



Environmental assessment of the impact of hydrocarbon pollution on the condition of cooling ponds

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✓ **Abstract.** Hydrocarbon pollution remains an important and unresolved problem that has worsened during a full-scale invasion, in particular due to the ingress of rocket debris with a significant amount of petroleum products into surface waters. The aim of the work was to provide an assessment of the ecological state of a water body exposed to hydrocarbon and other uncharacteristic pollutants. Field methods: 5 water samples were taken to determine the content of petroleum products and the pH value, and 5 water samples were taken to determine the physical properties, main ions, and heavy metal content. Laboratory and instrumental methods: titrimetric – used to determine the content of chlorides, alkalinity, hardness. According to the results of studies, it was found that chloride ions were in the range of 264-274 mg/dm³, alkalinity values – 3.6-5.5 mmol/dm³. As a result of the hardness study, it was found that the waters are soft. The content of nitrites was determined by photocolometric method (their traces were recorded). Measurement: the pH value was determined by the electrometric method. According to the results, the water was classified as neutral and slightly alkaline. The content of petroleum products in the range of 0.19-16.36 mg/dm³ was determined by fluorimetry (exceeding the standard by 54.5 times). The content of cadmium, zinc, manganese, copper, chromium, and ferric iron was determined by modulation polarisation spectrophotometry. The content of chromium, cadmium, copper was in the range of 0.001 mg/dm³, manganese content – from 0.001 mg/dm³ up to 0.004 mg/dm³, zinc content – from 0.004 mg/dm³ up to 0.008 mg/dm³, ferum content – from 0.004 mg/dm³ up to 0.02 mg/dm³. Using the Ruffel method, the total dilution factor of wastewater in the reservoir was determined to be 125.24. According to the method of calculating the amount of compensation for losses, the damage caused by hydrocarbon pollution was determined, which is 143 thousand UAH. The practical value of the work lies in improving scientific and practical approaches to determining the strategy for conducting a comprehensive environmental study of the state of multifunctional artificial water bodies

✓ **Keywords:** oil products; reservoir; environmental regulations; environmental condition; water dilution ratio; economic losses

✓ Introduction

Hydrocarbon pollution is one of the most common and dangerous pollutants in water bodies. Their ingress with untreated wastewater and stormwater requires detailed

analysis, identification of factors, and research into self-purification processes. The problem was exacerbated during the full-scale invasion due to drones hitting oil depots,

Suggested Citation: Rychak, T., & Arkhypova, L. (2025). Environmental assessment of the impact of hydrocarbon pollution on the condition of cooling ponds. *Ecological Safety and Balanced Use of Resources*, 16(1), 9-18. doi: 10.63341/esbur/1.2025.09.

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spills and oil products entering water bodies, broken military equipment in water bodies, wreckage of downed missiles with a significant amount of unproduced fuel and oil products, and many other facts. The global scientific community has been focusing its research on creating a management and decision-making strategy in the context of sustainable development in the field of oil pollution for a long time. According to the latest global research, the main postulates of the impact of oil products on surface waters have been identified.

The research of O. Kratko *et al.* (2023) found that various types of water pollution are observed during missile launches. The discharge of biogenic compounds into water bodies leads to blooms and eutrophication of water bodies, a decrease in the level of oxygen saturation, an increase in the content of biogenic and organic substances, an increase in water turbidity, contamination with pathogenic microorganisms, and as a result, a threatening effect on aquatic life and human health. According to the researcher V. Hryniuk (2021), the processes of self-purification of natural watercourses from oil pollution depend on the flow rate (which increases the rate of mixing of water masses) and an increase in water temperature, which accelerates biochemical processes in a natural watercourse. Scientists R. Yang *et al.* (2023) concluded that rapid microbial decomposition of oil components was observed in river water during the day, and the rate of decomposition depends on the presence and functioning of the components of bacterial and fungal communities that utilise oil products.

Oil products are usually not found in natural waters. In uncontaminated lake waters (reservoir waters), the content of petroleum products is tenths or hundredths of a milligram per dm^3 (from 0.1 to 0.2 mg/dm^3 , sometimes up to 1.5 mg/dm^3). Hydrochemical studies of the state of water bodies analyse the hydrocarbon fraction, namely aliphatic, aromatic and other hydrocarbons, which make up about 80% of the total of all substances that make up oil and oil products. O. Biedunkova *et al.* (2024) concluded that a high degree of self-purification was characteristic of chlorides, ammonium nitrogen, and phosphorus phosphate; nitrite nitrogen, nitrate nitrogen, BOD₅, and COD had an average degree of self-purification; the lowest degree of self-purification of the river's surface waters was found for suspended solids, dissolved oxygen, and fluorides. As for heavy metals (ferrous, copper, zinc, manganese), no evidence of self-purification of surface waters has been confirmed; scientists assume that they are mostly of background origin. Researcher T. Sadova (2022) proposed approaches to solving the problem of environmental protection during armed conflicts in the legal field. The solution lies in the need to adopt the Fifth Geneva Convention, the provisions of which should address the protection of the environment during armed conflict, should contain a description of the protected areas and should specify the provisions that would apply to the restoration and protection of the environment damaged as a result of the conflict.

The Burshtyn Reservoir is a cooling pond for the Burshtyn Thermal Power Plant and is also part of the Galician

National Nature Park with the Ramsar site status of international importance. In addition to the impact of oil products and related lubricants that have entered the aquatic environment of the Burshtyn Reservoir and cause the above-mentioned environmental risks, there is another threat: a 1,000-meter flood protection dam. The total area of territories with significant flooding risks is about 2 thousand km^2 . Ash dumps are located on the territory of potential emergency flooding, and thus the risk indicators for the environment increase dramatically. In the spring of 2024, the Burshtyn Reservoir was significantly impacted by oil pollution as a result of a ballistic missile explosion. Field studies were conducted with water sampling on the same day. The purpose of the study was to assess the contamination of the Burshtyn Reservoir as a result of rocket explosions. The scientific novelty of the results obtained is that: for the first time, comprehensive environmental studies were conducted for an artificial array of surface waters that was subjected to an unusual type of pollution during military operations; the hydrochemical composition was analysed and the behaviour of individual chemical compounds under conditions of unusual pollution was determined; an environmental assessment of the state of surface waters under unusual pollution conditions was performed.

✔ Materials and Methods

Field studies were conducted to conduct an environmental assessment of the impact of oil products on the state of the Burshtyn cooling pond. The distribution of petroleum products and natural hydrocarbons vertically and along the water body's surface is quite complex. The most polluted areas are the coastal zones, where oil slicks were observed over large areas, so sampling was carried out in the surface layer of the reservoir along the perimeter of the water body. Five water samples were collected at representative sites where the content of oil products was visually observed DSTU ISO 5667-4:2003 (2004). We also collected 5 water samples for physical and chemical studies at these sites. The water quality was monitored at the sites: No. 1 – the confluence of the Hnyla Lypa River into the cooling pond; No. 2 – 400 m from the river mouth (left bank of the pond); No. 3 – 2.75 km from the river mouth (left bank of the pond, rural area); No. 4 – 2 km from the river mouth (right bank of the pond, private development area); No. 5 – the dam of the cooling pond (Fig. 1). According to V. Khilchevskiy *et al.* (2021), the Burshtyn Reservoir is classified as a medium, midsized and small (MMS) reservoir in Ukraine ($V_{\text{full}} = 50$ million m^3). The morphometric characteristics of the reservoir are as follows: length 7.5 km, average width 2.5 km, total water surface area 12.6 km^2 (1,260 hectares), average depth 3.5 m (maximum 8 m). The average long-term runoff of water from the reservoir for 1 year is $82 \times 10^6 \text{ m}^3/\text{year}$. Measurement of the content of petroleum products and the acidity of the medium (pH) was carried out on 12.04.2024 in Ivano-Frankivsk, Ivano-Frankivsk Region, Ukraine, in the laboratory control department of the Municipal Enterprise "Ivano-Frankivskvo-doekoteprom" (Protocol No. 13/24-C of measurements of

water composition and properties). The department is certified for the right to perform measurements (Certificate of Technical Competence No. IF-402 dated 13.06.2022 issued by the State Enterprise “Ivano-Frankivsk Center for Standardisation, Metrology and Certification”). Measurements were carried out in accordance with the measurement

procedures approved for use (appendix to the certificate of attestation). The content of oil products was measured by a fluorate-02-3M fluid analyser No. 5922, and the acidity of the medium was determined using a pH/Cond3320 conductometer. Measuring instruments are approved for use by the relevant verification certificates.

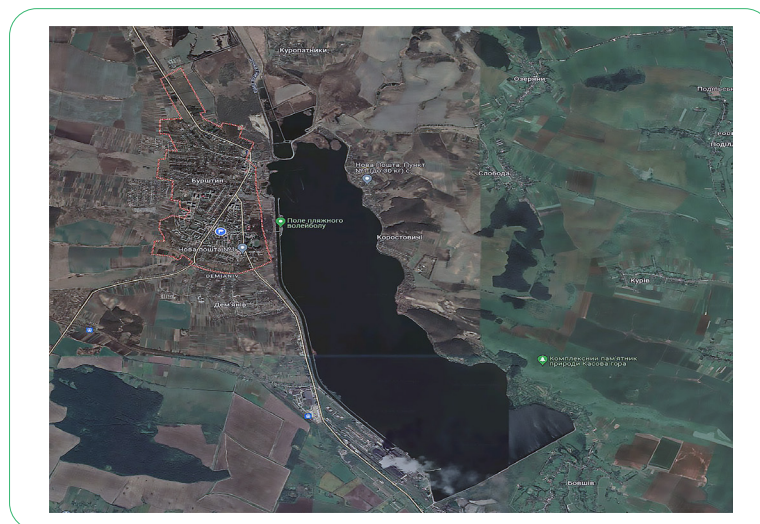


Figure 1. Representative water sampling sites in the Burshtyn cooling pond for physicochemical studies and determination of oil content (April, 2014)

Source: developed by the authors

Measurements of the content of heavy metals (HM) (cadmium, manganese, zinc, copper, chromium, and iron), nitrates, nitrites, chlorides, alkalinity, and hardness were carried out on 14.04.2024 in Kharkiv, Kharkiv Region, Ukraine, at the Educational and Research Laboratory of Analytical Environmental Studies of V.N. Karazin Kharkiv National University (Protocol No. 2006-2010 for the study of surface water). The HM content was determined by modulation polarisation spectrophotometry using an MTA 915 MD spectrophotometer, manufacturer with a hollow lamp

for the corresponding metals. The chloride content, hardness, and alkalinity were determined by titration. The nitrite content was determined using a KFK-2 photocolormeter, and the nitrate content was determined using a portable nitrometer. All measuring instruments used are authorised for use by verification certificates. The criteria for analysing the obtained results of the content of petroleum products, the chemical compounds and HM were Hygienic Water Quality Standards of Water Bodies to Meet the Drinking, Household and Other Needs of the Population (2022) (Table 1).

Table 1. Hygienic water quality standards for water bodies to meet drinking, household and other needs of the population

Name of the substance	MPC or SDT	Limiting sign of harmfulness	MPC or SDT in mg/dm ³	Hazard class
Nitrites, mg/dm ³ (for NO ₂)	MPC	s.-t.	3.3	2
Nitrates, mg/d ³ , (for NO ₃)	MPC	s.-t.	45.0	3
Chlorides, mg/dm ³	MPC	org. flavour	350.0	4
Iron, mg/dm ³	MPC	org. colour	0.3	3
Zinc, mg/dm ³	MPC	gen.	1.0	3
Copper, mg/dm ³	MPC	org. flavour	1.0	3
Manganese, mg/dm ³	MPC	org. colour	0.1	3
Cadmium, mg/dm ³	MPC	-	0.001	2
Chromium, mg/dm ³ (Cr ⁶⁺)	MPC	s.-t.	0.05	3
Heavy oil (mg/dm ³)	MPC	org. film	0.3	4

Note: s.-t. – sanitary and toxicological, affects human health; org. flavour – organoleptic, gives water an off-flavour; org. colour – organoleptic, affects the colour of water; g. – general sanitary, affects the processes of self-purification of water; org. film – organoleptic, forms a film on the surface of water

Source: made by the authors based on Hygienic Water Quality Standards of Water Bodies to Meet the Drinking, Household and Other Needs of the Population (2022)

The criteria for the analysis of ammonia content and organoleptic water quality indicators (odour, transparency

and turbidity), alkalinity and hardness were applied DSan-PiN 2.2.4-171-10 (2010) (Table 2).

Table 2. Sanitary and chemical indicators of water safety and quality

Name of the indicator (substance)	Drinking water standards in accordance with the State Sanitary and Epidemiological Norms 2.2.4-171-10
Ammonia	0.5 mg/l
Smell	≤ 2 points
Transparency	not less than 20 cm
Turbidity: quantitatively	≤1.0 mg/l
total alkalinity	≤6.5, mmol/dm ³
overall stiffness	≤7.0, mmol/dm ³

Source: made by authors based on DSanPiN 2.2.4-171-10 (2010)

To determine the dilution factor of pollutants in the cooling pond, the Ruffel method was used in the case of their entry into the upper third of the pond and spreading along the shore under the influence of wind disturbance. Calculations were made using the formula:

$$n_n = \frac{q+0.0087H^2}{q+0.000435H^2}, \quad (1)$$

where n_n – initial dilution when pollutants are released far from shore; q – waste water (pollutants) consumption; H – the average depth of the object where pollutants are diluted, in m. The main dilution depends on the place where the wastewater is released. For a release located far from the shore, the basic dilution is calculated using the formula:

$$n_o = 1.85 + 2.32(L / \Delta x)^{0.41 + 0.0064(L / \Delta x)}, \quad (2)$$

where n_o basic dilution; L – distance from the release of polluting water to the design alignment; $\Delta x = 4.41H^{1.167}$. The Methodology for Calculating Compensation for damage Caused to the state as a Result of Violation of Legislation on Protection and Rational use of Water Resources (2009) was used to calculate the damage caused as a result of oil products entering the water body. The calculations were based on the results of studies of the content of oil products and other pollutants in the Burshtyn Reservoir after the missile attack, and the inflation index for 2023. Ministry of Finance (2023), indexed specific economic damage from water pollution (γ) in 2023. Calculations were made using the formula:

$$Z = K_c \times K_{kat} \times K_p \times k_z \times [(M_{i1} \times Y_{i1}) + (M_{i2} \times Y_{i2}) + \dots (M_{iu} \times Y_{iu})], \quad (3)$$

where the coefficients take into account K_c – damage to the aquatic ecosystem; K_{kat} – water body category; K_p – shortage of surface water resources; k_z – damage to the aquatic ecosystem. And the following indicators were also taken into account: μ – the amount of pollutants; M_i – mass of excess discharge of the pollutant; Y_i – specific economic damage from water pollution, determined by the formula:

$$Y_i = Y \times A_p, \quad (4)$$

where the following economic losses were accounted for: Y – indexed loss calculated based on the current year's indicators using the formula (5):

$$Y = Y_{\eta} \times I \div 100, \quad (5)$$

where Y – indexed loss calculated based on the indicators of the previous year; I – inflation index; A – relative hazard indicator that was determined by the given formula (6):

$$A_i = 1 \div MPC_i, \quad (6)$$

where MPC_i is the MPC_i of the pollutant under study. The weight of petroleum products is calculated using the following formula (7):

$$M_{\eta} = M_{\pi} - M_p, \quad (7)$$

where M_{π} – the weight of the film was calculated using the given formula (8):

$$M_{\pi} = M_{\pi\mu} \times S \times 10^{-6}, \quad (8)$$

where $M_{\pi\mu}$ – specific gravity of oil per 1 m²; M_p – the mass of dissolved and emulsified oil that was calculated using the formula (9):

$$M_p = h \times S \times (C_{\eta} - C_{\varphi}) \times 10^{-6}, \quad (9)$$

where h – thickness of the water layer contaminated with oil, m; S – area of oil contamination of a water body, m²; C_{η} – average concentration of dissolved and emulsified oil in the contaminated volume of water under the oil slick, g/m³; C_{φ} – background concentration of dissolved and emulsified oil in the water of this water body, g/m³. The amount of damage caused to the Burshtyn Reservoir as a result of oil spills was calculated according to the Methodology for Calculating Compensation for Damages Caused to the State as a Result of Violation of Legislation on Protection and Rational Use of Water Resources (2009).

Results and Discussion

The results of studies of hydrogen ion activity in the upper part of the water body showed that the highest acidity values were recorded at two study sites: near the flood control dam (pH = 7.51 ± 0.1 pH units) and at the confluence of the Hnyla Lypa River into the reservoir (pH = 7.42 ± 0.1 pH units). In general, during the study period, conditions of neutral and acid-base balance of the environment were observed (Table 3).

Table 3. Results of testing water samples from the Burshtyn cooling pond for hydrogen reaction and oil content

Water samples	Measurement results and measurement error δ , $P = 0.95$		Information about measurement methods
	Hydrogen reaction (pH), pH units	Petroleum products, mg/dm ³	
1	7.42 ± 0.1 pH units	16.36 ± 6.5 mg/dm ³	Cipher MBB 081/12-0317-16 PH determination MBB 081/12-0230-05 measurement of petroleum products
2	7.17 ± 0.1 pH units	0.61 ± 0.24 mg/dm ³	
3	6.96 ± 0.1 pH units	0.84 ± 0.34 mg/dm ³	
4	7.10 ± 0.1 pH units	1.74 ± 0.6 mg/dm ³	
5	7.51 ± 0.1 pH units	0.19 ± 0.07 mg/dm ³	

Source: developed by the authors

The analysis of the selected water samples showed that the concentration values of petroleum products were in the range from 0.19 ± 0.07 mg/dm³ up to 16.36 ± 6.5 mg/dm³. The pollutant levels exceeded the environmental standards by 54.5 times (respectively, at the MPC of 0.3 mg/dm³). Significant exceedances of the environmental standard were recorded: in the waters of the first channel ≈ 3 times, the second ≈ 54 times, the third ≈ 6 times, the fourth channel ≈ 2 times, and no exceedances were observed in the waters of the fifth channel (Fig. 1-2). Field surveys and visual observations were complicated by the fact that, as a result of wind disturbances, oil spills moved across the surface of the water body and along its perimeter during the day. The coastal part of the reservoir and a significant coastal part of the water mirror area were covered with a film of oil products.

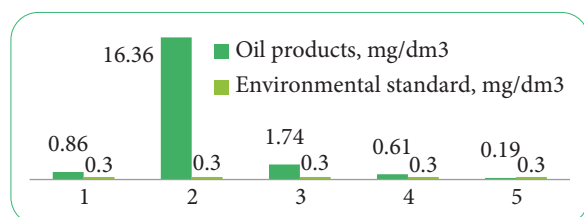


Figure 2. Comparison of oil products in the upper water layer at designated sites with their environmental standards
Source: developed by the authors

A specific feature was identified: the highest degree of acidity was characteristic of the water column with the lowest oil content. The main role in the ability of a water

body to self-purify is played by the dilution rate of water with pollutants. Water dilution is a process that reduces the concentration of pollutants in water bodies by mixing contaminated water with the surrounding water environment. The conditions for mixing polluting waters with reservoir waters differ from those in rivers. In reservoirs, the wind factor plays an important role because the currents created by the slope of the water surface are very small.

The oil products that got into the reservoir clogged a significant visible area of the water mirror. All visible oil slicks were examined for the content of oil products that had spread around the perimeter of the reservoir as a result of wind disturbance. For one of them, with the highest concentration of oil on the water surface with an area of up to 0.5 km² of oil film, and its emulsified state in the water column, the dilution coefficients for internal water exchange were calculated. Internal water exchange is characterised by the intensity of water mass transfer, turbulence, and convective processes related to the size of the reservoir. For a reservoir, the main indicators for calculating dilution are the initial (n_p) and basic (n_o) dilution (formulas 1-3). In the initial mixing zone, the concentrations of impurities are significantly reduced. However, complete mixing occurs at much greater distances from the point where pollutants enter the water body. When these substances enter a body of water at a certain distance from the shore, the initial dilution is faster. The calculated dilution ratio of contaminated water is 125.2 ($n_o = 120.4$, $n_p = 1.04$) (Rychak & Arkhypova, 2024a). In addition to petroleum products, the workstations analysed the content of heavy metals and individual physical and chemical parameters (Table 4).

Table 4. Results of physical and chemical studies of water samples of the Burshtyn cooling reservoir (April, 2024)

Name of the substance, units of measurement	Unit 1 (confluence of the Hnyla Lypa River into the reservoir)	Unit 2 (private buildings, agricultural land)	Unit 3 (private buildings, agricultural land)	Unit 4 (Burshtyn, recreational area)	Unit 5 (flood protection dam)
Ammonia, mg/dm ³	0.08	0.08	0.08	0.08	0.08
Smell	0	0	0	0	0
Transparency, cm	25	25	25	25	25
Turbidity, EMF	2.0	2.0	2.0	1.5	1.5
Nitrites, mg/dm ³	0.002	0.002	0.004	0.004	0.002
Nitrates, mg/dm ³	0	0	0	0	17
Chlorides, mg/dm ³	264	264	272	256	264
Alkalinity, mmol/dm ³	3.6	4.0	5.2	5.5	4.2
Hardness, mmol/dm ³	7.0	7.6	7.8	9.0	7.8

Table 4. Continued

Name of the substance, units of measurement	Unit 1 (confluence of the Hnyla Lypa River into the reservoir)	Unit 2 (private buildings, agricultural land)	Unit 3 (private buildings, agricultural land)	Unit 4 (Burshtyn, recreational area)	Unit 5 (flood protection dam)
Iron, mg/dm ³	0.0204	0.0346	0.0289	0.00421	0.02506
Zinc, mg/dm ³	0.006	0.006	0.006	0.008	0.004
Copper, mg/dm ³	0	0.001	0	0	0
Manganese, mg/dm ³	0.004	0.002	0.004	0.001	0
Cadmium, mg/dm ³	0.001	0.001	0.001	0.001	0.001
Chromium, mg/dm ³	0	0.001	0	0.001	0

Source: developed by the authors

A summarising analysis of surface water hardness and alkalinity showed that the water was within the permissible limits of environmental standards. In the water area used for recreational activities, the quantitative indicators of alkalinity and hardness differed slightly. Increased hardness (9.0 mmol/dm³) and alkalinity (5.5 mmol/dm³). The lowest indicators characterised the water at the confluence of the Hnyla Lypa River into the Burshtyn Reservoir: hardness was 7.0 mmol/dm³, alkalinity 3.6 mmol/dm³. This is due to the introduction of natural river water into the reservoir, which is characterised by lower hardness and lower alkalinity.

The content of heavy metals in the upper layer of water was investigated: ferrous, zinc, copper, manganese, cadmium, and chromium. The content of chromium and copper was not recorded in 60% to 80% of water samples. At well No. 2 (400 meters from the confluence of the Hnyla Lypa River, left bank, impacts from private development and agricultural land cultivation), the copper content was 0.0001 mg/dm³, which is one hundredth of a percent of the environmental standard (1.0 mg/dm³). In the waters sampled at the first site (the water area was under the influence of coastal recreational load), the chromium content was found to be 0.001 mg/dm³, which is 0.2% of the environmental standard (0.5 mg/dm³).

The content of manganese and zinc was detected in the waters at all study sites. However, their content, like the previous metals, was quite low. The manganese content was about 1% of the standard content (0.13 mg/dm³). The highest zinc content was recorded in the water area of recreational impact of the reservoir and amounted to about 1% of the environmental standard (1 mg/dm³). The presence of cadmium and iron was recorded in water samples at all study sites (Fig. 3).

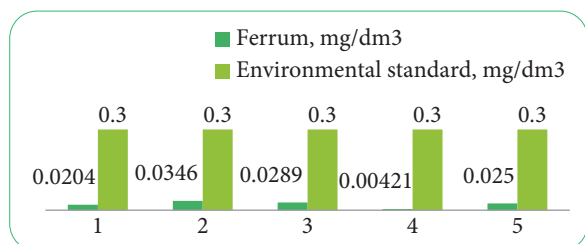


Figure 3. Ferrum content compared to the environmental standard in the surface water of the cooling pond

Source: developed by the authors

The highest content of iron was recorded in the well, where the largest oil slick was located and the highest concentration of oil products was recorded. In all other reservoirs, the content of iron was low compared to the environmental standard (about 8% of the environmental standard). The cadmium content in surface waters at the four study sites was 0.001 mg/dm³ (Fig. 4). This concentration of the pollutant is 77% of its environmental standard. This is the highest value obtained when studying the content of heavy metals in surface waters after hydrocarbons enter the reservoir.

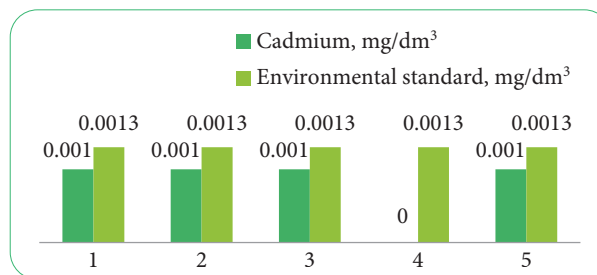


Figure 4. Cadmium content compared to the environmental standard in surface waters of the cooling pond

Source: developed by the authors

As a result of calculations, in the most polluted water area of the reservoir (the concentration of petroleum products was 16.36 mg/dm³) on an area of 0.5 km² (according to formulas 4-9) the amount of losses was 27,267.87 UAH. During the field surveys, four more, smaller in terms of concentration and area, were found to be contaminated with oil products. The amount of damage to four other areas of pollution was about 68 thousand UAH. In total, one missile attack and hydrocarbon contamination in the cooling pond caused economic losses of about 95 thousand UAH.

Burshtyn Reservoir is part of the Galician National Nature Park. In 2019, the reservoir received the conservation status of a Ramsar site of international importance. The reservoir is home to up to a hundred different species of birds, 19 of which are listed in the Red Book of Ukraine. During the spring migration, taking into account the thermal peculiarity of the drainage canal and the cooling pond, up to 22.3 thousand individuals can be in the coastal zone. Methodology for Calculating Compensation for damage Caused to the state as a Result of Violation of Legislation

on Protection and Rational Use of Water Resources (2009) when recognising the special environmental value of an ecosystem that has suffered damage as a result of pollution, the losses received increase by 1.5 times. Summarising the calculations, the total damage from hydrocarbon pollution was determined to be 143 thousand UAH.

The release of hydrocarbons into the aquatic ecosystem is an environmental disaster (Venesjarvi *et al.*, 2023), affects the state of mineralisation, specific electrical conductivity (Aluwong *et al.*, 2024), changes in water pH directly affect the survival, growth, and reproduction of fish species (Sahu *et al.*, 2024), because the suitable pH level for the growth and reproduction of fish species ranges from 6.0 to 9.0 (Mariu *et al.*, 2023). The behaviour of oil products in the aquatic environment is regulated by the processes of evaporation, sorption, spreading, biochemical and chemical oxidation, dissolution, biodegradation, dispersion, and sedimentation. Weak preparedness for natural disasters and regulatory mechanisms are also recorded, leading to serious hydrocarbon spills and their impact on the aquatic environment. In this context, in order to ensure a rapid and effective response to incidents of hydrocarbon spills in a particular area, the trajectories of their spills should be investigated, and the treatment should be carefully planned by decision support tools to eliminate emergency oil spills (Yang *et al.*, 2021).

A film on the surface of the water formed from oil residues or other lubricants and fuels prevents heat, water, and gas exchange between the water body and the atmosphere. This leads to carbon dioxide absorption, oxygen production, and the creation of primary products as a result of phytoplankton photosynthesis. The organic fraction in the pond rots when there is no oxygen, and this leads to a pestilence of fish. If the rotting organic fraction is not collected, a bacteriological threat arises. The oxidation of oil products in their natural state is very slow and requires a lot of oxygen, and they also pollute the entire water column at all horizons – on the surface as a film, in the thickness as a solution, and at the bottom as a heavy sediment. As for the surface contamination in the form of a film, studies conducted at the Burshtyn Reservoir, where the concentration of oil products exceeding environmental standards by 54 times was recorded, confirm the negative effects of hostilities that caused the destruction of the Kakhovka HPP dam in 2023 and the draining of the reservoir, discharges of pollutants with a concentration of 1.1-51.8 MPC and pollution of the estuary with an area of 6,800 km² of the system and the Black Sea, according to V. Pichura *et al.* (2024).

According to the research of V. Khilchevskiy *et al.* (2023), the content of petroleum products in the waters of the Dniester River is insignificant with a tendency to decrease average concentrations from spring flood to summer-autumn low water and to a minimum in winter low water. In the Hnyla Lypa River, where the Burshtyn Reservoir was created, and in other left-bank tributaries of the Dniester, the concentration of oil products during spring floods is 0.007 mg/dm³ (with a range of 0.004 to 0.015 mg/dm³ in different rivers), and in summer low

water 0.005 mg/dm³ (with a range of 0.002 mg/dm³ to 0.007 mg/dm³). In all the rivers and left-bank tributaries of the Dniester that were studied, the absence of oil products in the water was recorded in different years. Zero values of petroleum products were recorded in 75-80% of the water samples analysed.

As a result of research by S. Hughes *et al.* (2023) found that seasonality factors and morphological characteristics (shallow water, estuaries, bays) of the water body where the oil spill occurred are extremely important. The strength and direction of the wind has a significant impact on the spread of oil products on the water surface. During the visual assessment of the movement of oil products in the Burshtyn Reservoir, it was noted that shallow water and small bays (rugged coastline) significantly contribute to the presence and stagnation of oil products, the formation of oil slicks and their persistence in shallow water and inshore bays for a certain period of time. Regulatory processes for oil spills have a different impact on the scale of the disaster. The concentration of petroleum products and their derivatives in surface waters can significantly decrease and their chemical composition can change. An important indicator is the location of the pollutant source, mixing of water masses, and the quality of the natural water state. Changes in the types and nature of pollutants entering the reservoir change over time, which may be the reason for the increase in water pH observed in this study (from 6.5 pH to 7.5 pH), confirming the results of studies conducted in the Hirakud reservoir (Hussain *et al.*, 2020). Water environment factors, such as hardness, pH, salinity and alkalinity, affect the toxicity of heavy metals, zinc toxicity to aquatic organisms decreases with increasing water hardness (Li *et al.*, 2021), so the study of physicochemical properties of water, concentration of heavy metals is important for further research on water toxicity and its hydrochemical characteristics (Rychak & Arkhypova, 2024b). Prior to the hydrocarbon pollution, in the fall of 2023, a slightly polluted water quality class was observed at the accident site, where the concentration of oil products exceeded the MPC by up to 2 times, and where the water quality class was clean water, the concentration of oil products exceeded the MPC by 6 to 54 times.

The vulnerability of aquatic and terrestrial ecosystems to hydrocarbon pollution was calculated in monetary, quantitative, spatial, and high-resolution detail by assessing physical, biological, and socioeconomic indicators (Feng *et al.*, 2021). To ensure a fast and effective response to oil spill incidents in a particular area, the trajectory of the oil spill needs to be predicted and the clean-up needs to be carefully planned in advance. According to J. Neafie *et al.* (2024), scientists focus exclusively on physical sensitivity when studying the vulnerability of the coast and aquatic ecosystem to oil spills, thus neglecting socioeconomic factors. One explanation is that assessing the socio-economic impact of oil pollution is difficult due to the lack of proper reporting and monitoring. The proposed methods for calculating damages take into account the hazardousness of the pollutant, its concentration on the surface of the water body, in the water

column, location relative to the coastline, and the depth of the water body at the point of pollutant ingress. However, the methodology does not take into account socio-economic indicators, which are precisely the basis for the provision of ecosystem services (fisheries, tourism, cultural heritage). Studies by R. Venesjarvi *et al.* (2023) have shown that accidental oil pollution poses an additional threat to water systems, primarily in terms of oil-related losses and recovery potential. Aquatic and coastal ecosystems are regions of high biological productivity and accessibility, they have become centres of human activity, and provide important ecosystem services such as recreation, fisheries, and nutrient cycling. These ecosystems should be protected based on their conservation value, restoration potential and protection effectiveness. Vulnerability of aquatic and coastal ecosystems to oil spills is a measure of the level of sensitivity, impact and resilience of these areas in terms of biological, geological and socio-economic resources affected. Therefore, the determination of economic losses made it possible to estimate the losses caused by oil products.

✔ Conclusions

Military aggression has a very negative impact on the state of the water body. As a result of a single missile strike, rocket debris and fuel entered the Burshtyn Reservoir, which is part of the power plant's technological cycle and has the environmental status of a Ramsar site of international importance. It was found that a single missile strike led to the release of hydrocarbons into the reservoir, which exceeded the environmental standard by 54.5 times; the surface spread of oil products depends on the strength and direction of the wind and the ruggedness of the coastline. The combination of these factors indicates the maximum accumulation and increase in the concentration of hydrocarbon pollution. It was found that the water was within the permissible limits of environmental standards in terms of hardness and alkalinity. But with a water hardness of

7.6-7.8 mmol/dm³ there is a significant concentration of petroleum products, exceeding the maximum permissible concentration by 54 times, with a hardness of 9.0 mmol/dm³, the excess of petroleum products was up to 2 MPC.

It has been determined that among the six heavy metals contained in military missile fuels and lubricants, after hydrocarbon contamination, a significant cadmium content and a slightly lower iron content were found in the upper layers of surface waters. Other metals (zinc, manganese, copper, chromium) were at their lowest levels. The study determined that the dilution factor of contaminated water is 125.2. The amount of damages caused by violation of the legislation on the protection and rational use of water resources was calculated. In total, one missile attack caused economic losses of about 143 thousand UAH. It is necessary to continue researching water toxicity, conducting further studies of the state of the reservoir bottom sediments and microbiological studies, and research on the state of aquatic life to assess the full extent of missile aggression on artificial surface water bodies and to develop effective measures to minimise the negative effects. When calculating economic damages, take into account socio-economic factors that are the basis of ecosystem services not only for the aquatic ecosystem but also for the coastal ecosystem.

✔ Acknowledgements

Specialists of the Laboratory Control Department of Ivano-Frankivskvodoekotekhprom and the Educational and Research Laboratory of Analytical Environmental Studies of V.N. Karazin Kharkiv National University for conducting instrumental and laboratory research.

✔ Funding

None.

✔ Conflict of Interest

None.

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Екологічна оцінка впливу вуглеводневого забруднення на стан водойм-охолоджувачів

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✔ **Анотація.** Вуглеводневе забруднення залишається важливою та невирішеною проблемою, що загострилася під час повномасштабного вторгнення, зокрема через потрапляння уламків ракет зі значною кількістю нафтопродуктів у поверхневі води. Метою роботи було надати оцінку екологічного стану водного об'єкту, що зазнав вуглеводневого та інших нехарактерних забруднень. Польові методи: було відібрано 5 проб вод для визначення вмісту нафтопродуктів та величини рН та 5 проб вод для визначення фізичних властивостей, головних іонів та вмісту важких металів. Лабораторно-інструментальні: титриметричний – застосовано для визначення вмісту хлоридів, лужності, твердості. За результатами досліджень встановлено, що хлоридні іони знаходились у межах 264-274 мг/дм³, показники лужності – 3,6-5,5 ммоль/дм³. У результаті дослідження твердості встановлено, що води м'які. Фотоколориметричним методом визначався вміст нітритів (зафіксовано їх сліди). Вимірювання: електрометричним методом визначено величину рН. За результатами вода відноситься до нейтральних та слаболужних вод. Методом флуориметрії визначено вміст нафтопродуктів у межах 0,19-16,36 мг/дм³ (перевищення еконормативу в 54,5 рази). Методом модуляційної поляризаційної спектроскопії визначено вміст кадмію, цинку, мангану, купрум, хрому, феруму. Вміст хрому, кадмію, купрум знаходився у межах 0,001 мг/дм³, вміст мангану – від 0,001 мг/дм³ до 0,004 мг/дм³, вміст цинку – від 0,004 мг/дм³ до 0,008 мг/дм³, вміст феруму – від 0,004 мг/дм³ до 0,02 мг/дм³. За допомогою методу Руффеля визначено загальну кратність розведення стічної води на водосховищі, що становить 125,24. За методикою розрахунку розмірів відшкодування збитків був визначений збиток від вуглеводневого забруднення, який становить 143 тис. грн. Практична цінність роботи полягає у вдосконаленні наукових та практичних підходів щодо визначення стратегії проведення комплексного екологічного дослідження стану багатофункціональних штучних водних об'єктів

✔ **Ключові слова:** нафтопродукти; водосховище; екологічні нормативи; екологічний стан; кратність розведення води; економічні збитки