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THE EFFECT OF A FIRE AT A TIRE RECYCLING FACTORY ON THE STATUS OF SURFACE WATER BODIES: A CASE STUDY IN LITHUANIA

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On 16 October 2019, a large-scale fire that lasted for 15 days broke out at the "Ekologistika" company located in the northern industrial district of Alytus. During the fire, burning waste tyres released a significant amount of pollutants into the environment. The dispersed pollutants posed a serious risk to human health, drinking water quality and surface water bodies. It was decided to conduct a study to assess whether the fire had an impact on surface water quality not only immediately after the fire but also for four years afterwards. The aim - to assess the status of surface water after a fire at a tire recycling plant. After conducting an analysis of the status of surface water bodies in 2019 - 2022, it was determined that according to NH_4-N 78 - 100%; N 56 - 100%, PO_4-P 33 - 100%; BOD_7 67-100% of river water corresponded to the values of the class of bad or very bad ecological status. According to BOD_7 89 -100%; N 67-100% the ponds corresponded to the values of the class of bad or very bad ecological potential. After evaluating the relationships between the values of the quality indicators of surface water bodies and the distance from the fire, a negative relationship was established between the distance from the fire and NO_3-N and N. Also, in 2021 - 2022, a positive relationship was established between the distance to the fire source and the pH value. A negative relationship was established between the distance to the fire focus NO_2 and NO_3-N concentration.

Keywords: *Marginal rate, surface water, ecological condition, fire source, class of ecological potential*

INTRODUCTION

The disposal of vehicle tires is a global environmental problem. Every year, around 1000 million tires become unusable worldwide, and their quantity is constantly increasing, many of them are inevitably thrown away (Wang et al., 2019).

The tires present a structure complex made up of different materials as natural and synthetic rubber (40-45%), steel and carbon black stringing (27-33%), vulcanized with sulphur (1.5-2.5%), textile fiber, extender oils, nylon, and some chemical substances (Roy, 2005; Van de Lindt et al., 2008; Gupta et al., 2011). These vehicle parts also contain the strengthening agents, pigments, fillings (Pedram et al., 2017; Wang et al., 2019). Zinc, copper, chrome, and other heavy metals are also found in the tires (Degaffe and Turner, 2011; Rhodes et al., 2012; Lai et al., 2017).

The emissions from burning tires are rather toxic. Burning tires release a whole bunch of chemical compounds, such as carbon monoxide, sulphur oxides, volatile organic compounds, polycyclic aromatic hydrocarbons (PAHs), dioxins, benzenes, and a variety of heavy metals such as lead, zinc, nickel, vanadium, and others (Rhodes et al., 2012; Renan and Fukuya, 2010). It is known that these pollutants cause also malformations birth defects, diabetes, and adverse effects on hormonal, immune and nervous systems heart, as well as problems in the lungs, among others (Pawan et al., 2008; Zhendi et al., 2007).

People can not only inhale these substances, but they can also contaminate surface and ground waters, enter the soil (Ardila and Arriola, 2017; Pawan et al., 2008; DeMarini et al., 1994). Chrysikou et al. (2008) point out that due to the variety of compounds present in tire smoke and their unlike physical and chemical properties, different spatial and temporal distributions in the environment are possible.

The contaminants from burning tires like PAHs, may be present in the gas phase or associated with particles, and through air currents favours its dispersal over long distances, so have been detected in water and soil in remote sites from the source that generated them. Properties physics and chemistry of low-weight PAHs molecular weight (2 to 3 aromatic rings) make of them ideal candidates for dispersal through the atmosphere. Instead, PAHs higher molecular weight (4 to

7 aromatic rings) have a higher affinity for the material particulate, like ashes, and with matter organic soil, being more persistent in the environment (Wilcke et al., 2005; Wilcke, 2007). These contaminants, upon reaching the waters and soils of different ecosystems, affect their stability, interfering with the proper development of biogeochemical cycles and altering the chains food.

The effect of burning tires caused on the water quality in a section of the Piedras Blancas stream was studied. It was found a significant deterioration of water quality due to the burning of tires carried out in its basin, it varied between fair and very poor. The values obtained for most of the parameters exceeded the acceptable limits reported in the Colombian environmental regulations for the destination of water resources for human and domestic use as well as preservation of flora and fauna. The results of this study show that the physicochemical properties of water are strongly affected by combustion products of burning tires (Ardila and Arriola, 2017).

Heavy metals and polycyclic aromatic hydrocarbons are toxic, mobile, have a considerable accumulation potential (Webb et al., 2020; Kostka and Leśniak, 2020; Zhu et al., 2019; Niu et al., 2018; Zhao et al., 2016). During the burning of tires, both heavy metals and PAHs release into the environment in huge amounts (Nadal et al., 2016; Ziadat and Sood, 2014).

Extinguishing a tire fire takes longer than a normal fire, and even when there is no visible burning, the tires are still smoking, releasing substances hazardous to health into the surrounding air. Smouldering tires release much more harmful chemicals into the environment compared to burning tires, because the temperature is low er during smouldering and the pollutants do not burn.

In 2019, a tire fire occurred at the biggest tire recycling factories in the Baltic located in Alytus, a town in southern Lithuania. It was fully extinguished only after 10 days. About five thousand tons of used and recycled vehicle tires of various types were stored in the company's warehouse. About two thousand tons of tires were burned during this event. The possible environmental contamination caused great concern among Lithuanian society, and the incident itself was seen as a painful ecological disaster.

The assessment of the pollution level and pollutants distribution in the surrounding of a tire recycling factory in Alytus area, was conducted. High concentrations of total PAHs were found inside the fire zone, whereas those detected in the surrounding soils were significantly lower. It was found that the whole fire zone highly contaminated with the heavy metals (Raudonytė-Svirbutavičienė et al., 2022).

The aim of this work was to assess the status of surface water bodies after a fire at a tire recycling plant.

RESEARCH METHODS

On 16 October 2019, a large-scale fire broke out at the “Ekologistika” company located in the northern industrial district of Alytus, which lasted for 10 days, until 25 October. The fire involved the burning of waste tyres and the possible release of large quantities of chemicals into the environment - air, soil, groundwater and surface water. To assess the impact of the fire on surface water, a surface water survey was conducted at eighteen sites, including 9 flowing and 9 standing water bodies in the area affected by the fire (Figure 1).

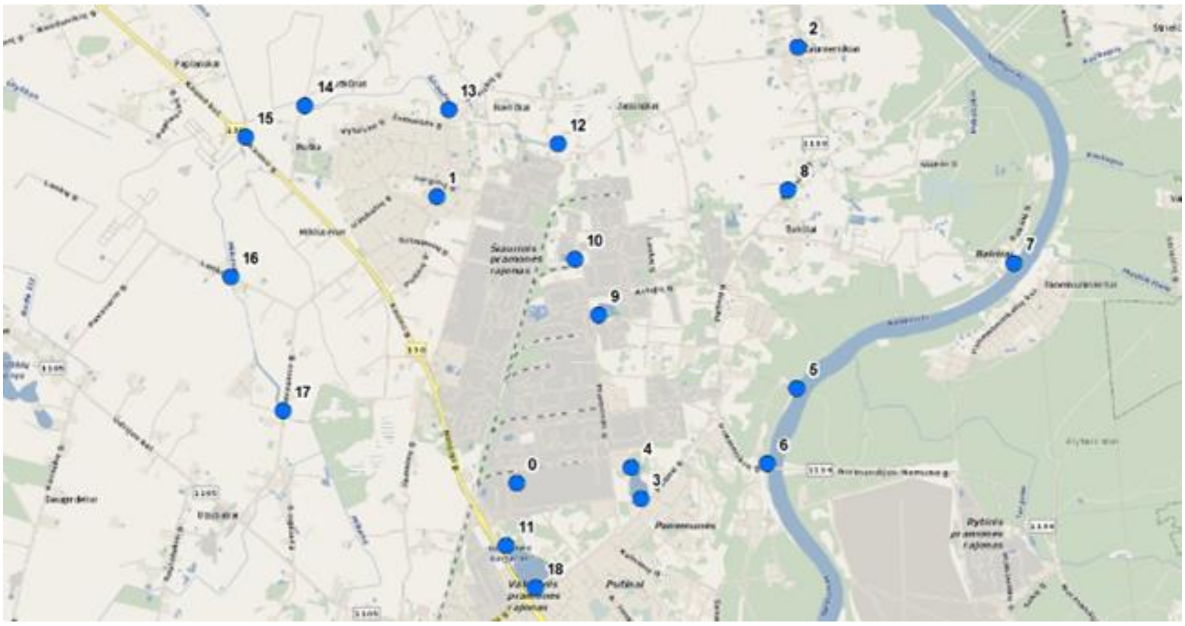

Figure 1. Scheme of surface water sampling

Water samples were taken after the Alytus tyre fire. The water was sampled every season for a four-year period from 2019 to 2022. Of particular interest are the water quality tests in ponds in the Alytus district, which were in the smoke dispersion area after the tyre fire. The following water quality parameters were investigated: Biochemical oxygen demand over 7 days (BOD_7); Phosphate phosphorus (PO_4-P); Nitrate nitrogen (NO_3-N); Ammonium nitrogen (NH_4-N);

Total nitrogen (N) LST EN ISO 11905-1:2000. The values of the water quality indicators are assessed by comparing them with the limit values of the indicators, which are regulated in the Methodology for Determining the Condition of Surface Water Bodies, approved by the Minister of the Environment of the Republic of Lithuania on August 10, 2016, No D1-533.

A correlation coefficient was used to assess the strength of the relationship between solute concentration and distance from the fire. The magnitude of the correlation coefficient is used to infer the strength of the correlation. The stronger the linear relationship, the closer the $|r|$ value is to 1. If $r > 0$, then as the values of one random variable increase, the values of the other increase linearly. If $r < 0$, then as the values of one random variable increase, the values of the other decrease linearly. If $r = 0$, there is no linear relationship, but there may be a non-linear relationship. The Pearson correlation coefficient, which assesses the strength of the linear relationship, was used. The program STATISTCA 10 was used.

RESEARCH RESULTS AND DISCUSSION

Phosphate phosphorus concentrations (PO_4-P), nitrate nitrogen concentrations (NO_3-N), ammonium nitrogen concentrations (NH_4-N), total nitrogen concentrations (N), and the biochemical oxygen demand value (BOD_7) were assessed. Ammonium nitrogen concentrations in pond and river water are shown in Figure 2.

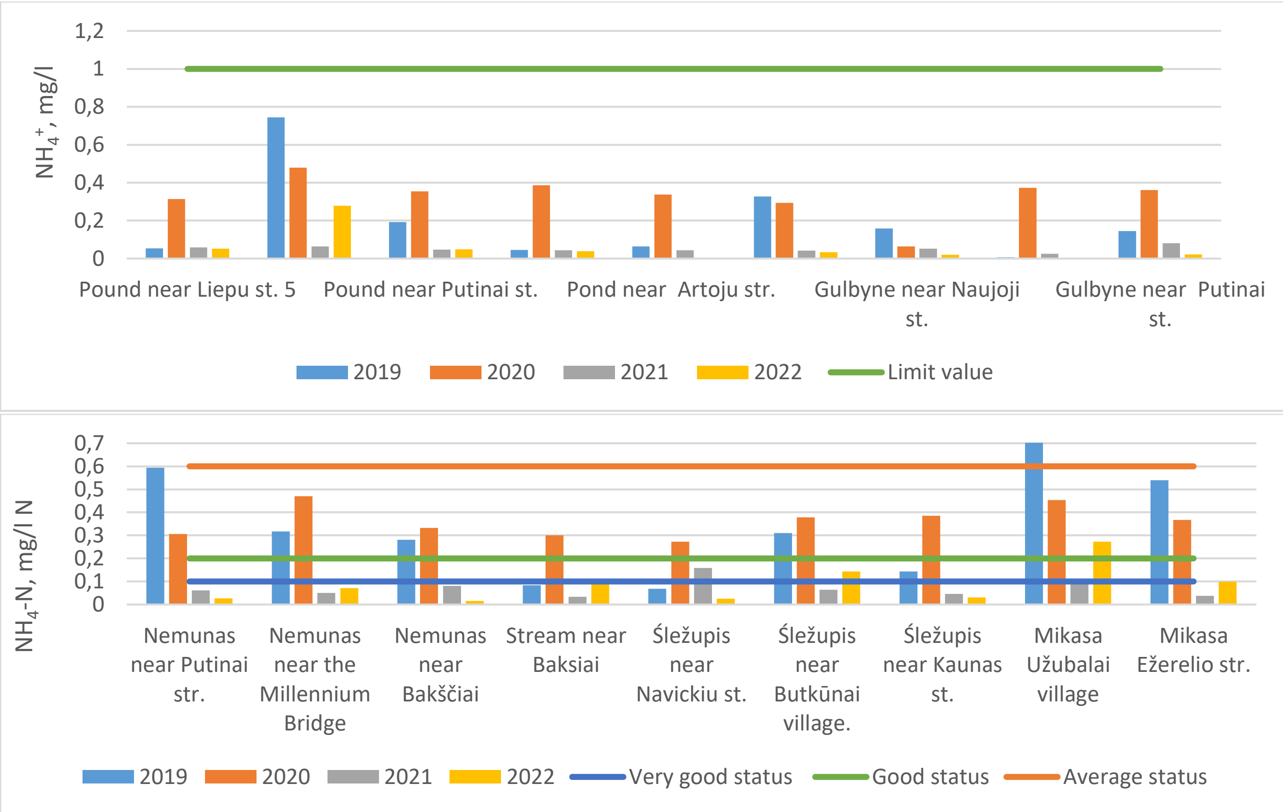

Figure 2. Ammonium nitrogen (NH_4-N) concentrations a. in ponds; b. in river water.

Concentrations of ammonium nitrogen (NH_4-N) in pond water are compared with the limit values set in the "Inventory of requirements for the protection of surface water bodies in which freshwater fish may live and breed" limit value ≤ 1 mg/l (Order of the Minister of Environment of the Republic of Lithuania, 2005). The figure below shows that for all four years of the study, the concentrations of ammonium nitrogen (NH_4-N) in the pond water did not exceed the limit value. The highest ammonium concentration of 0.957 mg/l was detected in the pond in Žiaunieriškiai village in 2019. Meanwhile, the lowest concentration was found in 2022 in the pond in Navickai village at 0.006 mg/l.

The obtained data were compared with the values specified in the methodology for determining the status of surface water bodies. The data presented in the figures show that in 2019, 78% of river waters had ammonia nitrogen (NH_4-N) concentrations in the class of bad or very bad ecological status, and the remaining 22% had good or very good ecological status. In 2020, all the studied rivers corresponded to values of bad or very bad ecological status. In contrast, in 2021 and 2022, all rivers were in the good or very good ecological status class for ammonia nitrogen values.

Nitrate nitrogen (NO_3-N) concentrations in river water are presented in Fig. 3.

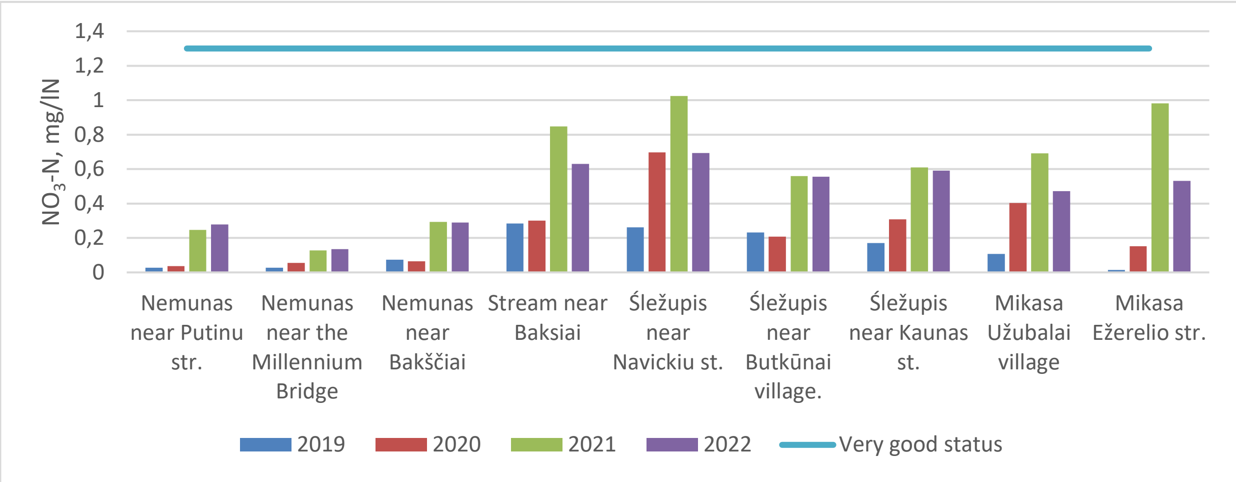

Figure 3. Nitrate nitrogen (NO3-N) concentrations in river water

The figure below shows that for all four years of the study period, the rivers studied met the values for nitrate nitrogen (NO_3-N) concentrations in the very good ecological status class. The lowest concentration was found in the first year after the fire in 2019, at 0.014 mg/l, and the highest concentration was found in 2021 at 1.024 mg/l.

The concentrations of total nitrogen (N) in river and pond water are shown in Figure 4.

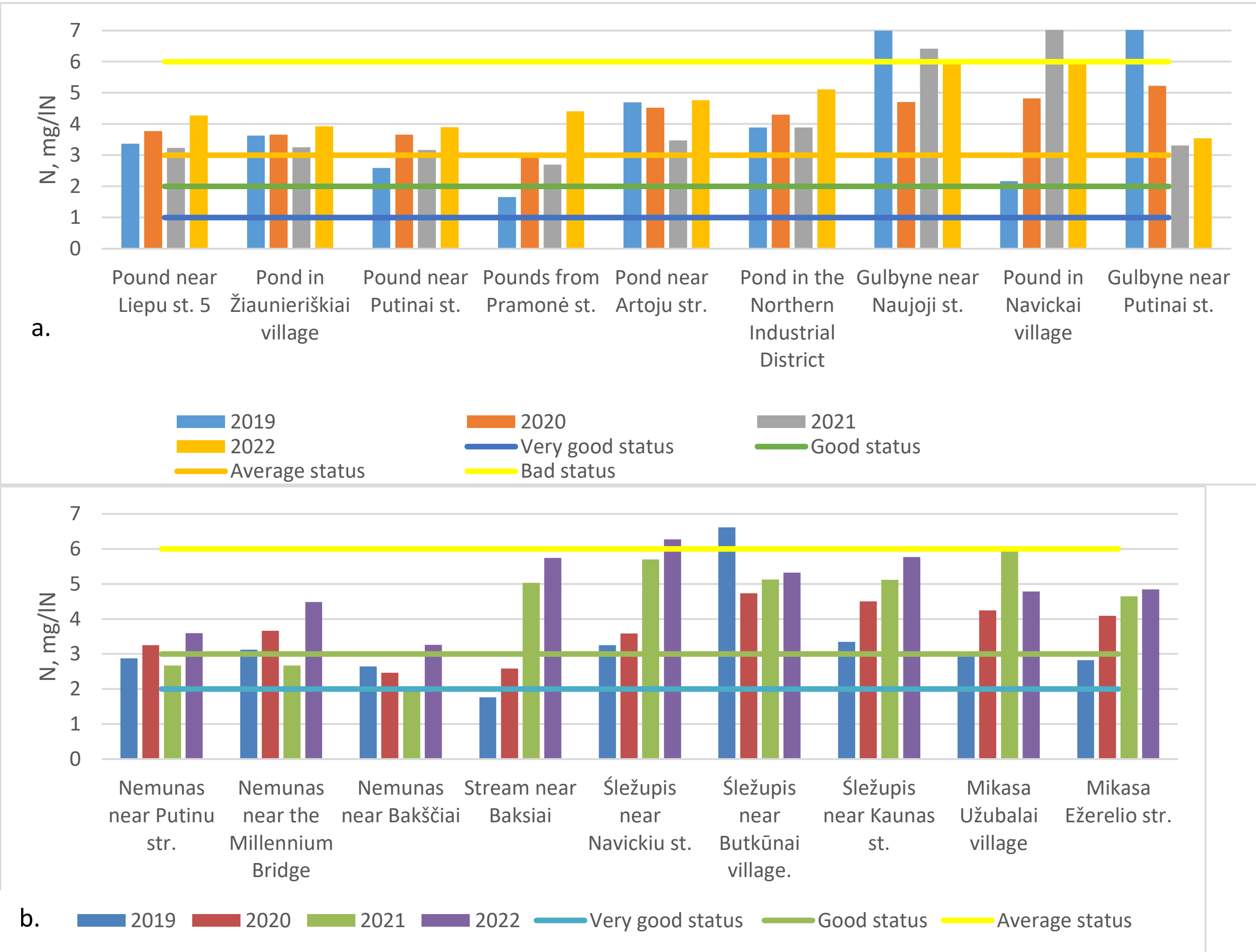

Figure 4. The concentrations of total nitrogen (N) in a. river and b. pond water

The data presented in the figure shows that in 2019, 44% of the rivers were in good or very good ecological status in terms of total nitrogen (TN) concentration and 56% were in bad or very bad ecological status. In the next year of the study (2020), 22% of the rivers were in good ecological status and 78% were in bad or very bad status. In the third year of the work

(2021), 33% of the rivers were in good ecological status and 67% were in bad or very bad status. In the fourth year of the study, all rivers were in bad or very bad ecological status for total nitrogen.

The figure shows that in the first year of the study (2019), 33% of the ponds were in the good ecological potential class for total nitrogen (N) concentration and 67% were in the bad or very bad ecological potential class. In the second year of the study (2020), all ponds were in the bad or very bad ecological potential class. In the third year of the work (2021), 11% of the ponds studied were in the good ecological potential class and 89% were in the bad or very bad ecological potential class. In the fourth year of the study, all ponds surveyed belonged to the bad or very bad ecological potential class.

The concentration of phosphate (PO_4) in pond and phosphate-phosphorus (PO_4-P) river water is presented in Figure 5.

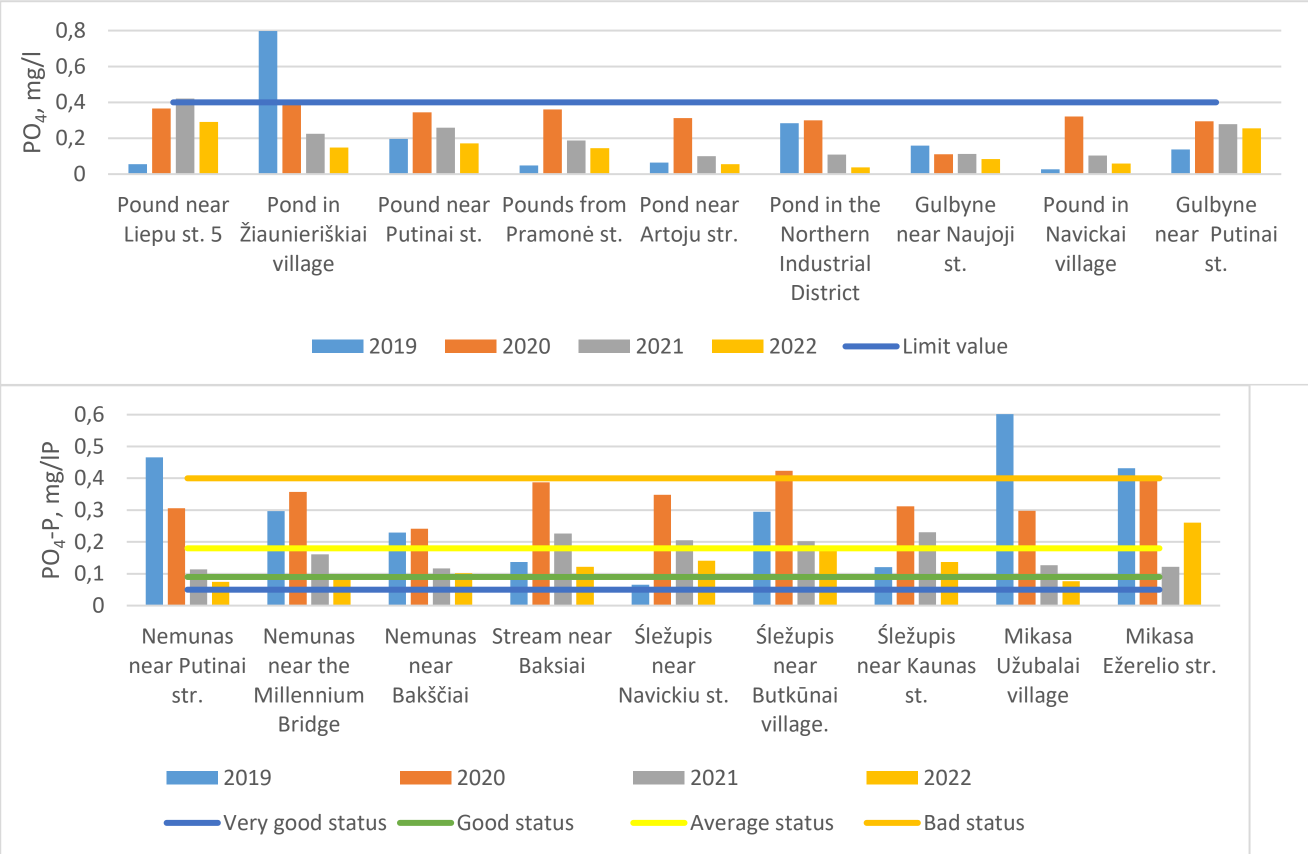

Figure 5. The concentration of phosphate (PO_4) in pond and phosphate-phosphorus (PO_4-P) river water.

The obtained data are compared with the limit values set in the "Inventory of requirements for the protection of surface water bodies where freshwater fish can live and breed" limit value for Carp water bodies $\leq$ 0.4 (Order of the Minister of the Environment of the Republic of Lithuania, 2005). The figure shows that phosphate (PO_4) concentrations in the first year after the fire, i.e. in 2019, exceeded the limit value in 44% of ponds. In this year of the study, the lowest concentration of 0.082 mg/l was found in the pond in Navickai village, while the highest concentration of 2.443 mg/l was found in the pond in Žiaunieriškiai village. In the second year after the fire, i.e. in 2020, phosphate (PO_4) concentrations exceeded the limit value in all ponds. In the third and fourth year after the fire, 56 % of the ponds exceeded the limit value.

In the first year of the study (2019), 11% of rivers met the good ecological status class values for phosphate-phosphorus (PO_4-P) concentrations, while 89% of rivers met the bad or very bad ecological status class values. In the second and third years of the study (2020 and 2021), all the rivers studied met the values of bad or very bad ecological status. In the fourth year of the study, 33% of the rivers were in good ecological status.

The biochemical oxygen demand after seven days (BOD_7) for pond and river water is presented in Fig. 6.

In the first year of the study (2019), 11% of the ponds were classified as good and 89% as very bad ecological potential in terms of biochemical oxygen demand (BOD_7) values. In the second, third and fourth years of the study (2020, 2021 and 2022), all the studied ponds belonged to the class of very bad ecological potential.

In the first year of the study (2019), 33% of the rivers were in good or very good ecological status and 67% were in bad or very bad ecological status based on biochemical oxygen demand (BOD_7) values. In the second year of the work (2020), all rivers met the values of bad or very bad ecological status. In the third year of the study (2021), 33% of the rivers were in good or very good ecological status and 67% were in bad or very bad ecological status.

Distance measurements were taken to assess whether the distance from the fire source to a surface water body affects the condition of water bodies. The results are shown in Fig. 7.

Figure 6. The biochemical oxygen demand after seven days (BOD_7) for pond and river water

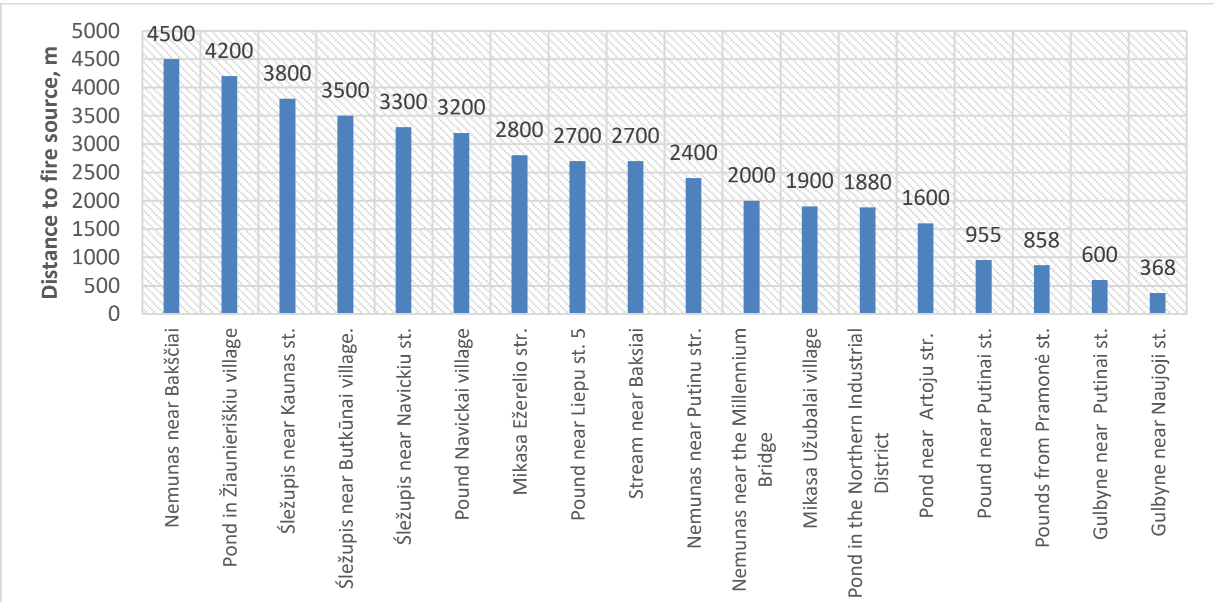

Figure 7. Distances from the fire source to the surface water body

The data presented in the figure shows that the nearest surface water body is the Gulbynė quarry at Naujoji street, located 368 m from the pollution source. The most distant water body is the Nemunas River at Bakščiai, at a distance of 4.5 km.

In order to evaluate the relationship between the values of surface water quality indicators and the distance to the fire source, correlation coefficients were calculated in different years of the study. The results are presented in Table 1.

Table 1. Correlation matrix of the values of surface water quality indicators and the distance to the fire source.

	pH	**NH_4-N, mg/lN**	**NO_2, mg/lN**	**NO_3-N, mg/lN**	**O_2, mg/lO2**	**BOD_7, mg/lO_2**	**N, mg/lN**	**PO_4-P mg/lP**
2019	r=0.031 p=0.902	r=0.230 p=0.348	r=-0.250 p=0.310	r=-0.540 p=0.048	r=0.180 p=0.454	r=-0.450 p=0.045	r=-0.530 p=0.049	r=0.260 p=0.294
2020	r=-0.210 p=0.400	r=0.330 p=0.172	r=-0.180 p=0.467	r=0.230 p=0.351	r=0.016 p=0.950	r=-0.250 p=0.308	r=-0.270 p=0.263	r=0.360 p=0.137
2021	r=0.420 p=0.049	r=0.180 p=0.480	r=-0.470 p=0.041	r=-0.470 p=0.048	r=-0.230 p=0.360	r=-0.240 p=0.333	r=0.040 p=0.868	r=0.020 p=0.936
2022	r=0.510 p=0.030	r=0.260 p=0.301	r=-0.410 p=0.046	r=-0.580 p=0.012	r=-0.110 p=0.665	r=-0.360 p=0.140	r=0.070 p=0.759	r=0.020 p=0.933

The correlation coefficients in the first year after the fire (2019) showed a statistically strong negative correlation between the distance to the fire and nitrate nitrogen concentrations (NO_3-N) (r=-0.540; p=0.048), biochemical oxygen demand value (BOD_7) (r=-0.450; p=0.045), and total nitrogen concentrations (N) (r=-0.530; p=0.049). The lower the distance to the fire, the higher the nitrate nitrogen, biochemical oxygen demand values and total nitrogen concentrations.

In the second year after the fire (2020), no statistically strong correlation was found between the distance to the fire site and the values of surface water quality indicators.

In the third and fourth year after the fire (2021-2022), there was a statistically strong positive correlation between distance to fire and pH value (r=0.420; p=0.049 and r=0.510; p=0.030). The smaller the distance to the fire, the lower the pH value of surface water and the more acidic the water. A statistically strong negative correlation was found between distance to fire and nitrite (NO_2) concentration (r=-0.470; p=0.041 and r=-0.410; p=0.046) and nitrate nitrogen (NO_3-N) (r=-0.47; p=0.048 and r=-0.580; p=0.012). The smaller the distance to the fire, the higher the concentration of nitrite and nitrate nitrogen. The process of nitrification takes place.

Ardila and Arriola (2017) studied the effect of burning tires caused on the water quality in a section of the Piedras Blancas stream was studied. The physicochemical and microbiological parameters were measured in order to compare a pattern sample and a problem sample. The comparison of the average values of the sample problem with the sample pattern, showed a significant increase.

In the following physicochemical parameters of the test sample: COD, BOD_5, TOC, oxygen dissolved, total solids, total volatile solids, suspended solids, copper, chrome (VI), cadmium, lead, nickel, zinc, mercury and other heavy metals, as well as acidity, sulphates, nitrates, nitrites, surfactants, phenols, and other matters. The variation in the values of these characteristics allows to show the strong environmental impact caused by burning tires on various physicochemical properties from the waters of the Piedras Blancas stream.

However, parameters such as temperature, pH, free residual chlorine, calcium, phosphates, manganese, molybdenum, magnesium, chlorides, fluorides, aluminium and arsenic did not have a significant change. A significant deterioration of water quality due to the burning of tires carried out in the analysed basin, it varied between fair and very poor.

The Environmental Protection Agency conducted surface water tests immediately after the fire. Summarized tests of samples taken from the Nemunas River revealed that the amount of heavy metals in the water did not exceed the current maximum permissible concentrations. PAHs, volatile organic compounds, and petroleum hydrocarbons did not exceed the norms. A month after the fire, there was an increase in the concentration of phosphatic organics and nitrogenous substances, which could have been influenced by the impaired operation of the wastewater treatment plant. Concentrations did not meet the requirements of good condition but became close to good condition in November. During the fire, Nemunas water was not toxic (Environmental Protection Agency, 2019).

In order to better assess the effect of the fire on surface water bodies, samples were taken from ponds in the villages of Jasunskai, Miklusėnai and Navickai. Gulbynė quarry and Kavalis lake. Heavy metals did not exceed the maximum instantaneous concentration in Gulbynė quarry, but benz (g,h,i) perylene exceeded the concentration 1.5 times. The concentrations of petroleum hydrocarbons, volatile organic compounds, PAHs and heavy metals measured in Lake Kavalis did not exceed the limit values. Concentrations of other pollutants were low (Environmental Protection Agency, 2019).

CONCLUSIONS

The analysis of the surface water bodies condition for the period 2019-2022 showed that river water corresponded to the class of bad or very bad ecological condition in terms of ammonium nitrogen (NH_4-N) 78-100%, total nitrogen (N) 56-100%, phosphate phosphorus (PO_4-P) 33-100%, biochemical oxygen demand (BOD_7) 67-100%. The ponds corresponded to values for biochemical oxygen demand (BOD_7) 89-100%; total nitrogen (N) 67-100%; ponds belonged to the class of bad or very bad ecological potential.

Evaluation of the relationship between surface water quality values and distance from fire in 2019 showed a statistically strong negative relationship between distance from fire and NO_3-N (r=-0.540; p=0.048), BOD_7 (r=-0.450; p=0.045), and N (r=-0.530; p=0.049). In the third and fourth year after fire (2021-2022), there was a statistically strong positive correlation between distance to fire and pH value (r=0.420; p=0.049 and r=0.510; p=0.030). A statistically strong negative correlation was observed between distance to fire and NO_2 concentration (r=-0.470; p=0.041 and r=-0.410; p=0.046), and NO_3-N (r=-0.47; p=0.048 and r=-0.580; p=0.012).

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