentages of given exceedance ranges (1–6) for coliforms in well water in 2015–2018

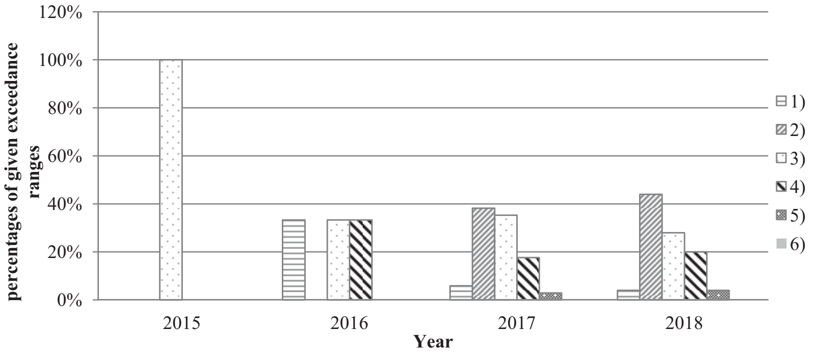

Fig. 7c. Cumulative percentages of given exceedance ranges (1–6) for E.coli in well water in 2015–2018

Despite the lack of assessment of the condition of the environment that is directly adjacent to the analysed wells, the authors argue that the main cause of bacteriological contamination of domestic wells is fecal pollution, providing the following arguments:

i. households whose inhabitants decided to take the pilot test were not covered by the collective water supply system or the collective system was an auxiliary source of water supply, and very often they did not use the sanitary sewage system (despite such a possibility). Sanitary sewage was most likely collected in holding tanks (septic tanks), or illegally discharged into the ground (this procedure is still common),
ii. in rural but also urban areas, a frequent phenomenon is the location of backyard wells in the immediate vicinity of farm buildings, slurry and manure dumps, and septic tanks,
iii. the analyzed types of microbiological contaminants are considered indicators of fecal contamination of the environment,
iv. high concentrations of bacteriological contamination in well water are proof of the presence of an outbreak of contamination near the well (a distance of several meters).

It should be noted that bacterial contaminants in the transport process in the water layer undergo a natural biodegradation process. The disappearance of a bacteriological substance is taken by the half-life (t ½), which characterizes the rate of decline in bacteriological contamination according to first order kinematics. Due to the above, the range of the front of bacterial contamination (migration paths) would have to be significantly larger to lead to such a significant reduction of bacteriological contamination in wells.

The obtained results of the analyses were compared to the data of the Central Statistical Office of Poland (2018) on the incidence of water-borne diseases in the Lesser Poland Province in which the analyzed communes are located (Fig. 8). For statistical studies, the incidence of diarrhea in children under 2 years of age and other bacterial food poisoning were taken into account as they are the most common effects caused by the examined microbial pathogens. Additionally, the choice of the indicated effects of bacteriological contamination suggests that children and the elderly are the groups most vulnerable to health effects. Assuming that drinking water, especially for children, is boiled, there is still a problem of dermal contact with contaminated water (baths, hand washing) and accidental consumption of contaminated water. Registered numbers of cases of diarrhea in children accounted for 11.89% (2015) to 12.76% (2017) of the number of cases recorded throughout the country, while for other bacterial food poisoning they accounted for 0.79% (2017) to 3, 39% (2016) of domestic quantities (https://bdl.stat.gov.pl). It should be remembered that gastrointestinal complaints of a relatively mild course are not diagnosed if they do not require hospitalization, and as a result they often are not reported at all, or are reported giving an unspecified etiology. This underlines the fact of underestimating the data. According to the data of the WSSE in Kraków (Foremny et al., 2016, 2017), the number of cases of diarrhea in children under 2 years of age, including diarrhea of an unspecified etiology, shows an unfavourable upward trend. Nevertheless, the authors agree that the above correlation test between bacteriological contamination of drinking water and the incidence of food poisoning may be subject to a high level of uncertainty and requires further research. In particular due to the significant individual variability resulting from the different level of resistance of human organisms to the possibility of falling ill (age, general health, intestinal microflora, diet or past diseases and treatment including antibiotic therapy).

Repeated tests

During the follow-up tests in the analyzed period, a negligible number of repeated control tests was recorded (note, n = 14). This means that despite receiving the information on bacteriological contamination of water (results in the test report), the inhabitants did not decide to check the suitability of drinking water again. In accordance with the recommendations of the Chief Sanitary Inspectorate (2018) concerning the procedure in case of finding pathogen exceedances in drinking water, the following actions should be applied: *(a)* disinfection, *(b)* rinsing and *(c)* control tests should be made to determine the suitability of drinking water, and after obtaining normative values, *(d)* independent monitoring tests should be made at regular intervals. The authors emphasize that for exceedances recorded as a result of the pilot study, for the

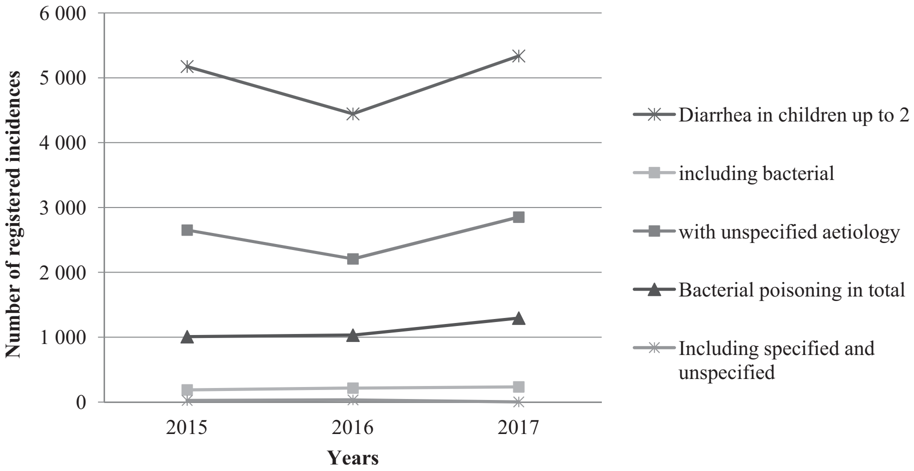

Fig. 8. Incidence of diarrhea in children up to 2 years old in 2015–2018 in the Lesser Poland Province

water collected from the wells to be suitable for living, the above-mentioned procedures should be used. The obtained results and the fact of the insignificant number of repeated control tests justify the conclusion that inhabitants did not comply with the required recommendations and that water in wells is still unfit for consumption. Health threat as a result of using microbiologically contaminated water confirms the antibiotic-resistant nature of a significant number of strains of the indicated pathogens (Łebkowska, 2009).

Comparison with other authors' research

The results of the pilot study were compared with the results of other authors dealing with the subject of bacteriological risk of drinking water. This topic was addressed by, among others, Policht-Latawiec et al. (2017) for the Besko water reservoir (Poland, Sub-Carpathian Province) intended for collective water supply to the population. A similar trend was demonstrated based on the results of the research from 2004–2014. An unfavourable growing trend was found for both coliforms and fecal streptococci. Żurek and Bilek (2016) also dealt with the problem of using well water for drinking purposes in Poland. However, it should be noted that the studies did not take into account the study of microbiological indicators, and was limited to the analysis of parameters that should be performed based on the Regulation of the Minister of Health (2017), which, among others, requires testing of pathogenic indicators in water. One of the basic reasons for the occurrence of the analyzed microorganisms in water are domestic and municipal points, in particular leaking septic tanks and fecal contaminants. As Kuczyńska and Janica (2017) write, the problem of fecal contamination of groundwater intakes is characteristic mainly of developing countries due to the lack of collective water supply and sewage disposal systems. The research conducted by Okullo et al. (2017) in northern Kenya and by Osborne et al. (2018) in Bangladesh confirmed a connection of bacteriological contamination of water used for human consumption with the lack of hygiene, and the relation between sanitation research and the contamination of water sources. The results of the pilot study in southern Poland confirm that the indicated problem also applies to countries with a much higher level of development. The relationship between the bacteriological state of water intended for consumption and the size of registered health effects in the form of water-borne diseases is confirmed by numerous world studies.

However, it should also be noted that, despite the health risk of many individual wells resulting from bacteriological pollution, these reservoirs are a valuable source of drinking water and require protection. This condition is important due to the progressing problems in access to drinking water for both Polish residents and the world population, as well as increasing periods of hydrological drought. As reported by the results of Żurek et al. (2017) the majority of individual wells from the commune in the Podkarpackie province showed good chemical status of water in terms of heavy metal content, as one of the most dangerous analytes that can cause mutagenic and carcinogenic effects. Only 8% of the analyzed well waters showed exceedances of acceptable standards for Cr, Ni and Cd, and no exceedances in terms of Pb were noted in the course of the tests. Tests of water quality from 38 individual wells (excavated and drilled) carried out in the Podkarpackie region by Bilek and Rybakowa (2014) showed that nitrate (V) standards were exceeded for 26% of the wells tested. Especially for dug wells (and therefore usually shallower ones), exceedances were found in relation to wells drilled for the indicated inorganic anions. Nevertheless, the results of research from individual wells so far confirm that the majority of drinking water exceedances were insignificant, and very few were recorded for the most dangerous analytes, i.e. nitrates (III) and heavy metals. As noted by Michałkiewicz and Mądrecka (2014), an increase in residents' awareness of possible health threats arising from ill-considered construction and neglect during the operation of private wells, would contribute to the improvement of water quality in these wells and the safety of their use.

In the submitted discussion, it is not the authors' intention to reduce the importance of individual intakes in a distributed water supply system, especially in areas where there is still no collective water supply systems, and in water-drained areas – they are an alternative source of water in the event of a breakdown or sabotage. Nevertheless, the results of testing the bacteriological status of the well clearly show that these installations require taking immediate steps to cover them with legal protection and to raise the health awareness of residents using them and self-control.

Summary and conclusions

Based on the analyses, the following conclusions were formulated:

i. the results of water tests in private wells showed unacceptable values for bacteriological contamination in comparison with the requirements of the Regulation of the Minister of Health (2017),
ii. of the 425 well water samples tested in the years 2015–2018 and adopted for analysis, bacteriological contamination related to as many as **300** samples, respectively due to the content of: coli group bacteria – 80% of samples, fecal streptococci – 65% of samples and *E. coli* – 36% attempts,
iii. as the main cause of the microbial contamination with fecal streptococci, coliforms and *E. coli*, the contamination of water and soil environment with fecal contamination in the immediate vicinity of domestic wells should be indicated,
iv. the observed increase in the number of cases of diarrhea in children results from the reported cases of diarrhea, the actual number of incidences can be much higher,
v. only 3% of households under the study, after receiving information about the results of the study (test report), decided to re-check the suitability of drinking water,
vi. the obtained results confirm that waters from private wells are not covered by any type of monitoring or treatment, and the verification test was probably the only way to check the quality of the collected waters,
vii. no impact of seasonal variation on the bacteriological status of the water was found – also in periods of reduced temperatures, bacteriological contamination of fecal origin was observed,

viii. for the urban commune, a strong relationship was found between the development of the collective wastewater collection system and the increase in the number of inhabitants using it, and the reduction of microbiological contamination of well water, which was not found for rural and rural-urban communes,

ix. there was no reduction in *E. coli* contamination despite the progressive expansion of the sewer network and the increase in the number of people using it in rural areas,

x. individual wells are a valuable drinking water reservoir that requires effective protective measures, including legislation, to develop specific monitoring and quality control procedures for water used by residents,

xi. protection of individual water intakes should take place in full cooperation with the scientific (further research) and educational environment, including the Sanitary Inspection and other state and local authorities responsible for the security of the population.

Information on the quality status of groundwater in private (farm) wells comes **only** from scientific or verification (pilot) studies, such as study made by a water and sewage company. State monitoring institutions do not make tests on the quality of individual intakes that are not subject to any control. The authors pay attention to the advisability of conducting research in this area, in particular the repetition of research at cyclic intervals. To increase the ecological and health awareness of inhabitants, a survey is planned to assess threat awareness and possible health effects resulting from the consumption of bacteriologically contaminated water. Undertaking significant actions increasing the awareness of residents' use of safe and clean water should be a priority in health prevention. Underestimating the bacteriological process of water pollution in home wells carries a huge health risk for current residents and subsequent generations. The lack of control over the technical condition of domestic and economic sewage tanks, especially taking into account their tightness, contributes to the increase in the probability of pathogen migration at the usable water layer.

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