POLLUTION ANALYSIS OF SURFACE (RAIN) WATER FROM PIG-BREEDING ENTERPRISE PRODUCTION TERRITORY

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Abstract
Pollution of surface (rain) wastewater forming in the production territory of a pig-breeding enterprise was investigated in the period 2007–2011. The surface water is collected from the production territory from yards with a hard covering and from roofs, enters the rain sewerage, and is released untreated into the natural environment.
The aim of this work is to find out what influence on the environment is exerted by surface wastewater released into the natural environment from the production territory of pig-breeding enterprises.
Surface wastewater pollution indices and the research frequency were identified according to the requirement to carry out surface water monitoring: surface wastewater samples are collected three times per year.
Because of the uneven rainfall distribution during the year, less surface wastewater runoff occurred during the cold period; however, concentrations of indices were higher compared to the end of the warm period (TSS – 18 %, BOD_7 – 39 %, N_{total} – was unchanging, oil products – 12.5 %). Only P_{total} concentrations were higher in the end of the warm period in 14 %.
The organic pollution in surface wastewater was increased by total suspended solids. The increased concentrations of TSS and biochemical oxygen demand (BOD_7) were related to a higher precipitation level.
The indices' TSS, BOD_7, N_{total}, P_{total} and oil products concentrations in the surface wastewater runoff from the pig-breeding enterprise's production territory complied with the requirements for surface water which is collected from this area and released into the environment.
Key words: environment, production territory, runoff, surface wastewater.

Introduction

Water body pollution is still a crucial environmental problem in both Lithuania and other EU member states. Due to anthropogenic activities, there are many suspended solids, metals, pesticides, polyaromatic hydrocarbons, oil and oil products, miscellaneous bacteria, and biogenic substances in rainwater (Paul and Meyer, 2008; Rentz et al., 2011).

According to data of the Environmental Protection Agency of Lithuania, only a small part of all surface wastewater collected in Lithuania is treated. In 2012, 10.6% of all surface wastewater was treated to the set standards. Insufficiently treated wastewater comprised 0.3%, but untreated wastewater - 89.1% (Satkūnas, 2013).

Severe environmental problems in Lithuania are caused by 24 operating pig-breeding complexes with livestock capacities higher than 5000, keeping 573000 pigs, 65 pig-breeding companies and farms with livestock capacities higher than 200, keeping 77000 pigs, 2179 dairy/beef cattle farms with livestock capacities higher than 50, keeping 319400 cattle, and 21 poultry farm with livestock capacities higher than 1000, keeping 9946700 fowls. The key reason is inadequate sewage treatment and poor technologies (Lietuvos..., 2012).

Naturally, environmental pollution increases significantly when a large amount of livestock is kept in one place. However, special attention should be paid to polluted cattle-shed and farm areas, where dung is collected and stored and surface wastewater is formed. Farms usually have inadequate wastewater treatment facilities or do not have them at all. Therefore, untreated wastewater is released into the environment and contaminates it.

The Government of the Republic of Lithuania, in pursuance of implementation of the Framework for the EU Community Action in the field of Marine Environmental Policy and the provisions of the Baltic Sea Action Plan adopted by the Helsinki Commission Ministerial Meeting in Krakow on 15 November 2007, passed the resolution "On Approval of the Baltic Sea Environment Protection Strategy", No. 1264, on 25 August 2010.

The ultimate strategic objective of this resolution is to achieve and maintain the good environmental status of the Baltic Sea up to 2020. The strategy approved by the Government provides that in the period up to by 2015, fewer nutrients (nitrogen: 11750 tonnes, phosphorus: 880 tonnes) should enter the marine environment in comparison to the period from 1997 to 2008 (Dėl Baltijos..., 2012).

For a long time, great attention was paid to the pollution of storm wastewater from urbanized areas, roads, or waste storing places. Storm wastewater from the production territories of stock-breeding farms was less well analysed. Storm wastewater from production territories is the natural atmospheric rainfall precipitated in the production territory of the enterprise during its operation (Hogland et al., 2003).

The aim of this work is to find out what influence on the environment is exerted by surface wastewater released into the natural environment from the production territory of pig-breeding enterprises. The

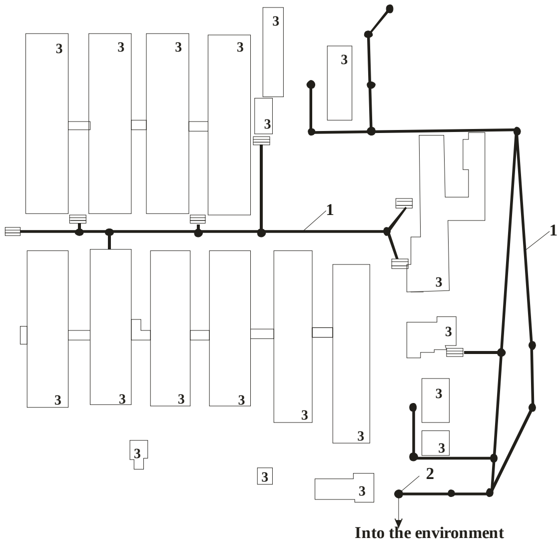

Figure 1. Production territory scheme of the pig-breeding enterprise. 1 – Surface wastewater (rainwater) sewerage, 2 – manhole for release of wastewater into the environment, 3 – roofs of buildings.

tasks are to determine the amount of wastewater buildup in the production enterprise territory and estimate their pollution.

Materials and Methods

The production territory of the pig-breeding enterprise comprises is 11.35 ha. The northern, eastern, and southern sides of the production territory of the enterprise are surrounded by protective ditches, and 5.98 ha of the industrial area without buildings are sown with perennial grasses. The surface water (rainwater) is collected from the production territory from 1.71 ha of yards with hard coverings and from 3.66 ha of cattle-shed roofs, enters the rain sewerage, and is released untreated into the natural environment on the southern side of the production territory (Figure 1).

Surface wastewater pollution indices and the research frequency were identified according to the requirement to carry out surface water monitoring: surface wastewater samples are collected three times per year: in spring, during the snowmelt; in summer, at the first onset of the heavy rainfall period; and in autumn, before freezing. The following indices were identified in the wastewater: total suspended solids (TSS), biochemical oxygen demand during seven days (BOD_7), oil products, total nitrogen (N_{total}), and total phosphorus (P_{total}). The samples were analysed in the Chemical Analysis Laboratory of the Water Resource Engineering Institute of Aleksandras Stulginskis University, which is certified by the Environment Ministry of the Republic of Lithuania.

The following indices were determined: BOD_7 was determined by titrometric method (Vincler), with the difference in oxygen level being calculated after seven days of incubation, and TSS by gravimetric method after filtering the substance through a 0.45 μm diameter filter. Total nitrogen (N_{total}) was determined by the Kjeldahl method, and total phosphorus (P_{total}) was determined by spectrometric method after mineralization with potassium persulphate. Colorimetric analyses were done using an FIA Star 5012 System analyser. Concentrations of oil pollutants were determined with the help of an IKAN-1 infrared spectrophotometric device in the Analytical Department of the Agrochemical Research Laboratory of the Lithuanian Research Centre for Agriculture and Forestry.

The surface water runoff was measured by a volumetric method, falling more rainfall. To evaluate the meteorological conditions, the data from Laukuva meteorological station was used.

In Lithuania, the surface wastewater, which is released to the environment, quality is assessed in accordance to the surface wastewater management regulation. This document states that the concentrations of the suspended solids in the discharged surface wastewater should not be higher than 50 mg L^{-1}, BDS_7 – 57.5 mg O_2 L^{-1}, oil products – 7 mg L^{-1}, total nitrogen (N_{total}) – 30 mg L^{-1}, total phosphorus (P_{total}) – 4 mg L^{-1} (Paviršinių nuotekų..., 2007).

Mathematical and statistical analysis of the data was performed using the computer program Excel and Statistica.

Results and Discussion

As in other countries, precipitation in Lithuania is very uneven. Two rainfall distribution periods may be distinguished: cold (November to March), when the average precipitation per month is from 21 to 81 mm,

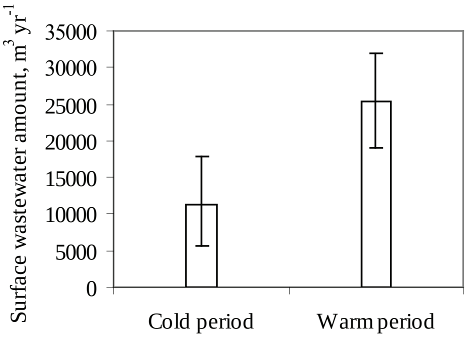

Figure 2. Average surface wastewater runoff the production territory of the enterprise during the cold and warm periods (error bars in figure represent standard deviation).

and warm (April to October), when the precipitation is from 45 to 115 mm.

The most part of the surface wastewater runoff in the production area of the enterprise was find during the warm period of rainfall distribution and accounted for 25402 m^3 on average. During the cold period, the runoff was less by a factor of 2.3, being 11212 m^3 (Figure 2).

The surface wastewater runoff quantity differed considerably between the cold and warm periods ($t_{act.} = 4.61 > t_{theor.95\ \%} = 2.31$), because during the five research years, the precipitation level was 149 mm lower during the cold period on average.

In cold winters in 2009 and 2010 not much surface wastewater formed, 16 and 12% of total runoff amount respectively. In 2007, 2008, and 2010 winter the surface wastewater constituted 39, 28 and 35% of the total runoff amount. During the warm period the largest amount of runoff formed in 2008, 2009, and 2010, (72, 84, and 88% respectively, while in 2007 and 2011 it was 61 and 65% of the total runoff volume). At the beginning of the warm period, the amount of the surface wastewater was greatly increased by precipitation, which, in the form of snow, had accumulated in the production area of the enterprise (Figure 3).

After conducting the research, an extremely strong relationship between precipitation, weather temperature and surface wastewater discharge was determined:

$$z = -192.054 + 37.824\ x + 93.126\ y, \qquad (1)$$

where x = precipitation (mm), y = weather temperature (°C), z = surface wastewater discharge ($m^3\ month^{-1}$).

If there is a higher level of precipitation and if the average weather temperature is positive, the amount

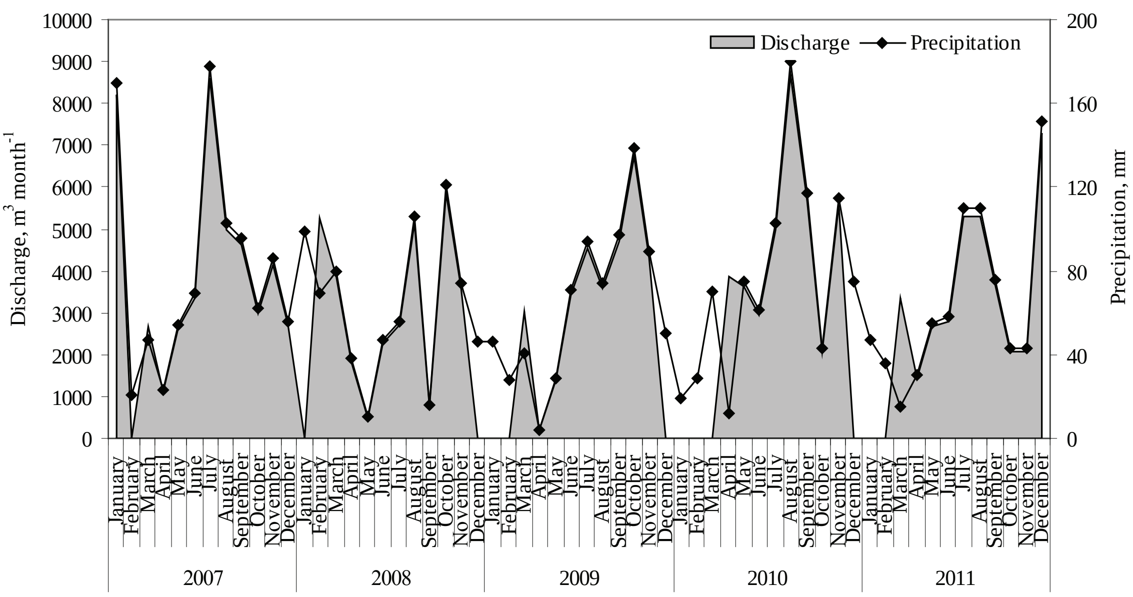

Figure 3. Precipitation and surface wastewater amount distribution.

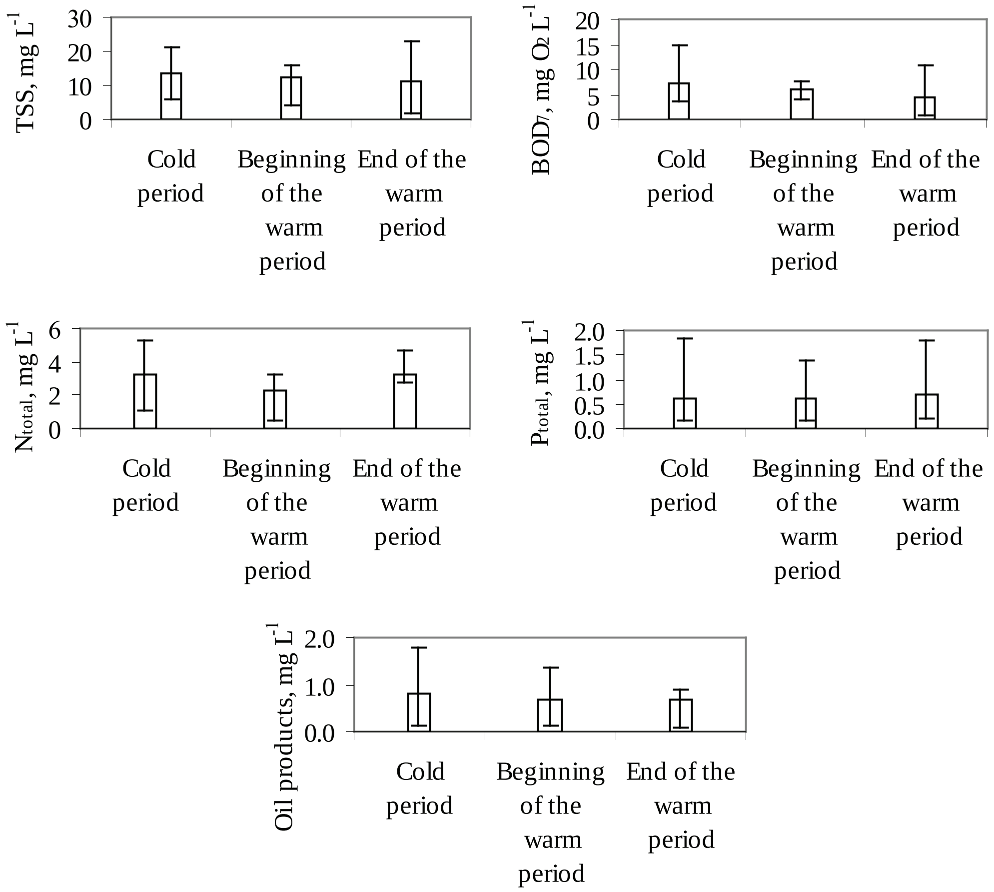

Figure 4. Average concentrations of indices TSS, BOD_7, N_{total}, P_{total} and oil products in the surface wastewater at the beginning and the end of the warm period and the cold periods (error bars in figure represent standard deviation).

of the runoff tends to increase ($r = 0.83$, $n = 60$, $F_{act.} = 61.86 > F_{theor.95\%} = 2.57$). A partial regression analysis has determined that the bigger impact on the formation of surface wastewater has the precipitation ($r = 0.83$) rather than the weather temperature ($r = 0.47$). However, during the cold period, when the weather temperature is usually negative, the surface wastewater does not form.

Due to the sub-zero weather temperature in December, January, and February, precipitation accumulated in the form of snow in the enterprise area and part of it evaporated; therefore, during the spring snow break, the amount of surface wastewater runoff from the enterprise's production territory was lower compared with the warm period. In spring, during the snowmelt, concentrations of indices increase in the surface wastewater, since the cold period, during which these substances gather on the surface area and accumulate in the snow, has the greatest impact on the surface wastewater quality. Higher concentrations of pollutants in the snow are caused by the longer winter period and the lower average temperature (Reinosdotter and Viklander, 2005). When surface runoff starts, pollutants accumulated during the cold period are removed from the area. Higher average concentrations of indices were measured in the cold period compared to the beginning of the warm period: the values of TTS, BOD_7, N_{total}, P_{total}, and oil products in the cold period were as follows: 13.3, 7.4, 3.3, 0.6, and 0.8 mg L^{-1}, respectively (Figure 4).

Brezonik and Stadelmann (2002) have found that the highest concentrations of indices were measured during snowmelt than during rainwater runoff, however Mallin et al. (2009) have determined that TSS, P_{total} and BOD were significantly higher during rain events compared to nonrain periods. This is also confirmed by these research results, as concentrations of the indices in the surface wastewater measured during the warm period were lower. Measured concentrations of TSS, BOD_7, N_{total}, and oil products at the beginning of the warm period were 5%, 20%, 30%, and 12% lower, respectively, than during the snowmelt in the cold period. It is apparent from the analysis of the concentrations of indices at the end of the warm period that concentrations of TSS, BOD_7, and oil products were 18%, 39%, and 12%, respectively, than during the cold period. However, the concentration of P_{total} increased by a factor of 14% and that of N_{total} showed no change. The increase in concentration of P_{total} at the end of the warm period may be related to asphalted roads and yards in the production territory of the enterprise, as measured concentrations from asphalted roads were found to be higher (Gilbert and Clausen, 2006). Furthermore, concentrations of nitrates and orthophosphates are usually higher in agricultural catchments (Coulter et al., 2004).

It is stated in the literature that at the first part of the wet season concentrations were ranged from 1.2 to 20 times higher than ones near the end of the season (Lee et al., 2004). Such a phenomenon is known as "seasonal first flush" (Stenstrom et al., 2005; Bae, 2013). This statement is confirmed by the research results, which demonstrated that concentrations of TSS and BOD_7 measured at the beginning and end of the warm period were 1.2 and 1.3 times higher, respectively, at the beginning of this period. Concentrations of N_{total} and P_{total} were lower at the beginning of the warm period than at the end of the period, and concentrations of oil products remained unchanged.

Major indices describing the surface wastewater pollution are concentrations of TSS, BOD_7, and oil products. TSS, by forming sediments in surface water bodies, exert the greatest influence on the water quality (Davis and McCuen, 2005; Li et al., 2014).

The quality of surface water runoff from the production territory of the pig-breeding enterprise was very good with regard to TSS, as the maximum permissible concentrations (MPCs) were never exceeded. Within the study period, average measured concentrations of TSS at the beginning of the cold period and the warm period and at the end of the warm period were 13.3, 12.6, and 10.9 mg L^{-1} respectively; that is, 3.8, 4.0 and 4.6 times lower than the MPCs.

Within the study period, the pollution of surface water with organic substances in the study area was very low: average measured concentrations of this index at the beginning of the cold period and the warm period and at the end of the warm period were 7.4, 5.9, and 4.5 mg O_2 L^{-1}, respectively, that is, 7.8, 9.7, and 12.8 times lower than the MPCs, respectively.

The pollution of the surface wastewater with organic compounds is relevant to TSS, since up to 90% of the organic substances comprising BOD_7 are suspended solids, and contamination with other pollutants, that is, oil products and heavy metals, is of random character (Jakubauskas and Račys, 1997). It was established by means of regression analysis that as the amount of TSS in the surface wastewater of the pig-breeding enterprise increased, oil products increased ($r = 0.94$, when $t_{act.} = 5.72 > t_{theor.95\%} = 2.77$; $n = 6$) (Table 1).

Correlation coefficients between TSS concentrations in surface wastewater and researched elements were determined to be strong, average and weak, however statistically insignificant.

It is maintained that oil and oil products are among the most frequent and most dangerous pollutants of the ground and water bodies; their composition changes under the influence of the environment, and natural communities of microorganisms oxidizing the oil decompose them completely only over a long time (Leahy and Colwell, 1990; Čipinytė and Grigiškis, 2000).

Within the study period, the measured amounts of oil products in the surface wastewater released into the natural environment were especially low: average concentrations of oil products at the beginning of

Table 1

Correlation between TSS and BOD_7, N_{total}, P_{total}, oil products in the surface wastewater of the pig-breeding enterprise

Indices	Form of relation	Determination coefficient	Correlation coefficient	n	$t_{theor.95\%}$	t_{actual}
When TSS<10 mg L^{-1}						
BOD_7	$y = -0.23x^2 + 2.54x-2.79$	0.58	0.76	6	2.77	2.31
N_{total}	$y = -0.02x^2 + 0.14x-2.43$	0.007	0.08	6	2.77	0.16
P_{total}	$y = 0.14646x^{0.7773}$	0.20	0.45	6	2.77	1.01
Oil products	$y = 0.0509x^{1.5361}$	0.89	0.94	6	2.77	5.72*
When TSS>10 mg L^{-1}						
BOD_7	$y = 1.12x^2 -3.77x+35.02$	0.48	0.69	8	2.45	2.34
N_{total}	$y = -0.02x^2 + 1.13x-9.44$	0.47	0.69	8	2.45	2.32
P_{total}	$y = 0.009x^2-0.28x+2.65$	0.08	0.29	8	2.45	0.74
Oil products	$y = 0.0001x^{3.0455}$	0.37	0.61	8	2.45	1.89

x – the concentrations of TSS in the surface wastewater, mg L^{-1}; y – the concentrations of indices in the surface wastewater, mg L^{-1}; correlation connection values reliable according to the Student's criterion t ($t_{actual} > t_{theor.95\%}$) are signed with stars.

Table 2

Correlation between the concentrations of indices (TSS BOD_7, N_{total}, P_{total}, oil products), formed in the surface wastewater of the pig-breeding enterprise, and the rainfall

Indices	Form of relation	Determination coefficient	Correlation coefficient	n	$t_{theor.95\%}$	t_{actual}
TSS	y = 0.0393x - 20.479	0.25	0.50	15	2.2	2.41*
BOD_7	y = 0.0217x - 12.153	0.29	0.55	15	2.2	2.80*
N_{total}	y = 0.0054x - 1.4947	0.12	0.35	15	2.2	1.45
P_{total}	y = 0.0016x + 0.7064	0.06	0.24	15	2.2	0.93
Oil products	y = 0.0007x + 0.1359	0.02	0.13	15	2.2	0.48

x – amount of precipitation, mm; y – the concentrations of indices in the surface wastewater, mg L^{-1}; correlation connection values reliable according to the Student's criterion t (t_{actual}> $t_{theor.95\%}$) are signed with stars.

Table 3

Trends of change in concentrations of indices in the surface wastewater of the pig-breeding enterprise within the study period

Indices	Form of relation	Determination coefficient	Correlation coefficient	n	$t_{theor.95\%}$	t_{actual}
TSS	y = -0.7664x + 18.265	0.27	0.51	15	2.2	2.51*
BOD_7	y = -0.4842x + 9.8077	0.39	0.62	15	2.2	3.68*
N_{total}	y = -0.0976x + 3.7674	0.11	0.33	15	2.2	1.33
P_{total}	y = -0.0443x + 0.9918	0.12	0.34	15	2.2	1.39
Oil products	y = -0.0171x + 0.8446	0.03	0.17	15	2.2	0.63

x – study period, yr; y – the concentrations of indices in the surface wastewater, mg L^{-1}; correlation connection values reliable according to the Student's criterion t (t_{actual}> $t_{theor.95\%}$) are signed with stars.

the cold period and the warm period and at the end of the warm period were 0.8, 0.7, and 0.7 mg L^{-1}, respectively, and were thus 8.8 to 10 times lower in comparison with the MPCs.

Average concentrations of N_{total} and P_{total} in the surface wastewater runoff from the production territory of the enterprise at the beginning and end of the warm period and in the cold period were 9.1, 13.0, and 9.1 times and 6.7, 6.7, and 5.7 times lower than the MPCs, respectively. Since measured concentrations of these chemical elements in the surface wastewater were very low, no correlation with rainfall, the number CL of the enterprise, or the TSS in the wastewater was established.

It was established by means of correlation analysis that the increase in concentrations of TSS and BOD_7 in the wastewater is related to higher rainfall (Table 2).

A higher precipitation had no effect on the concentrations of N_{total}, P_{total}, and oil products, because the correlation coefficients were very low and not statistically significant.

Indices in the surface wastewater of the pig-breeding enterprise fluctuate very little and never exceed the MPCs. A downward trend of concentrations of TSS (r = 0.51), BOD_7 (r = 0.62) was observed in the pig-breeding enterprise within the five-year study period (Table 3). It was influenced by the completed reconstruction of the enterprise.

It can be seen from the equations in Table 1 that N_{total}, P_{total}, and oil products concentrations in the surface wastewater, which is released to the environment, due to reconstruction of the enterprise, which was carried out, have a tendency to fall, however, the correlation coefficients were determined to be extremely low.

Conclusions

1. Due to the uneven distribution of precipitation, 2.3 times more surface wastewater ran off the production territory of the enterprise during the warm period than in cold period.
2. Concentrations of indices in the surface wastewater of the pig-breeding enterprise fluctuated within a very narrow range (for example TSS – from 5.8 to 21 mg L^{-1}) and never exceeded the MPCs; however, they were higher during the spring snow break and at the beginning of the warm period.
3. The higher amount of precipitation has led to an increase in the concentrations of TSS (25%) and BOD_7 (29%) in the wastewater.
4. Due to the reconstruction of the enterprise, which was carried out, contamination of the production territory has decreased significantly. A downward trend in concentrations of TSS (27%), and BOD_7 (39%), was observed in the pig-breeding enterprise within the five-year study period.
5. The water pollution formed in the production territory of the pig-breeding enterprise is not an

environmental hazard, as the concentrations of the indices investigated in the surface rain wastewater were 3.8 – 12.8 times lower than the MPCs. Therefore, this wastewater can be released into open water bodies untreated.

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