# Logging as an Environmental Risk for the Forest Environment

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**ABSTRACT**

This article aims to evaluate the impact of logging on water, soil, and vegetation in forest stands (736; 746 affected by logging and control area 400 — without logging) — and the occurrence of herbal synusia. The NES (non-polar extractable substances) indicator exceeded limits in all surface water samples. Thirty percent of the samples taken from Forest Stand 736 exceeded NES limits. In Stand 746, the ratio was 60 %. Forest area 400 remained under NES limits. Operating fluid leaks from transport-mechanization machines, pollution from older environmental loads, and the content of humic substances are possible reasons for the increased concentration of physic-chemical indicators. The NES content did not affect the number and coverage of species in the monitored areas. The EAI (Environment Accident Index, which utilizes knowledge about ecotoxicity) index method confirmed the environmental risk of logging in the forest environment.

**TANULMÁNY INFÓ**

*Kulcsszavak:*
Nem-poláros kivonható anyagok (NES)
Fakitermelés
Erdei környezet
Környezeti kockázat
Ökotoxikológia

**KIVONAT**

**A fakitermelés, mint környezeti kockázat az erdei ökoszisztémára.** Közleményünkben a fakitermelés hatását vizsgáltuk a vízre, a talajra valamint a fás- és lágyszárú növényzetre a fakitermeléssel érintett (736, 746) és kontroll (400) erdőterületeken. A nem poláros kivonható anyagok (NES) mutatója minden felszíni vízmintában meghaladta a határértéket. A talajminták NES értékei a 736-os erdőterületen 30 %-kal, míg a 746-os erdőterületen 60 %-kal haladták meg a határértéket. A 400-as erdőterületen a NES tekintetében nem volt határérték túllépés. A fizikai-kémiai paraméterek megnövekedett koncentrációjának oka lehet a szállító és fakitermelő gépekből történő üzemanyag és kenőanyag szivárgás, a régebbi környezeti terhelésekből visszamaradó szennyezés, valamint a minták humusz tartalma. A NES értékek nem befolyásolták a megfigyelt területeken található fajok számát és fedettségét. Az EAI (az ökotoxicitási indexek alapján számolt Környezeti Baleset Index) megerősítette a fakitermelés erdei környezetre gyakorolt hatásának környezeti kockázatát.

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## 1 INTRODUCTION

A forest is a specific complex ecosystem that is also a renewable natural resource, a producer of wood matter (production function of the forest), and a provider of ecosystem services. Logging — a vital activity in economic forests — affects the forest environment through transport-mechanization mechanisms (chainsaws, harvesters, forest rail tractors, and other machines) (www.lesy.sk 2018). Petroleum substances from operating fluids used in transport-mechanization machines (diesel, engine oil, transmission oil, hydraulic oil, and others) are a significant problem in forestry because they pollute the water. Concentrations of 0.1 $mg \cdot l^{-1}$ are enough to degrade water and make it undrinkable. Petroleum substances are poorly soluble in water and form water filters or insoluble emulsions on water surfaces. Toxicity depends on the degree of solubility. The more petroleum substances emulsify in water, the higher the toxicity (Hybská et al., 2017).

Oil substances on water surfaces cause oxygen deficits, reduce light access to the depths, and affect photosynthesis. Solar radiation absorption increases water temperature and endangers aquatic plant development, causing eutrophication (Nowak et al., 2019). Lighter, more volatile hydrocarbons contaminating the forest environment tend to evaporate. Sunlight oxidizes other photosensitive substances, causing density stratification and segregation in the water column, droplet condensation, and solidification (Zhang et al., 2019). Oil pollution also affects the physical properties of the soil — water evaporation decreases, and the hydrophobicity of soil aggregates increases. A greasy oil film on the soil surface restricts air circulation between the soil and the atmosphere. Soil particles coated with oil substances prevent the soil from "breathing," i.e., $CO_2$ escapes from the soil into the air (Błońska et al., 2016). It is also more difficult for water to soak into the soil and for plant roots to absorb water, causing plants to suffer from drought.

Oil pollution also changes the chemical properties of the soil — alkalinity increases, and the availability of nutrients (especially P and K) for plants decreases. Nutrient mobility decreases as their movement and dissolution in the soil solution become limited. The most significant effect of pollution is the deterioration of the biological properties of the soil. The content of petroleum substances in the range of 0.6–40 $mg \cdot kg^{-1}$ of soil is enough to alter the species composition of the microorganism community. The representation of species from the genera *Penicillium* and *Mortierella* increases at the expense of species from the genera *Streptomyces*, *Mucor*, and others. New species of *Aspergillus ustus* and *Penicillium tardum* are appearing (Chakravarty et al., 2022). The stabilization of organic contaminants due to interactions with hydrated iron and manganese oxides, clay minerals, and reactive $CaCO_3$ is, in principle, like the stabilization of "natural" organic substances naturally accumulating in the soil (Curiel-Alegre et al., 2022). The content of petroleum substances >270 $mg \cdot kg^{-1}$ of soil means the complete death of all microscopic organisms in the soil. After that, the contaminated soil requires radical rehabilitation. Even 10 ml of oil substances per kg of soil has a significantly negative effect on the soil macrofauna, and 20 ml will destroy all types of fauna in the soil. Oil substances with a concentration of >50 $ml \cdot kg^{-1}$ are toxic to plant roots and will cause a significant reduction in seed germination (Curiel-Alegre et al., 2022).

Plant species are resistant to the effects of petroleum hydrocarbons and can survive in polluted soils (petrophilic species: *Phragmites australis. Calamagrostis epigejos, Carex hirta, Bromus tectorum, Elytrigia repens, Lolium perenne, Dactylis glomerata, Deschampsia cespitosa, Agrostis stolonifera, Melilotus albus, Lotus corniculatus, Artemisia vulgaris, Medicago lupulina, Solidago canadensis, Cirsium arvense, Rubus caesius, Conyza canadensis, Urtica dioica, Galium aparine)* (Ollerová, 2004; Hybská et al., 2015; Bakina et al., 2021).

This article discusses the influence of selected chemical substances, determined as non-polar extractable substances, on the forest environment via the logging process.

## 2 MATERIALS AND METHODS

### 2.1 Characteristics of research sites

The research sites are in the Kremnické vrchy (Hills) mountain range, in Slovakia Two sites represent forest stands affected by logging, while the third is a control. From the phytocoenological point of view, these forest stands are classified as mesotrophic forest communities with beech dominance, occurring on deep soils of temperate Europe (*Fagion sylvaticae* Luquet 1926). More specifically, they belong to the association *Dentario bulbiferae-Fagetum sylvaticae* Mikyška 1939 nom. Invers. Concerning tree species representation, *Fagus sylvatica* dominates (50–75 %) in all sites. Other tree species are present to a lesser extent, including *Acer pseudoplatanus* (5–15 %), *Fraxinus excelsior* (3–10 %), *Picea abies*, and *Abies alba* (less than 10 %). Beech-stand ages on the control plot (No. 400) and plots 736 and 746 are 150 years, 110 years, and 95 years, respectively. The individual sites are similar in tree species occurrence and herb layer but differ in age. The soil type is cambisol.

### 2.2 Collection and preparation of samples

Soil sampling was from the area marked on the map Figure 1, as an area for phytocenological releves. Water samples were taken from the closest possible place to this surface.

Samples of soil and water were taken according to STN EN ISO 5667-1 (2006) and STN 48 1000 (2000) in the sense of the monitoring plan in the period from May 2021 to December 2022 on defined areas in forest stands:

No. 400: the control area, 8.09 ha, without logging, GPS 48.66060446313148, 19.03239290173866 (*Figure 1a*);
No. 736: the area with active logging, 21.18 ha, GPS 48.65188844667602, 19.023738640149453 (*Figure 1b*);
No. 746: the area with active logging, 16.66 ha, GPS 48.640456234455556, 19.018261886120037 (*Figure 1c*).

Soils were sampled from a depth of 0–10 cm into plastic bags. The weight of a soil sample was at least 1 kg. Plastic containers with volumes of 1.5 l and 1 l glass containers were used for sampling surface water at the Breznický Stream and the spring Bieň Stream. According to the map portal (www.zbgis.skgeodesy.sk), the monitored streams are as follows:

Breznický Stream: hydrological character – year-round; origin of the hydrographic object: natural, native; the stream is unnavigable on the terrain surface and is 2023 m long.
Bieň Stream: hydrological character – occasional; origin of the hydrographic object: natural, native; the stream is unnavigable on the terrain surface and is 524 m long.

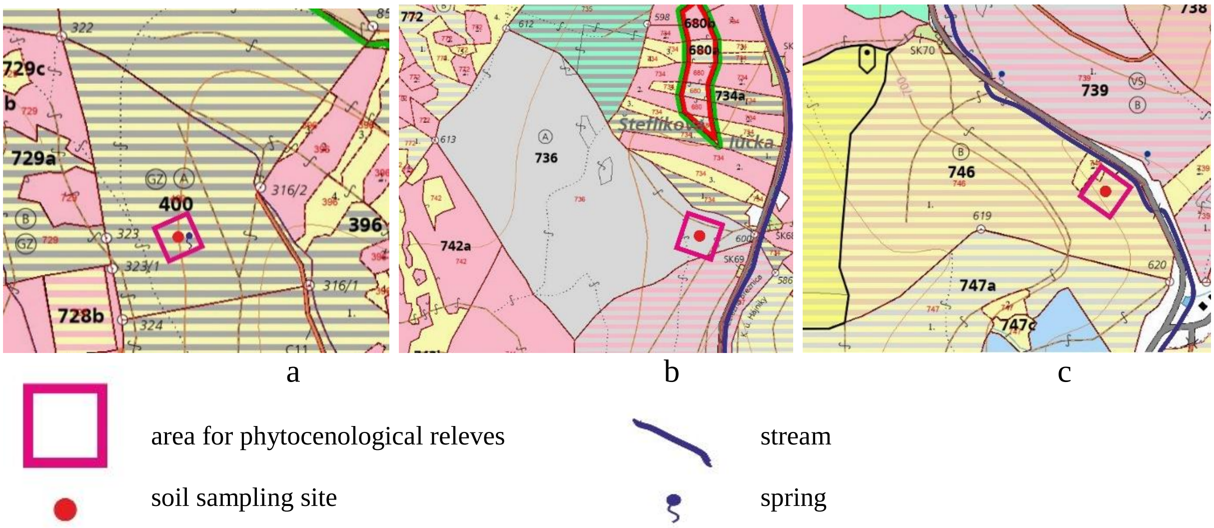


*Figure 1. Forest stand: a – 400, b – 736, c – 746 (www.gis.nlcsk.org)*

## 2.3 Principles of determination in surface water samples

Indicators determined in surface water samples: pH, conductivity, chemical oxygen demand by potassium dichromate (COD-Cr), non-polar extractable substances (NES), and biochemical oxygen consumption ($BOD_5$).

*The chemical oxygen demand (COD-Cr)*
Chemical oxygen demand is defined as the oxygen mass concentration, which is equivalent to the mass of the strong oxidation agent consumed under well-defined conditions of sample processing for the oxidation of the substances in 1 L of water. Potassium dichromate ($K_2Cr_2O_7$) is used as a reagent to determine the COD, in accordance with the ISO standard 8467 (2000).

*The biological oxygen determination ($BOD_5$)*
Biochemical oxygen consumption ($BOD_5$) is the amount of oxygen consumed by microorganisms for the biochemical decomposition of organic substances contained in water for five days under specified conditions, in accordance with the STN EN 1899-2(2001). Used device: oximeter WTW Oxi 340i, StirroxOxG.

*Determination of the pH*
The pH value significantly affects the chemical and biochemical reactions in water. A SenTix 81 electrode pH meter (WTW GmbH, Weilheim, Germany) was used to determine the pH: WTW GmbH, Weilheim, Germany InoLab pH Level 3 in accordance with the ISO standard 10523 (2008).

*Conductivity determination*
Conductivity is a basic criterion for assessing the number of electrolytes present in water. The determination of conductivity reflects the concentration of dissolved substances in the form of ions and water mineralization. A WtW LF 318 conductometer (GmbH, Weilheim, Germany) was used to determine the conductivity in accordance with the STN EN standard 27888 (1998).

*NES determination*
Oil substances in soil were determined as non-polar extractable substances (NES) using a spectrophotometer in an infrared area by the extraction with organic diluent (S-316 – polychlorotrifluoroethylene). The detection limit of NES was 0.15 $mg \cdot l^{-1}$. An artificial mixed

standard from compounds was prepared to control the measurement: methylbenzene, hexadecane, and pristane (2,6,10,14-tetramethylpenthadekane). The measurement was taken on an infrared spectrophotometer FTIR ATI MATTSON GENESIS (STN 83 0530-36: 1981).

## 2.4 Principles of determination of selected indicators in soil samples

Dry matter, pH/H2O, and non-polar extractable substances (NES) indicators were determined in forest soil samples. An InoLab Terminal level 3 - pH meter was used to measure pH/$H_2O$ in the soil using a SenTix 41 pH electrode (WTW, Germany). (STN ISO 10390: 2005).

Dry matter was determined gravimetrically by drying to a constant weight at 105°C (STN ISO 11465:2001).

Non-polar extractable substances (NES): The NES content in the samples was determined after extraction in a solvent (S 316) and analysis in the IR spectrum 2960 $cm^{-1}$, 2925 $cm^{-1}$, 3055 $cm^{-1}$ (ATI MATTSON GENESIS SERIES FTIR instrument). The detection limit of NES was 0.02 $mg \cdot l^{-1}$. The measurement was checked using an artificial mixed standard (description is in section Principles of determination in surface water samples – NES determination). The calculation was performed according to the Lambert-Beer law, while the necessary constants were obtained by measuring the calibration curves for the relevant standards or by calculation methods (TNI ISO/TR 11046: 2003).

## 2.5 Calculation of the EAI index (Environment Accident Index)

The EAI index result determines the further evaluation procedure. The EAI index is calculated according to the relationship:

$$EAI = Tox \times Am \times (Con + Sol + Sur), \text{ where}$$

Where:

| | |
|---|---|
| Tox: | acute toxicity for aquatic organisms ($mg \cdot l^{-1}$) |
| Am: | stored/transported quantity (t) |
| Con: | kinematic viscosity of the substance (cSt) |
| Sol: | solubility of the substance (wt. %) |
| Sur: | expresses the characteristics of the environment (distance to the nearest watercourse, depth of groundwater, gradient of groundwater, thickness of soil above groundwater). |

For a detailed assessment of environmental risks, it is recommended to consider all scenarios with an EAI index value > 100. For scenarios with an EAI value ≤100, the primary assessment of environmental risks is sufficient, and it is not necessary to take further measures in the form of a detailed risk assessment (according to the law of the Slovak National Council of the Republic No. 359/2007 Coll.).

Several authors (Scott, 1988; Pahl et al., 2005; Scott et al., 2007; Sikorova et al., 2017) document the use of EAI, but its use for impact assessment in the forest has not been published. The following sources were used for the calculation: Hybská (2018), MSDS of Cartechnic Hydrauliköl HLP 46, and maps of the locality.

## 2.6 Vegetation research

Phytocoenological records were used to study the vegetation and create a database of plant species occurring in the studied area, according to which syntaxonomic, synmorphological, and synecological characteristics of plant communities were developed. The recording areas were accorded with the soil sampling points for determining the NES. Phytocoenological records were conducted based on the principles of the Zurich-Montpellier school according to Braun-Blanquet (1964) and were completed three times in the growing seasons of 2021 and 2022, in the spring, summer, and autumn aspects on an area of 400 m$^2$. Qualitative and quantitative characteristics were observed within the records:

- Qualitative characteristics of plant coenoses represent a set of all species that occurred in the investigated area. The names of plant taxa are given according to Marhold and Hindák (1998).
- From the quantitative characteristics, the coverage estimate was evaluated using the combined seven-item scale of abundance and dominance according to Braun-Blanquet (1964).

The entries were processed in the Turboveg program into the database and subsequently exported and edited into tables in MS Excel. In the research areas, we obtained information about the biodiversity of herbaceous synusia in the forest stand.

## 3 RESULTS AND DISCUSSION

### 3.1 Surface water monitoring

NES, pH, conductivity, BOD5, and COD-Cr were determined. The Government of the Slovak Republic Regulation No. 269/2010 Coll., which establishes requirements for achieving good water status, was used for results evaluation.

Surface water samples were taken from small water sources and streams flowing near handling areas and unpaved roads in Stands 736 and 746. Water was not sampled in August and September 2022 due to the influence of weather conditions (high temperatures, extreme dryness), which dried out the streams. The Bieň Stream, from which the water samples were taken, originated in forest stand 400.

Conductivity and pH in samples from forest stand 736 comply with the Government of the Slovak Republic Regulation No. 269/2010 Coll. limits. NES limits were exceeded in samples during all samplings. BOD5 does not meet limit concentrations in 36 % of all samples. The results from the determination of COD-Cr do not show exceeding the limit (*Table 1*). The increased concentrations of NES and BOD5 were caused by the impact of the ongoing mining in 2022. Hybská (2010) monitored the same physicochemical indicators in surface water in Forest Stand 736. Due to the impact of the ongoing mining in the following years, we found that the water pollution in the stream increased in the monitored area, as noted in *Table 1*.

*Table 1. Monitoring of surface water in Forest Stand 736*

| Forest stand No. | Date of sampling | Parameters | | | | |
|---|---|---|---|---|---|---|
| | | pH | Conductivity [mS·cm$^{-1}$] | NES [mg·l$^{-1}$] | $BOD_5$ [mg·l$^{-1}$] | $COD_{Cr}$ [mg·l$^{-1}$] |
| 736 | 08.07.2021 | 7.56 | 1.14 | 0.37±0.03 | 1.32 | 2.21±0.04 |
| | 20.09.2021 | 7.45 | 1.96 | 0.25±0.07 | 0.54 | 5.47±0.27 |
| | 26.10.2021 | 7.29 | 0.15 | 0.5±0.07 | 0.88 | 7.04±0.88 |
| | 10.11.2021 | 8.44 | 1.48 | 0.25±0.03 | 0.47 | 6.21±0.04 |
| | 15.02.2022 | 7.47 | 0.55 | 0.15±0.06 | 0.58 | 1.24±0.08 |
| | 14.03.2022 | 7.35 | 1.32 | 1.85±0.03 | 5.32 | 15.54±0.06 |
| | 26.04.2022 | 6.71 | 1.09 | 1.72±0.04 | 7.55 | 12.02±0.10 |
| | 24.05.2022 | 7.61 | 1.10 | 1.91±0.03 | 8.43 | 15.28±0.16 |
| | 13.06.2022 | 8.22 | 0.10 | 2.29±0.01 | 13.13 | 10.02±0.08 |

| Forest stand No. | Date of sampling | Parameters | | | | |
|---|---|---|---|---|---|---|
| | | pH | Conductivity [mS·cm-1] | NES [mg·l-1] | BOD5 [mg·l-1] | CODCr [mg·l-1] |
| | 28.07.2022* | - | - | - | - | - |
| | 24.10.2022 | 7.49 | 0.13 | 2.6±0.03 | 8.73 | 17.05±0.09 |
| | 12.12.2022 | 7.51 | 1.79 | 1.51±0.04 | 6.43 | 18.02±0.04 |
| Indicators** | | 6-8.5 | <110 | <0.1 | <7 | <35 |

* *Water sources were dried up due to high temperatures.*

** *The Government of the Slovak Republic Regulation No. 269/2010 Coll., which establishes requirements for achieving good water status.*

*Table 2* lists the surface water monitoring values in Forest Stand 746. The pH and conductivity indicators were satisfactory compared to the limit concentrations. NES limits were exceeded compared to the declared limit during the entire monitoring period. $BOD_5$ did not comply in 40 % of samples, and COD-Cr was <35 mg/l; the values were within tolerance. We note that the ongoing mining influences the water quality in the Breznický Stream.

*Table 2. Monitoring of surface water in the Forest Stand 746*

| Forest stand no. | Date of sampling | Parameters | | | | |
|---|---|---|---|---|---|---|
| | | pH | Conductivity [mS·cm-1] | NES [mg·l-1] | BOD5 [mg·l-1] | CODCr [mg·l-1] |
| 746 | 08.07.2021 | 7.57 | 1.37 | 2.07±0.03 | 6.01 | 12.26±0.09 |
| | 20.09.2021 | 7.21 | 0.60 | 2.54±0.01 | 8.38 | 17.29±0.19 |
| | 26.10.2021 | 7.38 | 1.86 | 2.83±0.03 | 9.15 | 18.04±0.07 |
| | 10.11.2021 | 7.14 | 1.95 | 2.01±0.03 | 5.38 | 14.36±0.16 |
| | 15.02.2022 | 7.19 | 2.95 | 5.03±0.03 | 10.54 | 21.25±0.04 |
| | 14.03.2022 | 7.17 | 0.86 | 2.04±0.03 | 8.41 | 11.33±0.09 |
| | 26.04.2022 | 6.69 | 0.26 | 0.83±0.01 | 1.64 | 7.06±0.09 |
| | 24.05.2022 | 7.35 | 0.52 | 0.46±0.03 | 0.98 | 6.25±0.04 |
| | 13.06.2022 | 7.26 | 0.25 | 1.46±0.04 | 3.08 | 8.05±0.01 |
| | 28.07.2022* | - | - | - | - | - |
| | 24.10.2022 | 7.20 | 0.15 | 1.12±0.02 | - | - |
| | 12.12.2022 | 7.39 | 0.84 | 1.63±0.04 | 4.24 | 7.06±0.01 |
| Indicators** | | 6-8.5 | <110 | <0.1 | <7 | <35 |

* *Water sources were dried up due to high temperatures.*

** *The Government of the Slovak Republic Regulation No. 269/2010 Coll., which establishes requirements for achieving good water status.*

Lindén and Palsson (2013) found up to 900 times the concentration of NES (7420 $\mu g \cdot l^{-1}$) compared to World Health Organization (WHO) recommendations when monitoring surface waters in Nigeria. The dissolved oxygen content ranged from 1.5 to 6.9 $mg \cdot l^{-1}$, depending on the water flow and aquatic flora. Salinity and conductivity ranged from 3.0 $\mu S \cdot cm^{-1}$ to 27,600 $\mu S \cdot cm^{-1}$. They report an active soil reaction (pH) between 4.7 and 7.3 and an average of 6.1.

Moslen and Aigberua (2018) found the total content of petroleum hydrocarbons in surface waters near oil refinery storages in Nigeria to be 20.34±1.79 - 27.40±5.32 $mg \cdot l^{-1}$.

In their work dealing with the contamination of surface and groundwater due to oil extraction, Raimi et al. (2021) report a biological oxygen demand of 3.8 $mg \cdot l^{-1}$ and an acidic pH for all surface water samples as evidence of the presence of oil pollution.

*Table 3. Monitoring of surface water in the Forest Stand 400*

| Forest stand no. | Date of sampling | Parameters | | | | |
|---|---|---|---|---|---|---|
| | | pH | conductivity [mS·cm$^{-1}$] | NES [mg·l$^{-1}$] | $BOD_5$ [mg·l$^{-1}$] | $COD_{Cr}$ [mg·l$^{-1}$] |
| 400 | 08.07.2021 | 6.95 | 0.95 | 0.04±0.01 | 0.36 | 0.98±0.01 |
| | 20.09.2021 | 6.58 | 1.95 | 0.05±0.01 | 0.44 | 1.00±0.03 |
| | 26.10.2021 | 6.27 | 0.21 | 0.08±0.01 | 0.57 | 1.09±0.01 |
| | 10.11.2021 | 7.01 | 0.99 | 0.13±0.01 | 0.87 | 1.21±0.01 |
| | 15.02.2022 | 7.24 | 0.98 | 0.10±0.71 | 0.71 | 1.15±0.01 |
| | 14.03.2022 | 6.85 | 2.12 | 0.08±0.01 | 0.67 | 1.08±0.01 |
| | 26.04.2022 | 6.84 | 0.09 | 0.07±0.01 | 0.59 | 1.01±0.02 |
| | 24.05.2022 | 8.21 | 0.15 | 0.04±0.01 | 0.43 | 0.96±0.01 |
| | 13.06.2022 | 7.49 | 0.11 | 0.04±0.01 | 0.42 | 0.97±0.03 |
| | 28.07.2022* | - | - | - | - | - |
| | 24.10.2022 | 7.50 | 0.09 | 0.07±0.03 | 0.58 | 1.01±0.03 |
| | 12.12.2022 | 7.72 | 0.94 | 0.08±0.01 | 0.66 | 1.08±0.01 |
| Indicators** | | 6-8,5 | <110 | <0,1 | <7 | <35 |

* *Water sources were dried up due to high temperatures.*
** *The Government of the Slovak Republic Regulation No. 269/2010 Coll., which establishes requirements for achieving good water status.*

The samples complied with the limit parameters resulting from the legislation at control site 400 (*Table 3*). The graph (*Figure 2*) confirms the impact of oil pollution from logging on water quality. The impact of logging (*Tables 6 and 7*) confirms the load of oil pollution on water.

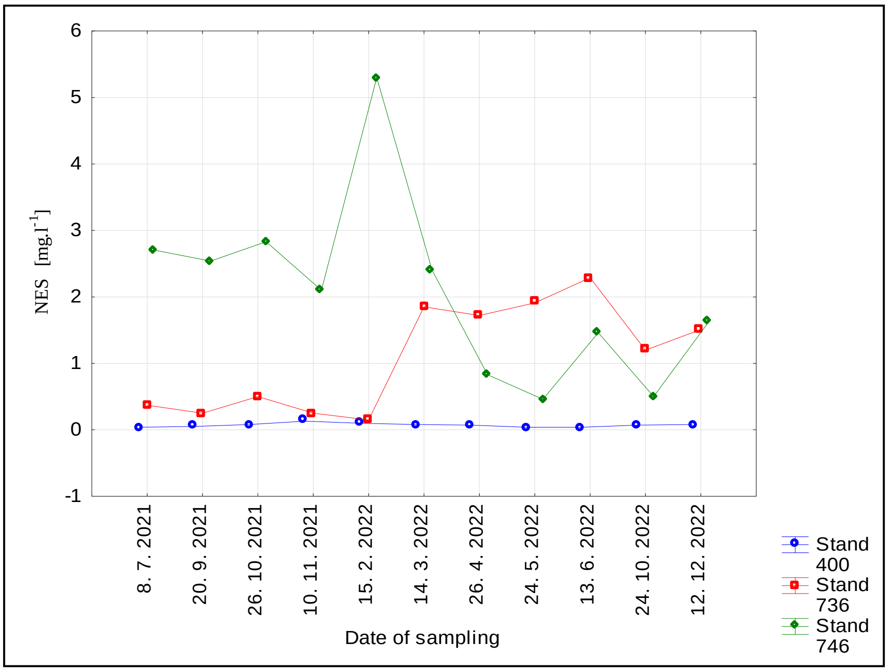


*Figure 2. Water pollution due to logging in monitored stands*

## 3.2 Monitoring of forest soils

NES content monitoring and physicochemical parameter analysis in soil and surface water were performed in samples from forest stands with different logging intensities. Forest Stand 400 was a control area, without intervention (no logging), and Stands 736 and 746 were designated as areas with active logging. *Tables 4*, *5*, *7*, and *Figure 3* show the sample analysis results. Based on Decree No. 59/2013 Coll. on the protection and use of agricultural land, the limit value of NES in agricultural land is 100 mg·kg$^{-1}$ of dry matter. NES results in *Table 4* stay within the limit, confirming that there are no operations related to wood harvesting or other activities in Forest Stand 400 that could result in increased NES content.

*Table 4. Forest soil monitoring in Forest Stand 400*

| Date of sampling | Parameters | | |
|---|---|---|---|
| | pH | Dry matter [%] | NES [mg·kg$^{-1}$] of dry matter |
| 08.07.2021 | 6.73 | 94.88 | 10.12±0.04 |
| 20.09.2021 | 6.91 | 96.76 | 14.24±0.03 |
| 26.10.2021 | 5.91 | 93.76 | 10.59±0.04 |
| 10.11.2021 | 5.68 | 96.73 | 8.97±0.06 |
| 15.02.2022 | 6.40 | 98.23 | 2.54±0.07 |
| 14.03.2022 | 5.64 | 97.63 | 2.41±0.06 |
| 26.04.2022 | 5.50 | 97.23 | 7.25±0.10 |
| 24.05.2022 | 6.20 | 86.36 | 16.19±0.14 |
| 13.06.2022 | 6.98 | 87.45 | 5.28±0.07 |
| 28.07.2022 | 5.66 | 92.10 | 2.16±0.07 |
| 24.10.2022 | 5.91 | 95.69 | 5.84±0.04 |
| 12.12.2022 | 8.03 | 96.30 | 5.11±0.03 |

Sáňka and Materna (2004) notes the active soil reaction (pH) that is valid for all types and horizons of forest stands and classifies these into five classes. We classify them in the fourth class of soil with an acidic pH (5.6–6.5), in the fifth class of slightly acidic to neutral soil (6.6–7.2), and finally in the sixth class of alkaline soil with a pH above 7.2. Based on this classification, the pH results in *Table 3* ranged between 5.5 and 8.03. Soils from Forest Stand 400 showed strongly acidic, acidic, slightly acidic – neutral to alkaline pH.

*Table 5. Forest soil monitoring in Forest Stand 736*

| Date of sampling | Parameters | | |
|---|---|---|---|
| | pH | Dry matter [%] | NES [mg·kg$^{-1}$] of dry matter |
| 08.07.2021 | 4.84 | 95.12 | 32.22±1.41 |
| 20.09.2021 | 5.68 | 96.86 | 77.51±0.08 |
| 26.10.2021 | 5.60 | 96.27 | 85.45±0.01 |
| 10.11.2021 | 6.69 | 96.16 | 36.24±0.04 |
| 15.02.2022 | 6.09 | 96.76 | 119.14±1.48 |
| 14.03.2022 | 6.94 | 97.35 | 120.25±0.13 |
| 26.04.2022 | 6.09 | 97.16 | 85.35±0.24 |
| 24.05.2022 | 6.98 | 82.42 | 74.14±0.14 |
| 13.06.2022 | 6.48 | 89.05 | 55.45±0.11 |
| 28.07.2022 | 5.64 | 93.70 | 45.54±0.04 |
| 24.10.2022 | 6.18 | 98.02 | 132.64±0.11 |
| 12.12.2022 | 5.57 | 98.02 | 154.41±0.04 |

Based on the overview of wood harvesting in Forest Stand 736 (*Table 6*), 500 $m^3$ of woody plants were harvested during the monitoring period 2021–2022, of which 11 $m^3$ were coniferous and the remaining 489 $m^3$ were deciduous.

*Table 6. Overview of timber harvesting in Forest Stand 736 (www.gis.nlcsk.org)*

| Year | Wood [$m^3$] | | Together [$m^3$] |
|---|---|---|---|
| | Coniferous | Deciduous | |
| 2014 | 256 | 380 | 636 |
| 2015 | 272 | 250 | 522 |
| 2016 | 68 | 192 | 260 |
| 2017 | 0 | 24 | 24 |
| 2019 | 174 | 190 | 364 |
| 2020 | - | - | - |
| 2021 | - | - | - |
| 2022 | 11 | 489 | 500 |

In Forest Stand 736 (*Table 5*), 30 % of the samples exceeded the limit values compared to Decree No. 59/2013 Coll. on the protection and use of agricultural land. According to Sáňka and Materna (2004), the soil pH values were strongly to slightly acidic, ranging from 4.84 to 6.98.

*Table 7. Forest soil monitoring in Forest Stand 746*

| Date of sampling | Parameters | | |
|---|---|---|---|
| | pH | Dry matter [%] | NES [$mg \cdot kg^{-1}$] of dry matter |
| 08.07.2021 | 5.34 | 93.99 | 50.54±0.10 |
| 20.09.2021 | 5.34 | 95.96 | 122.14±0.03 |
| 26.10.2021 | 5.74 | 95.10 | 135.25±0.16 |
| 10.11.2021 | 5.46 | 98.30 | 127.84±0.07 |
| 15.02.2022 | 5.92 | 98.30 | 137.97±0.04 |
| 14.03.2022 | 5.93 | 96.93 | 125.47±0.16 |
| 26.04.2022 | 5.92 | 96.30 | 105.65±0.06 |
| 24.05.2022 | 5.99 | 93.36 | 57.87±0.06 |
| 13.06.2022 | 6.15 | 93.44 | 57.47±0.17 |
| 28.07.2022 | 6.16 | 94.43 | 34.58±0.03 |
| 24.10.2022 | 5.58 | 95.13 | 65.96±0.04 |
| 12.12.2022 | 5.66 | 92.99 | 70.47±0.08 |

In Forest Stand 746 (*Table 8*), 796 $m^3$ of woody plants were harvested during the 2021–2022 monitoring period, of which 212 $m^3$ were coniferous and 584 $m^3$ deciduous.

*Table 8. Overview of timber harvesting in Forest Stand 746 (www.gis.nlcsk.org)*

| Year | Wood [$m^3$] | | Together [$m^3$] |
|---|---|---|---|
| | Coniferous | Deciduous | |
| 2014 | 221 | 245 | 466 |
| 2015 | 196 | 477 | 673 |
| 2017 | 450 | 612 | 1062 |
| 2020 | 0 | 29 | 29 |
| 2021 | 108 | 579 | 687 |
| 2022 | 104 | 5 | 109 |

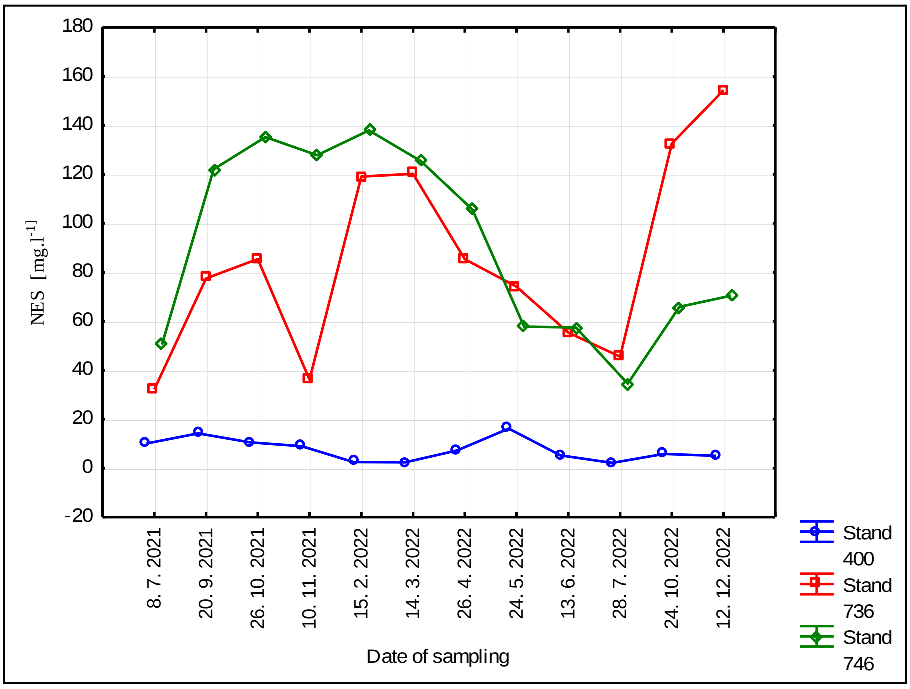


*Figure 3. Soil pollution due to logging in the monitored stands*

The NES limit value was exceeded in 50 % of the analyzed samples in Forest Stand 746. We conclude that the increased NES contents were related to logging intensity (*Table 7*). According to Sáňka and Materna (2004), the pH results in *Table 7* are sorted into the classification classes of strongly acidic, acidic, slightly acidic-neutral, and alkaline, in total, ranging from 5.34 to 6.16.

Klamerus-Iwan et al. (2015) monitored the influence of operating oils of petroleum origin on physical and biological processes in forest soil and stated that forestry work using transport-mechanization mechanisms causes annual leakages of up to 7 million liters of various mineral oils into forest soils. These oils are toxic and affect various biological and physical processes in the soil environment. They also found that soil contaminated by petroleum substances at concentrations of 100 $g \cdot m^{-2}$ of soil will reduce the porosity of soils by 4 %, and at concentrations of 200 $g \cdot m^{-2}$, reduce soil breathability by 10 %. Increased concentrations of mineral oils increase soil hydrophobicity and affect enzyme activity. The lowest amount of oil (50 $g.m^{-2}$ of soil) causes only a slight decrease in urease activity, but 100 and 200 $g.m^{-2}$ of soil reduce it by 40-50 % compared to the control area (area without pollution).

Buzmakov et al. (2019) found that coniferous and deciduous forest ecosystems are less susceptible to oil pollution. Their studies found that forest soil becomes acutely toxic (bioassay with test organisms *Daphnia magna* Straus) at oil concentrations above 200 $g.kg^{-1}$ soil for animals.

Acidic to neutral pH characterizes most forest soils. Rather et al. (2022) noted higher pH (6.797 ± 0.136) and electrical conductivity (0.286 ± 0.028) in the polluted area in contrast to the undisturbed area with a pH (5.39 ± 0.230). The increased pH in the deforested and affected forest zone disrupts the natural habitats of flora and fauna and reduces the amount of organic material, leading to the spread of bare and disturbed forests. Increased pH can also mitigate soil organic residues, causing the flow of organic acids into the soil solution. Increased pH and electrical conductivity in disturbed forest stands are attributable to poor forest vegetation cover.

### 3.3 Characteristics of vegetation on monitoring areas affected by economic activity (mining)

In 2021, the number of species in the herbaceous layer in the monitored areas ranged from 11 to 31 at the time of optimal vegetation development (summer aspect). In 2022, during the summer aspect, the number of species was lower than the previous year, in the interval from 6 to 13. In both years, the number of species logically decreased from the spring to the autumn aspect.

In the mining-affected area (746), we recorded the highest number of species, 31, in the summer of 2021. The area was illuminated after mining, and the increased light caused the occurrence of a higher number of species. In 2022, the number of species dropped to 13, which is more than a 50% reduction. The species missing include, *Rubus fruticosus* agg., *Rubus idaeus, Asarum eurapaeum, Carex 34ilosa, Fragaria vesca, Hypericum maculatum, Prenanthes purpurea, Prunesla vulgaris, Urtica dioica, Epilobium montanum, Cerastium holosteoides, Mentha longifolia, Poa nemoralis, Ranunculus repens, Actea spicata, Senecio vulgaris, Sonchus arvensis, Stachys sylvatica,* and *Plantago media*.

We recorded fewer species in the second area (736). In 2021, the number of species was 25, and in 2022 it was 12. Again, less than half. Species missing included, *Rubus fruticosus* agg.*, Rubus idaeus, Euphorbia amygdaloides, Asarum eurapaeum, Fragaria vesca, Hypericum maculatum, Prunesla vulgaris, Glechoma hederacea, Scrophularia nodosa, Senecio nemorensis, Stachys sylvatica, Plantago media, Equisetum sylvaticum, Lycopus europaeus, Melittis melissophyllum, Mycelis muralis, Stellaria media,* and *Veronica prostrata.*

We observed the lowest number of species in the control area unaffected by logging – 11 in 2021 and 6 in 2022.

A few factors — climatic, soil, ecological, economic, and cultivation — influence the downward trend in the number of species in the areas between two years. The monitored research period is very short from the point of view of vegetation assessment, and more vegetation periods are needed to assess and evaluate vegetation development trends.

The coverage of the herbaceous layer varied from 10 % to 60 % in all areas in the observed period. We recorded 74 species in total on the E1 floor. The vegetation in the areas is relatively species-poor, which corresponds to communities from the *Fagion sylvaticae* association. This union brings together the most widespread climax communities of mesotrophic to eutrophic mesophilic beech trees in Western and Central Europe. Communities are linked to cambism with balanced nutrient content and favourable humification.

Stand 746 reached 60 % coverage in E1 in the first year of monitoring and 50 % at the same time in the second year. Stand 736 reached 30 % coverage in 2021 and 40% in 2022. The coverage did not change significantly even at the control site, reaching values of 10 % and 20 %. However, these are the lowest coverage values of all monitored areas.

The herbaceous species with the highest stability are *Galium odoratum, Rubus fruticosus* agg., *Salvia glutinosa,* and *Dryopteris filix-mas*. The species *Dentaria bulbifera, Galium odoratum, Rubus fruticosus* agg., and juvenile individuals of *Fagus sylvatica* achieve the highest abundance and coverage. Of the shrubs, *Fagus sylvatica, Fraxinus excelsior, Picea abies,* and *Acer platanoides* represent the highest stability and coverage. *Fagus sylvatica*, forest beech, is the growth edifier in all of the areas. In addition to the dominant beech, *Fraxinus excelsior, Picea abies, Abies alba,* and *Acer pseudoplatanus* are represented in E3.

The plant community in the monitored areas belongs to the association *Dentario bulbiferae-Fagetum sylvaticae* Mikyška 1939 nom. Inverse. The community does not have a high number of species, which is also confirmed by the control area. Economic stands have a simple vertical structure, with no canopy layer under the beech canopy, or the layer consists of young beech and several other species. *Dentaria bulbifera* mainly achieves a higher coverage in the spring aspect. Only sciophyte (shade-loving) geophytes with special adaptations to these conditions (vegetative reproduction, mycorrhiza, heterotrophy) — *Dentaria bulbifera, Neottia nidus-avis, Epipactis helleborine, Monotropa hypopitys* — often prevail in heavily shaded undergrowth and on the thick layer of litter. Permanent species with low abundance values are usually the most common species of mesotrophic beech trees of the *Fagetalia sylvaticae* family – *Galium odoratum, Mycelis muralis, Dryopteris filix-mas, Viola reichenbachiana* (Valachovič et al. 2021). We also recorded these species in the monitored areas.

The intense competitive pressure the dominant tree exerts limits the development of the herbaceous layer, especially on the northern slopes of lower mountain positions or in the rain shadow. The relatively smaller amount of precipitation can only effectively use the surface root system of beech, and the competition of roots in the rhizosphere of herbs is the main explanation for the existence of nodal types (Slavíková et al., 1986; Barna et al., 2011).

When evaluating the ecological requirements, we can state that the species with the highest stability represented in the research areas are mesotrophic. According to soil moisture, these are moist soil types. The species are neither significantly drought-loving nor moisture-loving. According to the soil reaction, these are plants that like weakly acidic to neutral soils, and according to the nitrogen supply in the soil, they are moderately nitrophilous species.

Dependence was not confirmed. NES content in soil and surface water did not affect vegetation — the number and coverage of species in the monitored areas. The amount of NES was the lowest in the control plot, which was not affected by logging. At the same time, the lowest number of species was also recorded here, influenced by the abovementioned factors (canopy, light conditions, and fallow height).

### 3.4 Determination of the EAI index

The EAI index method used in environmental risk assessment depends primarily on the amount of hazardous substances that can escape into the environment. Economic activities in the forest, such as logging, should be performed in a way that causes no changes in biodiversity, water quality deterioration, and soil composition. The proposed scenarios result from engineering approaches that aim to clearly describe the qualitative and quantitative causality of the respective scenario.

Three scenarios were chosen to determine the EAI for operating fluids that can escape into the natural environment from three different mechanisms: Zetor 7245, LKT 81 ITL, HSM 805 (traffic accident (damage to the tank with the operating fluid), leakage, and equipment neglect).

Scenario 1: leakage of the entire volume of operating fluid from the tank
Scenario 2: leakage of 1/2 volume of operating fluid from the tank
Scenario 3: leakage of 1/3 of the volume of operating liquid from the tank.

*Table 9. Results of the EAI index of operating fluids Zetor 7245, LKT 81 ITL, HSM 805*

| Oil | Tox | Am | Con | Sol | Sur | EAI index | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Scenario 1 | Scenario 2 | Scenario 3 |
| hydraulic oil | 6 | 1 | 3 | 2 | 7 | 72 | 72 | 72 |
| diesel fuel | 4 | 1 | 4 | 2 | 7 | 52 | 52 | 52 |
| motor oil | 2 | 1 | 3 | 2 | 7 | 24 | 24 | 24 |
| gear oil | 2 | 1 | 3 | 2 | 7 | 48 | 48 | 48 |

Mechanisms move on unpaved surfaces and use operating fluids, including diesel fuel, engine oil, hydraulic oil, and gear oil. The calculated values of the EAI index are ≤ 100 (*Table*

9); further detailed assessment is unnecessary (Act of the National Council of the Slovak Republic No. 359/2007 Coll.).

The mechanisms use the same operating fluids. According to the selected scenarios (leakage of 100 %, 50 %, and 33 %), we found that when the amount of operating fluid in the mechanism does not exceed 0.5 t (Am = 1), the result of the EAI index is the same within one type of operating fluid. The purpose of the EAI index calculation was to determine the degree of load on the components of the environment (water, soil) and subsequently propose measures against the leakage of operating fluids into the environment. Given the facts, we propose to increase care for the technical condition of these devices, especially Zetor 7245, which was manufactured in the 1970s and has an increased failure rate. LKT was produced in 2018, and HSM in 2007. The adsorbent and tools are included in the equipment of these machines, but we recommend adding a chemical mobile emergency kit, which contains loose sorbent, sorption mats, sorption snakes, sorption pillows, sealant, gloves, protective glasses, shovel with a whisk, and bags for used waste. It is necessary to provide training for service personnel on procedures for accidental spillage of operating fluids. It is crucial to maintain the satisfactory condition of the equipment, but considering their age, it would be advisable to replace them with modern ones that are safer for the environment.

## 4 CONCLUSIONS

The indicator of non-polar extractable substances was chosen to evaluate the impact of mining on the forest environment. NES content monitoring and physicochemical indicator analysis in soil and surface water were conducted in samples from forest stands with different logging intensities. Forest Stand 400 was a control area, without logging, and Stands 736 and 746 were areas with active logging. A small water source flowed through the growth of 736 and 746. During water pollution monitoring in surface sources, concentrations of NES, BOD5, and COD-Cr that exceeded limits set by the Government of the Slovak Republic Regulation no. 269/2010 Coll., were recorded. The NES indicator was exceeded in all analyzed surface water samples.

In Forest Stand 736, 30% of the samples exceeded the limit values set by Decree No. 59/2013 Coll. on the protection and use of agricultural land. The NES limit value in Stand 746 was exceeded in 60 % of the analyzed samples. The soil from the control area, Forest Stand 400, was the least contaminated and did not exceed the NES limit. Increased physicochemical indicator values could be caused by operating fluid leaks from transport-mechanization mechanisms, pollution from older environmental loads, or the content of humic substances.

Dependence was not confirmed. NES content in soil and surface water did not affect vegetation — the number and coverage of species in the monitored areas. NES was the lowest in the unlogged control plot. At the same time, the lowest number of species was also recorded here. The low species number is influenced by the above-mentioned factors (canopy of the stand, light conditions, and fallow height).

The EAI index method was used to assess the environmental risk in the logging environment. Three operating fluid leak scenarios — traffic accident, tank damage, leakage, and equipment neglect — were chosen for Zetor 7245, LKT 81 ITL, and HSM 805 equipment used to determine EAI. The calculated EAI index values for all operating fluids used in all three mechanisms are ≤ 100 (*Table 9*), rendering further detailed assessment unnecessary (Act of the National Council of the Slovak Republic No. 359/2007 Coll.). Based on these findings, we recommend adding a chemical mobile emergency kit to transport vehicles and machines used in economic activities in the forest.

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