THREATS TO CHOSEN LOCALITY BY SURFACE RUNOFF, WATER EROSION, AND SURFACE WATER POLLUTANTS

Lukáš Buršík*,1, Miroslav Dumbrovský[1], Veronika Sobotková[1], Martina Kulihová[1], Marcela Pavlíková[2]

*187803@vutbr.cz
[1]Brno University of Technology, Faculty of Civil Engineering, Institute of Landscape Water Management, Veveří 331/95, 602 00 Brno, CZ
[2]Brno University of Technology, Faculty of Civil Engineering, Institute of Chemistry, Veveří 331/95, 602 00 Brno, CZ

Abstract

This paper aims to provide information about threats to a chosen locality in the South Moravian Region of the Czech Republic, specifically focusing on surface runoff and water erosion. The geographic information system ArcGIS Pro was primarily used for the analysis. This paper also deals with contamination of surface water by pollutants which are produced by an agricultural company in the locality. For this reason, water samples were taken from a stream and subsequently analysed in a chemical laboratory.

In terms of soils erosion proneness, it was discovered that most of the area consists of unthreatened soils. Regarding the chemical analysis of surface water, it was found that the results obtained are affected by the season of the sampling (wet or dry) in terms of water volume in the stream.

Keywords

Water erosion, proneness of soils to erosion, soil loss, phosphorus, nitrogen

1 INTRODUCTION

The paper titled “Threats to Chosen Locality by Surface Runoff, Water erosion, and Surface Water Pollutants” primarily deals with the analysis of threats to the area of interest caused by surface runoff and water erosion. The analysis is mostly done using the geographic information system ArcGIS Pro.

This paper is further aimed to address the contamination of surface water by pollutants which are produced by an agricultural company in the locality that uses part of the area of interest as a sod farm. For this reason, water samples were taken from a stream in the locality and then analysed in a chemical laboratory. These analyses were focused, among other parameters, on the nitrogen and phosphorus content.

In the following subsections it is possible to find not only theoretical information about surface runoff, water erosion, and contamination of surface water by pollutants but also a description of the area of interest.

In the Methodology section, methods of calculation of soil loss and soil threat, software programs used, as well as sampling methods and chemical analyses are described. The Results section is divided into two parts. The first part aims to provide information about threats to the locality by surface runoff and water erosion, and the second part is dedicated to the analysis of surface water, which is affected by agricultural pollutants, chemical parameters obtained *in-situ* and in the chemical laboratory.

Theory of Surface Runoff and Water Erosion

Water erosion is generally initiated by land surface disruption due to the impact of raindrops transferring their kinetic energy to soil aggregates. This process continues with surface runoff, which begins the release of soil particles down the slope [1]. The word “erosion” comes from the Latin word “erodere” which means “to gnaw away”. Water erosion is harmful to farmland productivity, eventually making the land unsuitable for agriculture [2]. The process of soil erosion is a natural process that cannot be completely stopped [3].

It is possible to distinguish between two types of erosion: normal (geological) erosion and accelerated erosion. Normal erosion constantly transforms the relief, it is natural and from the point of view of a human lifespan, it is practically unobservable. Normal erosion is in accordance with the soil-forming process. On the contrary, accelerated erosion washes away soil particles to such an extent that they cannot be replaced by a soil-forming process. Accelerated erosion is significantly influenced by human activity and farming [3].

Water erosion threatens more than fifty percent of the arable land in the Czech Republic. However, no systematic protection to prevent further losses is carried out on the majority of soils at risk of erosion [4].

DOI 10.13164/juniorstav.2024.24068

Theory of Contamination of Surface Water by Pollutants

The primary source of agricultural water pollution is soil which is washed off fields. Soil particles are carried by rainwater and deposited into nearby lakes or streams. Too much sediment can cloud the water, reducing the amount of sunlight that reaches aquatic plants. Furthermore, pollutants such as fertilizers, pesticides, and heavy metals are often attached to the soil particles and wash into water bodies, causing algal blooms and oxygen depletion which are lethal to most aquatic life [5].

Description of Area of Interest

The area of interest can be found in the South Moravian Region (NUTS 3) of the Czech Republic, specifically within the Brno-Country District (NUTS 4), in proximity to the south-eastern border of the city of Brno, as seen in Fig. 1. Brno Airport is situated near this area. The locality is part of a fourth-order watershed with a number of hydrological order 4-15-03-104, which falls into the Morava River basin. This chosen area extends into cadastral territories of three municipalities, Kobylnice (cadastral territory 667471 Kobylnice u Brna), Sokolnice (cadastral territory 752193 Sokolnice), and Šlapanice (cadastral territory 762792 Šlapanice u Brna). The locality of interest covers an area of approximately 215 hectares, while the majority (almost 66%) falls into cadastral territory Kobylnice u Brna.

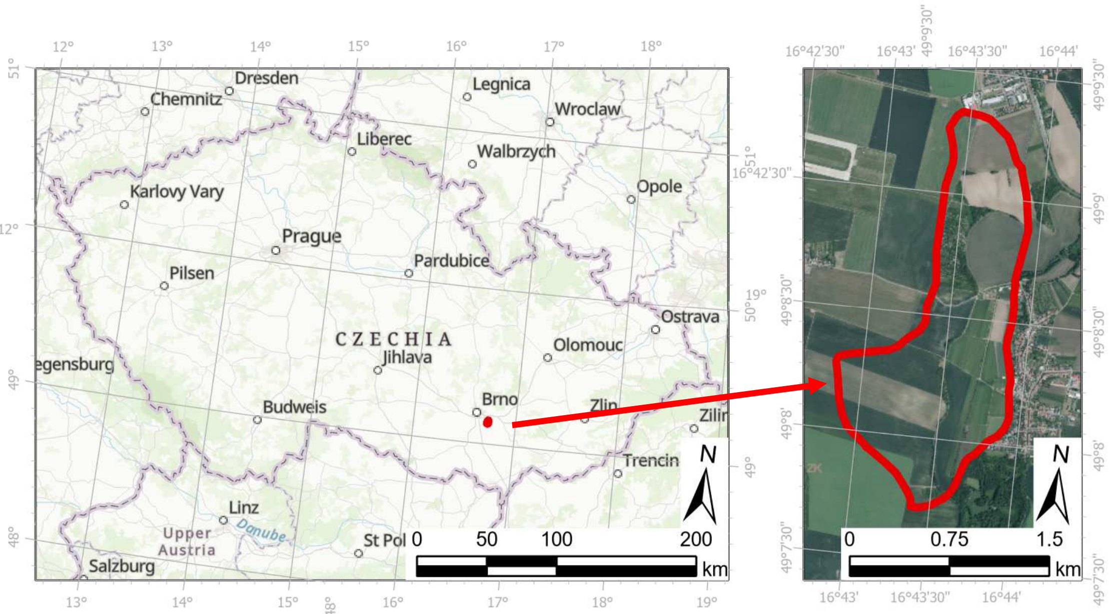

Fig. 1 Location of the area of interest.

Fig. 2 Watercourse (main drainage facility) and sod farm in the area of interest [own source].

Fig. 3 Sod farm in the area of interest [own source].

DOI 10.13164/juniorstav.2024.24068

According to LPIS (Land Parcel Identification System), most of the area of the locality is used for agricultural purposes. There are blocks of standard arable land and grassland (on arable land) – see Fig 4 a). As mentioned above, part of the area of interest is used as the sod farm that is also visible in Fig. 2 and Fig. 3.

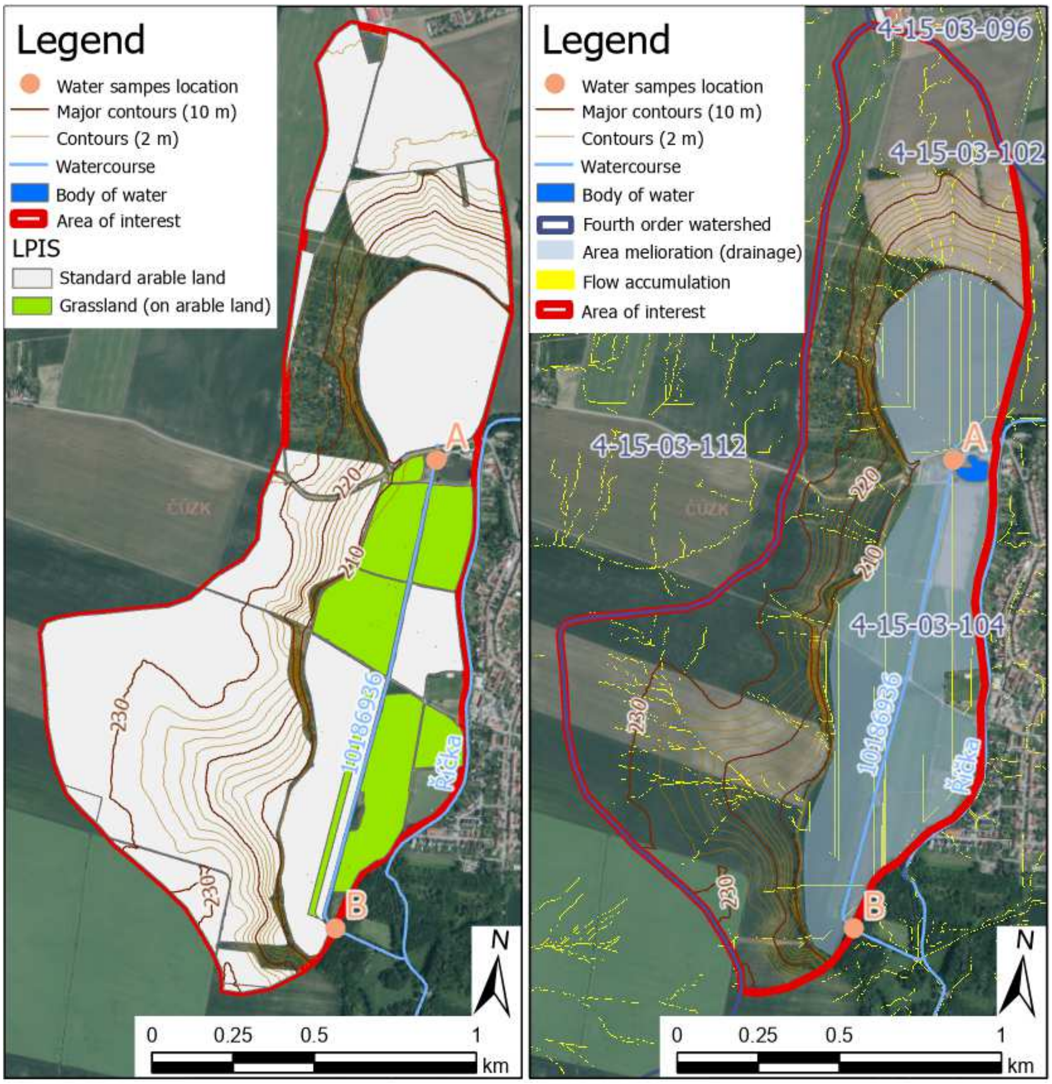

Fig. 4 a) Land-use (LPIS) – left, b) Area melioration (drainage system) – right.

Fig. 5 Location A of water samples [own source].

Fig. 6 Location B of water samples [own source].

The territory is partially drained, and an area melioration (drainage system) is built there – see Fig. 4 b). In the area of interest, a watercourse (ID 10186936) can be found that is a main drainage facility (Fig. 2) from which water flows into the watercourse Říčka that is outside the locality.

The area of interest is located at an altitude of 207 to 238 meters above sea level. The highest peak is at the northernmost point of the territory. There is a noticeable place in the territory where a pond used to exist, which can be seen as an approximately flat area.

In the locality, the predominant soil type is chernica fluvial (CCf). Different types of chernozems (CEm, CEl, CEx, CEp, and CEr) are here as well. From the point of view of hydrologic soil groups, most of the area belongs to group B (almost 59%). There are also groups A (approx. 5.5%) and D (approx. 35.5%). Hydrologic soil group C does not occur here. Regarding the soil depth in the area of interest, deep soils (approx. 94%) and deep, moderately deep soils (almost 6%) can be found.

2 METHODOLOGY

Calculation of Soil Loss and Soil Threat

The calculation of the risk to agricultural land from water erosion is based on the Universal Soil Loss Equation (abbreviated USLE), which is expressed in the form:

$$G = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (1)$$

where G is average long-term soil loss in tons per hectare per year, R is rain erodibility factor, K is soil erodibility factor, L is slope length factor, S is slope steepness factor, C is cover-management factor, and P is support practice factor (factor of anti-erosion measures) [6]. Factors L and S are usually together as LS factor.

Exceeding the level of erosion risk expresses the erosion risk of agricultural land, in which the permissible soil loss due to erosion is exceed. In the context of an anti-erosion decree (*Decree on the protection of agricultural land against erosion, No. 240/2021 Coll.*), which is put into effect in the Czech Republic, this is a situation when the maximum permissible product of values of the cover-management factor and support practice factor is exceeded on the evaluated area. In this decree, the USLE is transformed into the form:

$$C_P \cdot P_P = G_P / (R \cdot K \cdot L \cdot S) \quad (2)$$

where $C_P \cdot P_P$ is permissible product of the of values of the cover-management factor and support practice factor and G_P is permissible soil loss due to erosion tons per hectare per year. According to the decree, for deep soils and moderately deep soils, the value of G_p equals 9.0 $t \cdot ha^{-1} \cdot year^{-1}$ [6].

For the vast majority of agricultural land in the Czech Republic, the average annual value of R factor is 40 $MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}$ [4]. K factor is a raster obtained according to so-called main soil units which are parts of codes of estimated pedologic-ecological units (in Czech, an abbreviation BPEJ is used). This code consists of five digits in a form X.XX.XX (for instance 2.61.10). In this code, the second and third digits (x.XX.xx) are the main soil unit. LS factor is a raster obtained, besides other things, according to a digital terrain model and soil blocks in LPIS.

Based on the product $C_P \cdot P_P$, it is possible to divide soils into three categories (the second one has two subcategories) according to how prone they are to erosion: highly erosion-prone soils ($C_P \cdot P_P < 0.045$), slightly erosion-prone soils 1 ($0.045 \leq C_P \cdot P_P < 0.15$) slightly erosion-prone 2 ($0.15 \leq C_P \cdot P_P < 0.4$), and unthreatened soils ($C_P \cdot P_P \geq 0.4$) [7].

Description of Software Programs Used

The analyses in terms of surface runoff and erosion conditions are made mainly with the use of ArcGIS Pro software program, version 3.0. ArcGIS Pro which is a full-featured professional desktop GIS application created by the company ESRI (Environmental Systems Research Institute, Inc.). With ArcGIS Pro, users can explore, visualize, and analyse data, as well as create 2D maps and 3D scenes [8].

The LS factor is obtained with the use of software programs USLE2D and LSConverter. The first one is used for the calculation itself, and the second one is a simple tool for conversion between *.asc and *.rsc formats.

Sampling Method and Chemical Analyses

Ten water samples were taken from each location A and B, seen in Fig. 4–6, during the period of May 2023 to September 2023. The dates on which these were taken are the following: May 4, May 15, June 7, June 14, July 3,

DOI 10.13164/juniorstav.2024.24068

July 18, August 1, August 28, September 14, and September 25. The sampling was carried out in both dry and wet conditions (after rainfall).

One-litre PET bottles were used to collect the samples, and the samples were transferred immediately in a cooling box for analysis. Additionally, selected parameters were immediately measured *in-situ*, such as pH or O_2 (measured using a multiparameter Hach sonde). Other parameters were obtained from the chemical analyses in the laboratory which were focused on, for example, phosphorus or nitrogen content. N-NO_3 was determined indirectly by difference between N-NO_x (with the use of a multiunit Hach sonde) and N-NO_2 (spectrophotometric determination of NO_2^- by 1-naphthol/sulphanilic acid reagent). N-NH_3 was determined by spectrophotometric determination using a Nessler reagent. The samples were taken from the main drainage facility, containing largely drainage water from the agricultural area and surface runoff water. The water samples at location A represent a reference point, while the water samples at location B can be found near the end of a part of an opened channel of the main drainage facility, characterized by high sediment load.

3 RESULTS

Proneness of Soils in Area of Interest to Erosion

The result of the soil threat according to product of $C_P \cdot P_P$ expresses the proneness of soils to erosion – see Fig. 7. It is possible to observe that most of the area consists of unthreatened soils (approx. 75%). About 22% of soils belong to slightly erosion-prone soils (to each subcategory approx. 11%). Roughly 2% fall into highly erosion-prone soils.

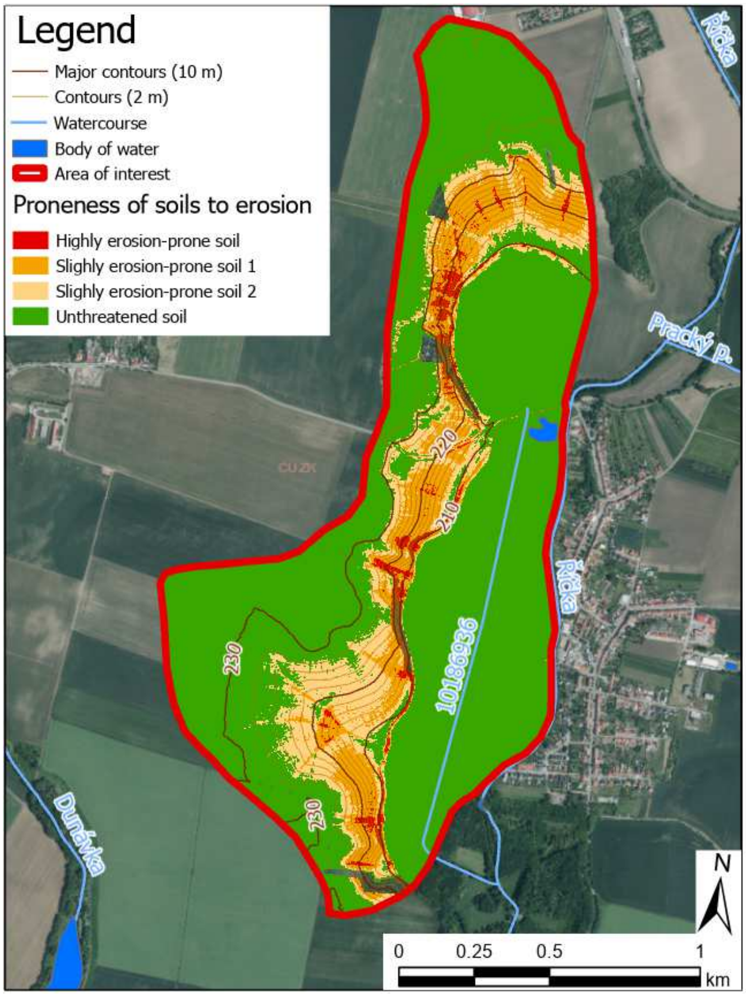

Fig. 7 Proneness of soils to erosion according to product of $C_P \cdot P_P$ – highly erosion-prone soils, slightly erosion-prone soils, and unthreatened soils.

DOI 10.13164/juniorstav.2024.24068

Analysis of Surface Water in Area of Interest

As already mentioned, some parameters were measured *in-situ*. Now, for instance, it is possible to observe the oxygen content (O_2) in the samples (Fig. 8) and pH of the water samples (Fig. 9).

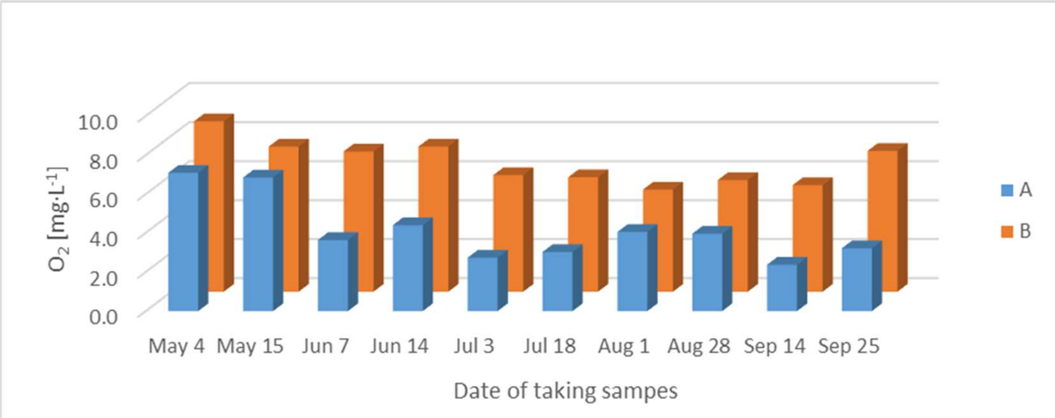

Fig. 8 O_2 content in the samples taken from locations A and B.

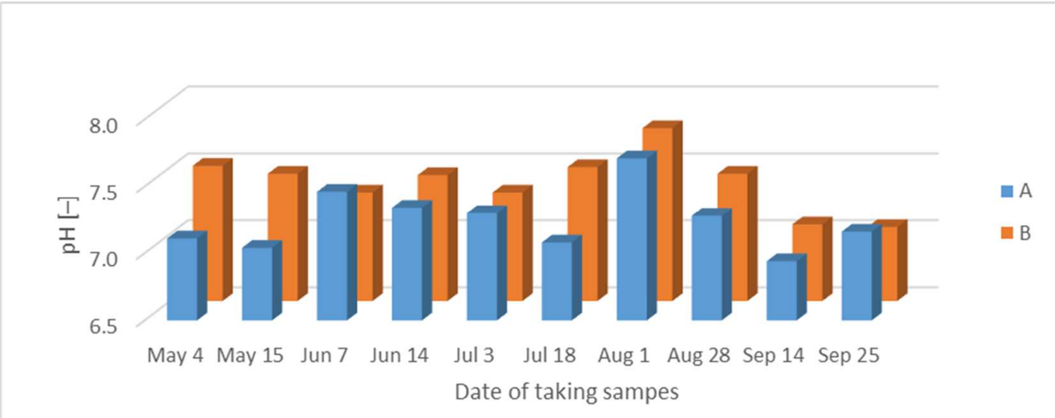

Fig. 9 pH of the samples taken from locations A and B.

In the chemical laboratory, values of several parameters were obtained. The following pictures show these selected parameters: nitrate nitrogen (N-NO_3; Fig. 10), ammoniacal nitrogen (N-NH_4; Fig. 11), and total phosphorus (TP; Fig. 12) contents.

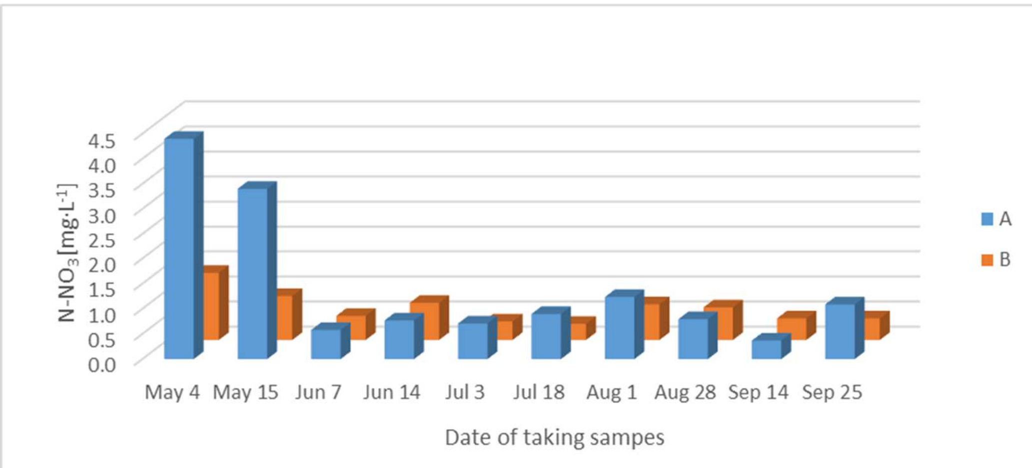

Fig. 10 N-NO_3 content in the samples taken from locations A and B.

DOI 10.13164/juniorstav.2024.24068

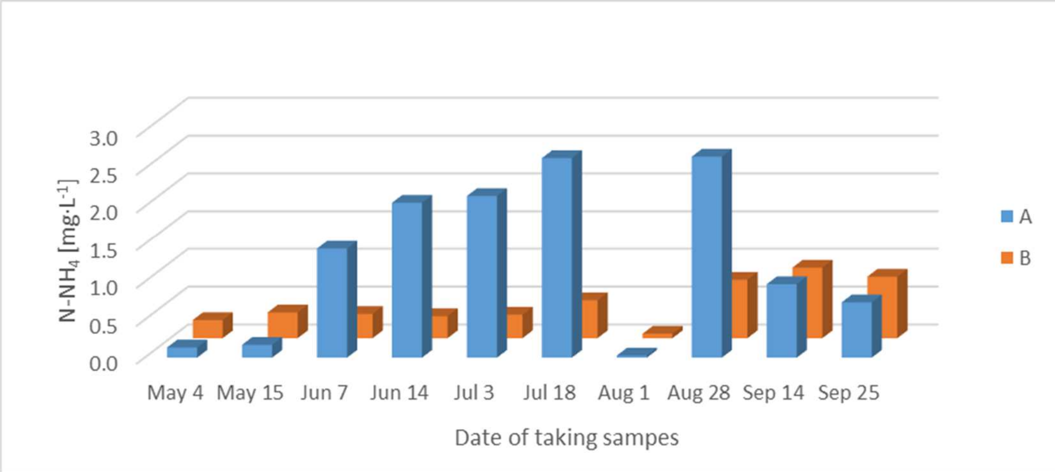

Fig. 11 N-NH$_4$ content in the samples taken from locations A and B.

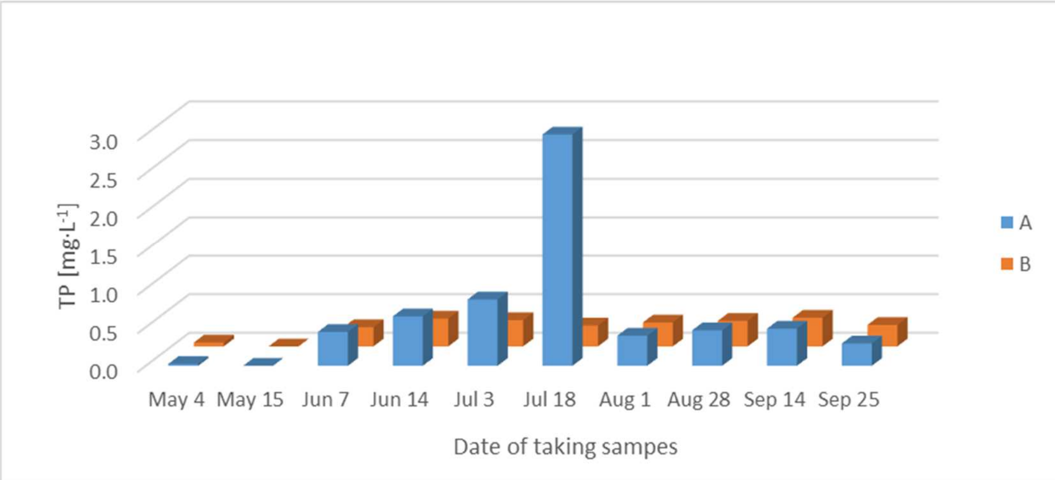

Fig. 12 Total phosphorus (TP) content in the samples taken from locations A and B.

4 DISCUSSION

The results obtained in the part devoted to proneness of soils to erosion show that approximately three quarters of soils in the area of interest are unthreatened soils. In the analysis, it was considered that P_p equals one, thus, in Fig. 7, it is possible to observe what C_P factor can be chosen when growing the crops. For instance, in case of unthreatened soils, the C_P factor can be greater or equal to 0.4, or in case of highly erosion-prone soils, it must be smaller than 0.045. Considering that a large part of the territory is flat, such results can be expected.

It is possible to observe that the results obtained in the part which deals with chemical analysis of surface water are affected by the season of the sampling (wet or dry), particularly in the sense of water amount in the watercourse. In the sample from the sixth sampling at location A, which took place on July 18, 2023, the total phosphorus (TP) content was extremely high – see Fig. 12. There was very little water during the sampling process. Pease [9] stated that nutrient loss in surface runoff tended to be more of an environmental concern. For example, surface runoff did not typically carry high amounts of nitrogen, but it could carry high amounts of sediment-bound phosphorus into streams and waterways. Excessive phosphorus availability in lakes and streams could result in harmful algal blooms.

Phosphorus is tightly bound to particles and therefore it is not available for plant uptake in the field (highly calcareous, high pH soils). However, when phosphorus moves into watercourses, it becomes more available at neutral pH levels [9]. It was observed that pH values in the main drainage facility and in following watercourse Říčka were in the range of 6.9 to 7.8.

In the case of chemical analysis, there is a limitation of total phosphorus, it can be correctly determined if the content is greater than or equal to 0.05 mg·L^{-1}. Thus, there were no values from the second sampling (May 15).

DOI 10.13164/juniorstav.2024.24068

From the first sampling (May 4), there were no values obtained for locations A and B with a total phosphorus content equal to 0.05 mg·L^{-1}. The highest value of TP content was obtained on July 18 (dry season) in the sample taken at location A. There was a small amount of water in the drainage channel and therefore the sample became very concentrated.

Lisboa et al. [10] stated that nitrate loads were not affected by the drought or post-drought sequence. The data obtained in this research confirm the finding. The values of N-NO_3^- from the first sampling were higher because the data were obtained during the dry season, and the second sampling data were obtained in the wet season. Both values were higher. Later samplings had similar values of N-NO_3^- in wet or dry season.

The values of ammoniacal nitrogen (N-NH_4) were higher during summer (from June to August). They were in a range of 0.02 to 2.6 mg·L^{-1}. N-NH_4 content was high in the samples taken at location A in summer and showed dangerous values for fish. This ammonia likely originated from a nearby sod farm storage of organic fertilizers. Surface runoff near this location could affect the samples from location A.

5 CONCLUSION

This paper was primarily aimed at the analysis of threats to the area of interest caused by surface runoff and water erosion and briefly describes the software programs used, sampling methods, and chemical analyses. For the calculation of soil loss and soil threat, according to Czech anti-erosion decree, a transformed form of the Universal Soil Loss Equation was used. The product of $C_P \cdot P_P$ was a result of this transformed form. Based on this product, it was possible to divide soils according to their proneness to erosion. It was discovered that about three quarters of soils in the area of interest were unthreatened soils. This result met the expectation because a large part of the territory was flat.

The paper also dealt with contamination of surface water by pollutants which were produced by an agricultural company that used part of the area of interest as a sod farm. To study this aspect, water samples were taken from the stream there and afterwards analysed in the chemical laboratory. These analyses were focused, among other parameters, on the nitrogen and phosphorus content. It was found that obtained parameters were affected by whether the sampling was done during the dry or wet season, and by amount of water in the watercourse. The values of N-NH_4 were high in the samples taken at location A. Input of ammoniacal nitrogen could be through surface runoff and from the fertilizer storage of the sod farm situated near location A.

Acknowledgement

This paper is a result of an inter-faculty (Faculty of Civil Engineering and Faculty of Chemistry) junior research FAST/FCH-J-23-8283 “Interdisciplinary Approach to Analysing Areas of Interest Leading to Measures for Improving Ecological State of Watershed in Terms of Erosion and Runoff Conditions, as well as Surface Water Pollution by Pollutants”.

References

[1] DUMBROVSKÝ, Miroslav. Adverse consequences of surface runoff and its conservation in the land consolidation process [online]. Brno, 2013. Thesis of the lecture on the professorial appointment procedure in the field of water management and water structures. Brno University of Technology, Faculty of Civil Engineering. ISSN 1213-418X. Available at: https://www.vut.cz/vutium/spisy?action=ukazka&id=1515&publikace_id=14485

[2] SERGIEIEVA, Kateryna. Water Erosion: Types, Causes, Effects, And Prevention. In: *EOS Data Analytics* [online]. Dnipro: EOS Data Analytics, Inc., 2021-02-11 [accessed 2023-10-09]. Available at: https://eos.com/blog/water-erosion/

[3] NOVOTNÝ, Ivan, Vladimír PAPAJ, Jana PODHRÁZSKÁ, Jiří KAPIČKA, Jan VOPRAVIL et al. *Handbook of protection against agricultural soil erosion* [online]. Prague: Ministry of Agriculture of the Czech Republic & Research Institute for Soil and Water Conservation, 2017. ISBN 978-80-7434-362-9 (Ministry of Agriculture of the Czech Republic) & 978-80-87361-67-2 (Research Institute for Soil and Water Conservation). [accessed 2023-10-10] Available at: https://eagri.cz/public/web/file/293635/MZE_prirucka_ochrany_proti_erozi_zemedelske_pudy_2017.pdf

[4] JANEČEK, Miloslav, Tomáš DOSTÁL, Jana KOZLOVSKY DUFKOVÁ, Miroslav DUMBROVSKÝ, Josef HŮLA et al. *Protection of agricultural land from erosion*. Prague: Czech University of Life

Sciences Prague, 2012. ISBN 978-80-87415-42-9

[5] Protecting Water Quality from Agricultural Runoff. In: *United States Environmental Protection Agency* [online]. Washington, D.C.: United States Environmental Protection Agency, 2005-03 [accessed 2023-10-10]. Available at: https://www.epa.gov/sites/default/files/2015-09/documents/ag_runoff_fact_sheet.pdf

[6] CZECH REPUBLIC. Decree No. 240/2021 Coll, on the protection of agricultural land against erosion. In: *Collection of laws of the Czech Republic* [online]. Rel. 2021-06-23 [accessed 2023-10-12]. ISSN 1211-1244. Available at: https://aplikace.mvcr.cz/sbirka-zakonu/SearchResult.aspx?q=240/2021&typeLaw=zakon&what=Cislo_zakona_smlouvy

[7] NOVOTNÝ, Ivan. *Basic information on soil protection solutions against water erosion in DZES 5 and in the anti-erosion decree.* Presentation from Expert seminar Analysis of erosion and runoff conditions and proposal of anti-erosion and water management measures in the process of land development [online]. [accessed 2023-10-11]. Available at: http://uvhk.fce.vutbr.cz/sites/default/files/aktuality/NOVOTN%C3%9D_VUMOP_DZES_a_Protierozn%C3%AD_vyhlaska.pdf

[8] Introduction to ArcGIS Pro. In: *Esri.com* [online]. Environmental Systems Research Institute (ESRI) [accessed 2023-10-19]. Available at: https://pro.arcgis.com/en/pro-app/latest/get-started/get-started.htm

[9] PEASE, Lindsay. When it rains, it pours. *Journal of Nutrient Management* [online]. November 2020, pp. 14-15. Rel. 2020-10-27 [accessed 2023-11-11]. Available at: https://jofnm.com/article-89-When-it-rains-it-pours.html

[10] LISBOA, Maria Sol, Rebecca L. SCHNEIDER, Patrick J. SULLIVAN, and Meghan Todd WALTER. Drought and post-drought rain effect on stream phosphorus and other nutrient losses in the Northeastern USA. *Journal of Hydrology: Regional Studies* [online]. April 2020, volume 28. Rel. 2020-03-10 [accessed 2023-11-11]. ISSN 2214-5818. Available at: https://doi.org/10.1016/j.ejrh.2020.100672

DOI 10.13164/juniorstav.2024.24068