VODOHOSPODÁŘSKÉ TECHNICKO-EKONOMICKÉ INFORMACE
(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

VTEI / 2022 / 2

Earth Day

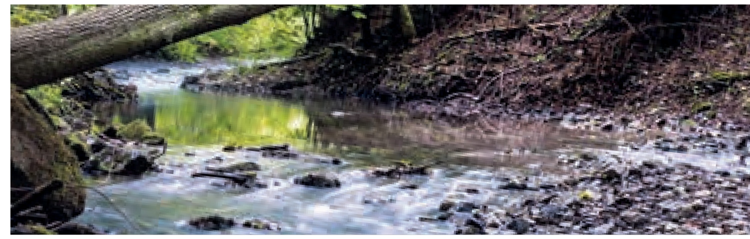
On Friday 22nd April, the entire planet will commemorate Earth Day. The history of this international environmental event dates back to the United States in early 1969, when the California coast was ravaged by a huge oil spill. Senator Gaylord Nelson of Wisconsin was deeply concerned about the state of the US environment and, along with activist John McConnel, suggested at a UNESCO conference in San Francisco that a day be set for the Earth. This day was later confirmed in a statement written by McConnell and signed by UN Secretary-General U Thant.

A year later, on 22nd April 1970, a nationwide environmental education event took place in the United States. The young activist Denis Hayes was appointed national coordinator. Nelson and Hayes agreed that the event would be called Earth Day to raise public awareness of the deteriorating environment. This first Earth Day inspired 20 million Americans – 10 per cent of their population at the time – to take to the streets and demonstrate about the effects of 150 years of industrial development. Thousands of colleges and universities organized protests against environmental degradation, and massive rallies took place in towns and villages from coast to coast. The demonstrations were part of a campaign to enforce environmental laws. Nelson later received the Presidential Medal of Freedom from Bill Clinton for his work.

Other countries soon joined the Americans and, after 1990, virtually the whole of the rest of the world, including the Czech Republic, had joined in. The 22nd of April thus became an international event. Today, more than a billion people in 193 countries celebrate Earth Day; thus, it is the largest secular event in which people are involved together, regardless of origin, religion, or nationality.

Mgr. Zuzana Řehořová
VTEI Editor

Contents



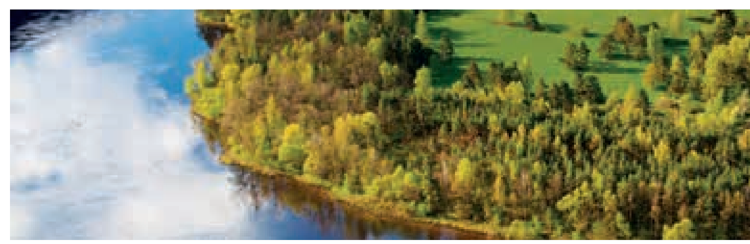



Photo: shutterstock.com

Dear readers,

like me, you will certainly perceive that the development of the current weather does not give us any certainty of what sort of year awaits us from a hydrological point of view. At the beginning, and in fact during the winter, it seemed that a relatively average season could occur; but after the new year, some farmers in the Vysočina region began to suggest that drought could return. And suddenly, at the beginning of March, the frost came again and snow began to fall. It is therefore difficult to predict further developments, but it can realistically be expected to be closer to the average, especially if we start using the new reference period 1991–2020, which already includes the six-year drought period. Thus, we have no choice but to wait for the crucial months of April and May. By the way, you can find out about the comparison of the two reference periods in an article in this issue of VTEI. You will also find information about Covid-19, which is already in decline, but it is almost a duty to keep informing about it; monitoring SARS-CoV-2 in wastewater is an ideal way to determine its distribution in the population, including scenarios for its further development. You will also learn about the research on popular topics such as climate change, erosion, and pesticides, and there is also an article on water quality. To finish the list of contributions, I want to mention the highlight of not only this issue, but certainly of the whole year, and that is an interview with the Minister of the Environment Anna Hubáčková.

However, in these days when the Russian military is shelling nuclear power plants in Ukraine, it can easily happen that all the issues we deal with in terms of the quality of the environment and the comfort of our lives can be completely thwarted in an instant by radioactivity or other forms of pollution. It is a harsh reminder that our environment does not end at our borders, and that not just climate change but also events in more distant locations affect our lives. We should therefore make every effort to actively help minimize all threats, so that we do not have to explain to ourselves or to our descendants why we have done nothing.

Ing. Tomáš Urban
Director of TGM Water Research Institute

Use of SARS-CoV-2 virus monitoring in wastewater from WWTP of various categories for epidemic surveillance in the Czech Republic

HANA ZVĚŘINOVÁ MLEJNKOVÁ, LUCIA GHARWALOVÁ, KATEŘINA SOVOVÁ, PETRA VAŠÍČKOVÁ, JAKUB HRDÝ, MAGDALÉNA KRÁSNA, VĚRA OČENÁŠKOVÁ, VLADIMÍR BENCKO, MILAN TUČEK, MILENA BUŠOVÁ, EVA JURANOVÁ

Keywords: wastewater monitoring — SARS-CoV-2 — RT-qPCR — WWTP — epidemiological data

SUMMARY

The principle of wastewater diagnostics is a suitable complementary approach that can help to gain epidemiological information on a large part of the population in a non-invasive way. The course of the pandemic spread of the new coronavirus (SARS-CoV-2) has been showing a cyclical course of successive waves of Covid-19 since 2020. For this model, a systematic detection of the occurrence of its agent in wastewater is a very effective approach.

In our study, the coronavirus SARS-CoV-2 was monitored in wastewater from selected wastewater treatment plants (WWTP) in the Czech Republic between April 2020 and January 2022. Current findings and conclusions of ongoing studies have clearly shown that, in its targeted and systematic implementation, wastewater monitoring can be a suitable complement to epidemiological forecasts, proposals for measures, and thus the protection of public health. In addition, our results showed that WWTP of all categories are suitable for epidemiological diagnostics of wastewater. However, in a systematic epidemiological approach to wastewater ("Wastewater-Based Epidemiology"; WBE), it will be necessary to consistently accept differences between the types and purposes of monitoring, the nature of wastewater, and the specifics of sampling points.

INTRODUCTION

Wastewater is a recipient of all waste substances and metabolic products excreted by humans. Provided that they do not decompose, these substances are detectable using appropriate methods. This also applies to pathogenic agents and other specific markers which detection in wastewater is one of the goals of wastewater diagnostics. The purpose is to obtain information about the studied population or a specific community. This alternative approach, which uses wastewater as a collective diagnostic medium, currently helps to eradicate polio (poliomyelitis). This infectious disease has been eliminated on some continents, but worldwide vaccination is still needed. In the Czech Republic, polio was completely eradicated in 1961 [1]. Investigation of polioviruses in wastewater in eight cities and refugee camps in the Czech Republic is currently underway according to WHO guidelines within the global polio eradication programme [2]. In non-medical fields, wastewater is used to determine lifestyle markers (drugs and other addictive substances, personal care products, medicines, etc.), both globally and in problematic regions.

Shortly after the outbreak of the Covid-19 pandemic, it became clear that outbreaks could not be monitored effectively enough using current epidemiological approaches, in which infected individuals are identified on the basis of clinical manifestations. The course of the pandemic spread of the coronavirus SARS-CoV-2 has shown a cyclical course of successive waves of Covid-19 since 2020. To implement effective measures to combat the epidemic, using WBE is appropriate. There are currently 3,166 WWTP in the Czech Republic, which makes it possible to keep for about 80% of its population under surveillance [3].

In environmental samples, such as wastewater, there is a presumption of the occurrence of the monitored agents even in very low concentrations. Therefore, it is appropriate to use a larger amount of sample for the analysis itself and to perform a step before isolating the nucleic acids which will allow the concentration of the given agents, in our case viruses. However, this procedure can be a source of increased number of errors, so each step of the analysis must be strictly monitored.

METHODOLOGY

Wastewater sampling from WWTP started in April 2020 and is planned until April 2022. Samples were taken from 66 WWTP of different sizes in different time regimes. In this paper, we present the results of eight selected WWTP with different numbers of connected inhabitants (CI) between April 2020 and January 2022: Buchlovice (2,340 CI); Slavkov u Brna (6,500 CI); Tišnov (11,500 CI); Přerov (41,000 CI); Kladno (80,000 CI); Brno (about 426,000 CI) and Prague Central WWTP (CWWTP) NWL (new water line) and EWL (existing water line), both about 600,000 CI.

In the initial stages, different sampling methods were used depending on current possibilities. Gradually, sampling was optimized to ensure the most representative samples possible. Time experiments were performed, when a series of 24 composite hourly samples (mixed four volume-identical samples taken every 15 min) obtained during 24 hours at the Brno WWTP were taken. In addition to SARS-CoV-2 RNA, selected chemical and physico-chemical parameters were determined in the samples (COD-Cr, N-NH4, o-PO4, suspended solids, faecal coliform bacteria, and enterococci). These experiments showed that the most concentrated wastewater at the WWTP is between 5 a. m. and 11 p. m. Based on this finding, wastewater sampling was tested at shorter intervals (15 min) in the above-mentioned time period and compared with the common 24-hour sampling [4].

In the current stage of sampling, composite 24-hour samples of untreated wastewater were taken using automatic samplers after rough mechanical pre-treatment (screening). Samples were stored refrigerated and processed within 48 hours of collection or frozen at –70 °C.

Detection of SARS-CoV-2 virus in wastewater

The research laboratories of Veterinary Research Institute (VRI) Brno and TGM WRI cooperated to create a methodological procedure for wastewater analysis which includes a precisely defined system of control points to ensure a proper and valid analysis of each sample. These points include:

1. Check of wastewater sampling, including samples transport to analytical laboratories under appropriate conditions (ideally: cooled to 3 ± 2 °C, within 48 hours).
2. Wastewater treatment check, i. e., concentrating the viral particles from a defined sample volume and subsequently isolating the nucleic acids. This external check of the analysis also makes it possible to determine the efficiency of the whole procedure, which guarantees a more accurate quantification of SARS-CoV-2 (genomic equivalents (GE)) in the monitored samples.
3. Check of the course of the SARS-CoV-2 (GE) detection and quantification step in the monitored samples using real-time reverse transcription polymerase chain reaction (RT-qPCR).

This method, which has been approved by the Ministry of Health [5], consists of concentrating a 500 ml sample of wastewater using polyethylene glycol (PEG) and sodium chloride. The commercially available QIAamp Viral RNA Mini Kit (Qiagen, Germany) is used for RNA isolation; moreover, RNA isolation can be fully automated. Quantitative RNA detection of SARS-CoV-2 virus is performed by RT-qPCR method targeted at three independent detection targets in the virus genome (two N gene targets and an area coding non-structural protein nsp12). The sensitivity (detection limit) of the entire methodological procedure (i. e. from the initial concentration of the wastewater sample to the actual quantification of GE SARS-CoV-2) is 2.5 viral particles (GE) in 1 ml of wastewater; the average efficiency of the procedure is 36%. The analyses were performed in the laboratories of VRI Brno and the Brno branch of TGM WRI.

Data evaluation

The obtained data were correlated with the number of people tested positive for Covid-19 in the monitored regions, i. e. cities and municipalities connected to the relevant WWTP. Epidemiological data were obtained from the Department of Biostatistics of the National Institute of Public Health (NIPH) from the national Information System of Infectious Diseases (ISID). People 10 days before the date of the first symptoms until the 3rd day after the positive PCR test (the 14-day interval) were included in the evaluation. Public data obtained from covid maps, which draw data from open data sets of the Ministry of Health, were used for preliminary evaluations. These data are often affected by error and do not include the number of inhabitants in smaller connected municipalities.

RESULTS AND DISCUSSIONS

Within the study, eight WWTP of different size categories were selected from a total of 66 WWTP, ranging from WWTP with 2,340 connected inhabitants (CI) to two water lines of Prague CWWTP with more than 600,000 connected inhabitants. These WWTP were used to evaluate the applicability of the chosen approach to predict disease trends and detect the possible onset of the epidemic. The selected WWTP also differed in the nature of the supplied wastewater. Comparisons of the number of SARS-CoV-2 GE in frozen samples of untreated wastewater and the number of positively tested people at selected WWTP are shown in *Fig. 1* to *8*.

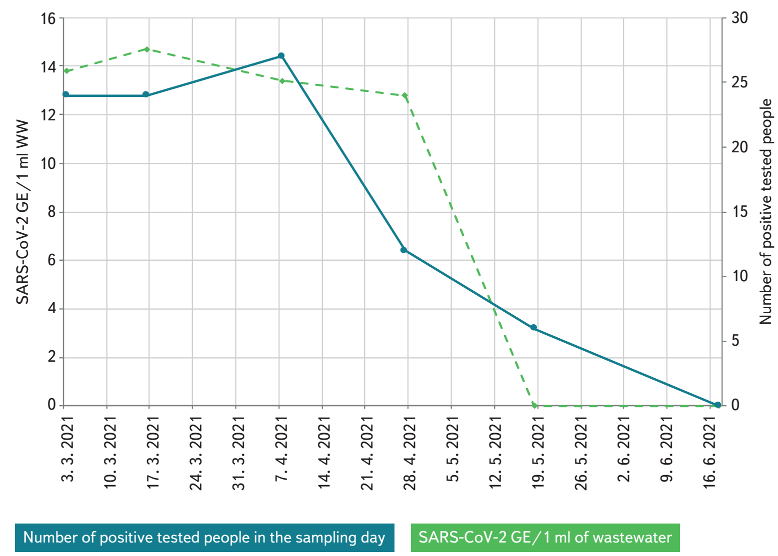


Fig. 1. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from Buchlovice WWTP (2,340 connected people)

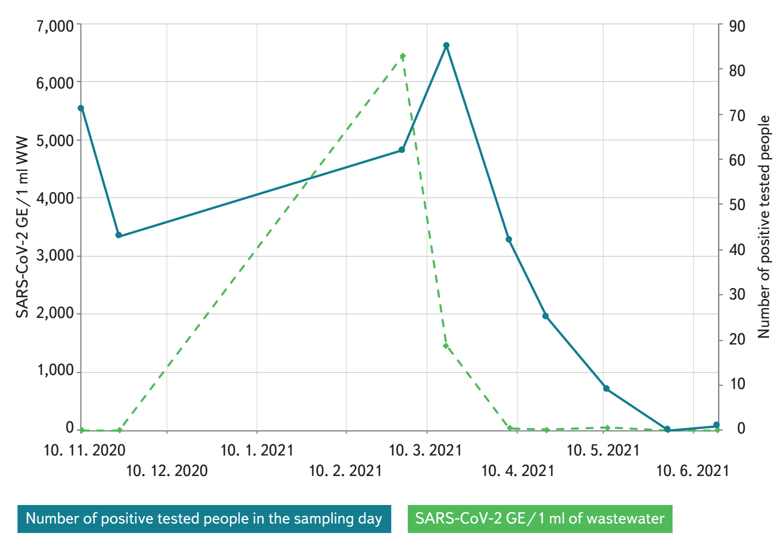


Fig. 2. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from Slavkov u Brna WWTP (6,500 connected people)

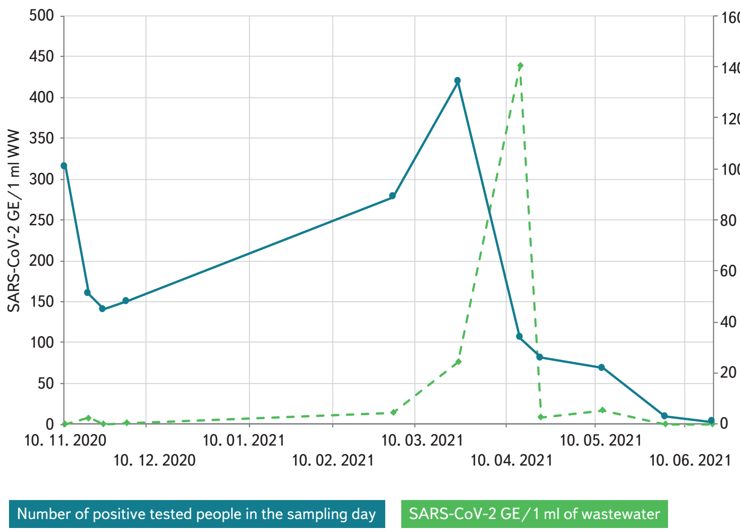


Fig. 3. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from Tišnov WWTP (11,500 connected people)

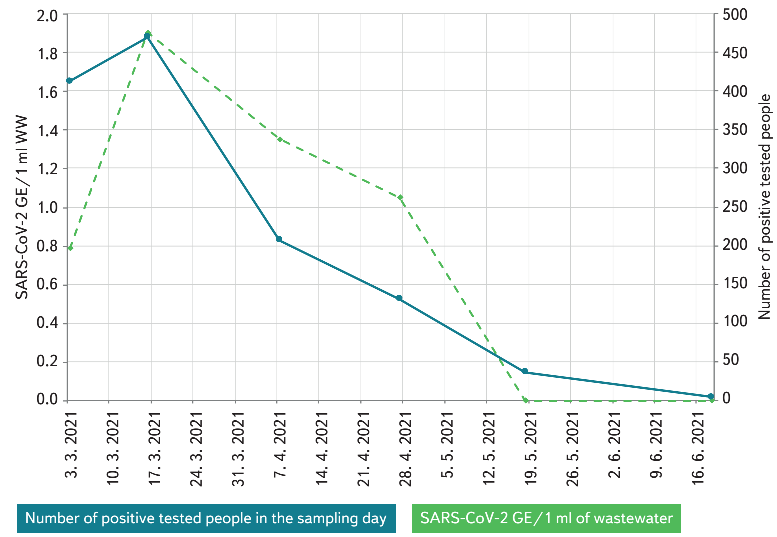


Fig. 4. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from Přerov WWTP (41,000 connected people)

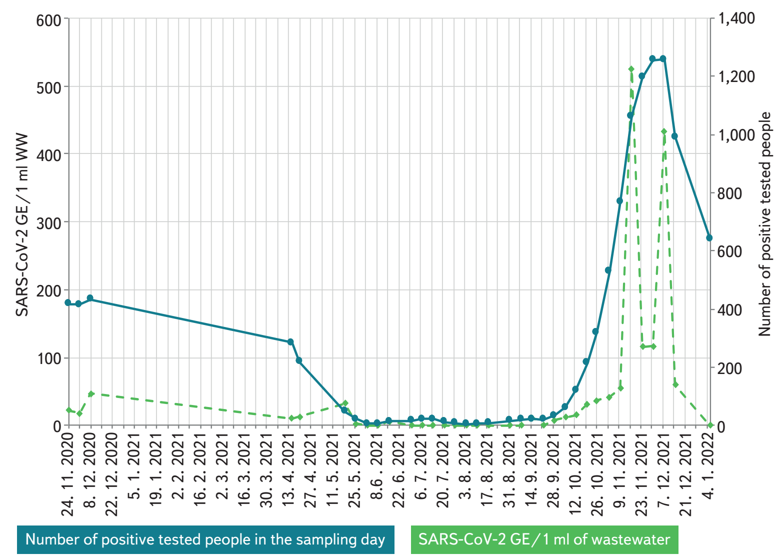


Fig. 5. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from Kladno WWTP (80,000 connected people)

The smallest of the evaluated treatment plants was the Buchlovice WWTP, to which 2,340 inhabitants are connected; the capacity corresponds to 2,756 population equivalent (PE) The WWTP was monitored in the autumn of 2020 and in the spring of 2021. The inflow of wastewater ranged from 570 to 700 m^3/day.

From the category up to 10,000 PE, the Slavkov u Brna WWTP was monitored, to which 6,500 inhabitants are connected; the capacity corresponds to 9,451 PE. The WWTP was monitored in autumn 2020 and spring 2021. The inflow of wastewater ranged from 1,200 to 4,000 m^3/day.

From the category of 10,000–100,000 PE, the Tišnov WWTP was monitored, to which 11,440 inhabitants are connected; the capacity corresponds to 18,000 PE. The WWTP was monitored in autumn 2020 and spring 2021. The inflow of wastewater ranged from 2,400 to 5,100 m^3/day.

Another treatment plant in the category of 10,000–100,000 PE was the Přerov WWTP, to which 41,440 inhabitants are connected and whose capacity corresponds to 112,170 PE; it was monitored in autumn 2020 and spring 2021. The inflow of wastewater ranged from 9,980 to 16,700 m^3/day.

The last selected treatment plant from the category of 10,000–100,000 PE was monitored in Kladno-Vrapice. 80,000 inhabitants are connected to this WWTP, the capacity corresponds to 85,000 PE. Monitoring took place in the autumn 2020 and from April 2021 to January 2022. The inflow of wastewater in this period ranged from 8,300 to 14,000 m^3/day.

The WWTP from the category of over 100,000 PE was represented by the Brno (Modřice) WWTP. 426,500 inhabitants are connected to this WWTP, the capacity corresponds to 640,000 PE. The WWTP was monitored from autumn 2020 to January 2022. The inflow of wastewater in the monitored periods ranged from 64,000 to 250,000 m^3/day.

The monitored treatment plants also included Prague CWWTP, consisting of two water lines – new (NWL) and existing (EWL). A total of 1,297,000 inhabitants of Prague (1,746,500 PE) are connected to the WWTP, with each of the two water lines serving about half of them. Prague CWWTP was monitored in autumn 2020, spring 2021, and from August 2021 to January 2022. The inflow of wastewater ranged from 81,200 to 215,000 m^3/day.

The interim results of the study presented in the figures show a good correlation between the amount of viral RNA in wastewater and the number of people tested positive (people tested positive in the figures are counted from day 10 before the date of the first symptoms to day 3 after the positive PCR test). Copying the trend of both curves is evident in all size categories of WWTP, while the value of reliability is up to 0.9. The presented results are gradually refined by supplementing epidemiological data and the results of other analysed frozen samples. Although the available data do not show a direct relationship between the number of infected people and the number of GE SARS-CoV-2 in the wastewater for selected WWTP, they demonstrably show the trends in the number of positively tested people and are, therefore, useful for estimating prevalence based on comparisons with previous waves of the epidemic (*Fig. 1–8*).

The sensitivity of the method depends on a group of factors that affect the character of the wastewater, i. e.:

1. the current amount of wastewater that will affect the dilution of viral RNA in the sample,
2. current share of industrial wastewater, rainwater, and municipal wastewater,
3. representativeness and homogeneity of the sample,

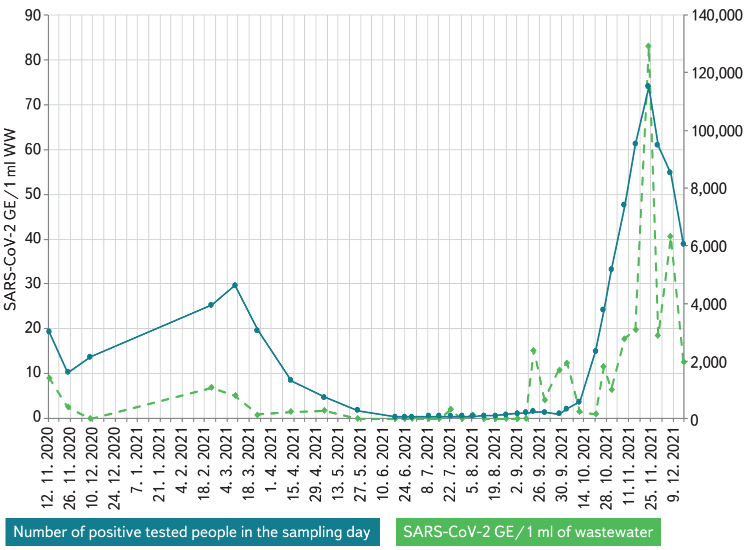


Fig. 6. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from Brno WWTP (626,000 connected people)

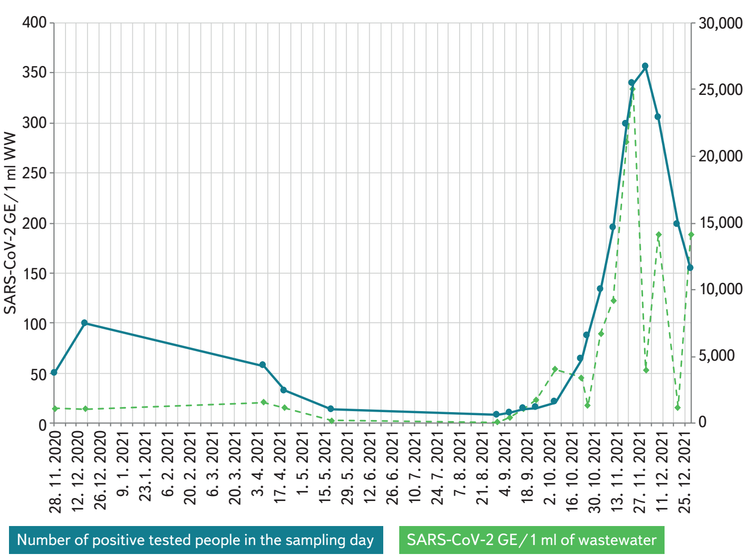


Fig. 7. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from the new water line of Praha WWTP (about 600,000 connected people)

4. weekly sampling regime (differences within working days/weekends),
5. length and branching of the sewerage network (RNA degradation before inflow to the WWTP, including the effect of temperature and pH of water in the sewerage system).

The correlation of both groups of data is also influenced by the robustness of epidemiological data, which are affected by the current epidemic regime. It determines the number of people who are tested, based on the frequency and method of testing, the mobility of people, the number of tests performed, etc. Another factor is the hitherto insufficient information on the proportion of people excreted viruses by the digestive or urinary tract and on the contribution from asymptomatic individuals.

It is often very difficult to estimate the amount of a virus in raw wastewater due to the lack of information on hourly and even seasonal changes in the number of viral agents in wastewater. Sampling of composite hourly samples

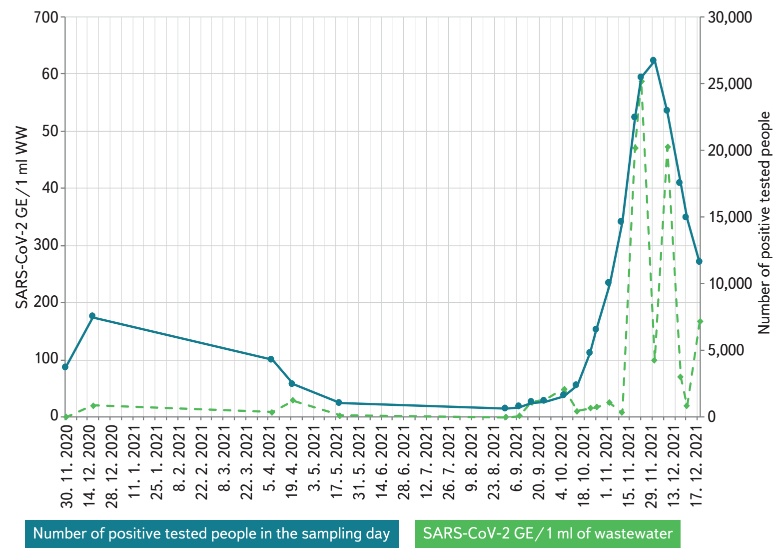


Fig. 8. Comparison of numbers of positive tested persons and amount of GE SARS-CoV-2 in wastewater from the current water line of Praha WWTP (about 600,000 connected people)

from the Brno WWTP, which was carried out in October 2021, showed the time periods in which the largest amount of viral RNA was detected in the inflow to the WWTP (*Fig. 9*). The results of time monitoring of SARS-CoV-2 RNA demonstrated the possibility of effective use of an abbreviated sampling regime (e. g. between 5 a. m. and 11 p. m.), especially if it is necessary to obtain samples with higher concentrations of viral RNA for sequencing purposes. If it is not possible to provide 24-hour composite samples for analysis and it is necessary to proceed with grab sampling, sampling at times when the faecal load is highest is preferred.

The high sensitivity of the method is evident from the finding that in the wastewater of smaller WWTP, there was a positive detection of viral RNA for units of up to dozens of people detected by clinical PCR testing (e. g., Buchlovice 12 people; Slavkov 9 people; Tišnov 3 people); tens to hundreds of positively tested people were detected at larger WWTP (Brno 86 people; Kladno 14 people; Přerov 131 people). In Prague CWWTP, which was monitored only in periods with a higher prevalence, a positive RNA finding was recorded

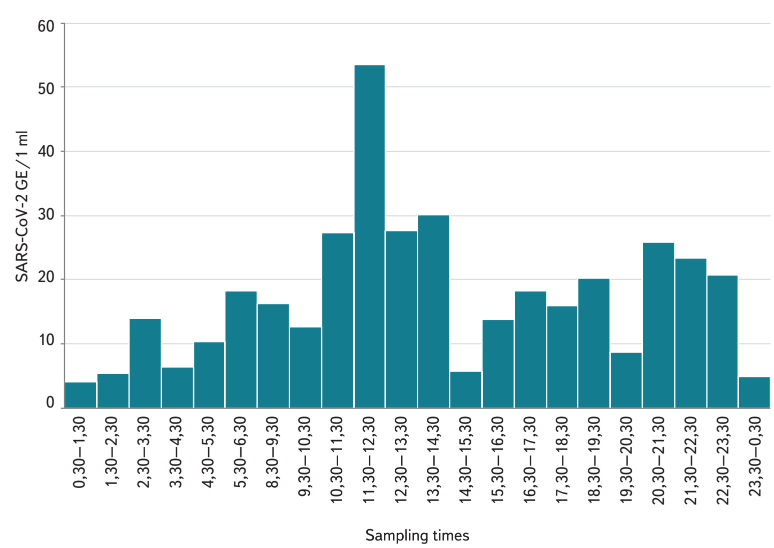


Fig. 9. Comparison of the amount of GE SARS-CoV-2 in wastewater from Brno WWTP at hourly intervals during 24 hours (11 October 2021)

for > 600 people. The results reflect the factor of dilution of wastewater with rainwater and industrial wastewater, which must be taken into account when interpreting the data correctly.

The results of the study correspond with the findings of researchers in other countries where WBE monitoring of SARS-CoV-2 is actively underway to expand the possibilities for effective measures to combat the spread of infectious diseases. Monitoring in the world is primarily targeted on large WWTP [6]. However, in many countries, smaller WWTP, city districts, or individual buildings are also monitored [7, 8].

In some countries, the WBE approach is already applied in practice; for example, at university dormitories in Carolina (USA), asymptomatic infected students were found who would not otherwise be detected. In the Netherlands, health professionals use wastewater data to determine where to send their mobile test buses. In Australia, where the number of cases was relatively low, wastewater monitoring helped reassure authorities that their pandemic surveillance is working [9].

When considering the potential limitations of WBE for SARS-CoV-2 surveillance in the studied population, it is important to consider a number of variables that determine the quantitative ability of WBE to determine the relationship between viral RNA levels in wastewater and the incidence of infection in the population. A major constraint on SARS-CoV-2 estimation in the community using WBE is the lack of reliable data on the rate of faecal and urinary excretion of virus RNA into wastewater. For asymptomatic individuals, the rate of virus excretion is typically much lower than in symptomatic patients. In addition, there are several variables that affect the rate of excretion, including the duration of infection, levels of viremia, age of the patient, in addition to the stage and severity of the disease. A combination of WBE approach with clinical testing data in public health decision making appears to be useful [10, 11].

Another thing to consider when using WBE for Covid-19 surveillance in population is ethical aspects, as WBE does not provide data regarding the individual. In order to assess the infection spread, ideally, smaller subpopulations are monitored to define the outbreak area. This raises some ethical questions, as these areas may be subject to changes introduced by local public health authorities, which may lead to stigmatization in the behaviour of the local population, such as increased activity by people who do not want to be vaccinated [10–12].

The reliability of WBE approach depends on the lowest possible load of viral RNA that can be detected in wastewater. This value is again determined by a number of variables, including the structure of the local sewerage network, the size of the sampling area, the excretion of individuals, and viral RNA quantification methods and back-calculation models [10, 11].

Another potential limitation when considering WBE approach is the ability of the public health service to respond to the findings. Although virus detection is accurate, if data is not delivered to public health authorities in a timely manner and is not used in a timely manner, it is ineffective. In addition, there may be areas where SARS-CoV-2 in faeces can be detected consistently, so these areas need to be closely monitored due to the sudden increase in viral RNA in wastewater [13–15]. Early detection of the presence of SARS-CoV-2 in communities can also give health authorities time to prepare for potential outbreaks and ensure that adequate medical supplies, including ventilators, ICU beds, and operating staff, are available in correlation with the level of risk [16].

CONCLUSION

Monitoring of viruses in wastewater is currently used as an early epidemic warning tool in many countries around the world, with some of them systematically at the level of national programmes. Based on the Recommendation of the European Commission on the introduction of systematic monitoring of SARS-CoV-2 in wastewater of 17 March 2021 [17], which is obligatory for all member states, the Czech Republic will participate in monitoring wastewater from WWTP in towns with more than 150,000 inhabitants.

The results of our research and the conclusions of many ongoing studies clearly show that in its targeted and systematic implementation, wastewater diagnostics can be a suitable approach to the formulation of epidemiological prognoses, and thus the protection of public health. Wastewater monitoring is a sensitive method that can be used at WWTP of various sizes, even with a low prevalence of infected people in the catchment area. In Prague, the functionality of the approach was proven for smaller urban areas and individual buildings (e. g. schools and retirement homes). By adjusting the sampling time, we demonstrated the possibility of increasing the recovery of viral RNA from wastewater samples. For responsible implementation of WBE monitoring, it is necessary to accept differences between the types and purposes of monitoring, the nature of wastewater, and the specifics of sampling points.

Acknowledgments

This paper was created with the support of the project VI04000017 "Use of wastewater monitoring as an early warning tool against the emergence of the epidemiological situation" of the 4. VS BV III programme and institutional resources of the Ministry of the Environment. The authors thank the WWTP operators for their helpful cooperation in providing wastewater samples and the Department of Biostatistics of the NIPH for the provided data on the number of infected people in the monitored localities.

References

[1] BENCKO, V., ŠÍMA, P., BUŠOVÁ, M. Epidemie, pandemie: poučení z historie infekčních nemocí. *Hygiena*. 2021, 66(2), p. 48–54.

[2] RAINETOVÁ, P., FITTLOVÁ, J. Vyšetřování odpadních vod na přítomnost poliovirů a ostatních enterovirů v ČR v roce 2013. *Zprávy Centra epidemiologie a mikrobiologie*. 2014, 23(2), p. 53–54. ISSN 1804-8668.

[3] eAGRI. *Voda – Vybrané údaje z majetkové evidence (VÚME) a provozní evidence (VÚPE) za rok 2019*. 28 January 2021. Available from: http://eagri.cz/public/web/mze/voda/vodovody-a-kanalizace/vybrane-udaje-z-majetkove-a-provozni-evidence-vodovodu-a-kanalizaci/vybrane-udaje-majetkove-evidence-vume-a.html

[4] GHARWALOVÁ, L., JURANOVÁ, E., MLEJNKOVÁ, H., OČENÁŠKOVÁ, V., SOVOVÁ, K., VAŠÍČKOVÁ, P. Optimalizace způsobu odběru vzorků pro monitorování viru SARS-COV-2 v odpadních vodách. *TZB-info*, 1 November 2021. Available from: https://voda.tzb-info.cz/likvidace-odpadnich-vod/23005-optimalizace-zpusobu-odberu-vzorku-pro-monitorovani-viru-sars-cov-2-v-odpadnich-vodach

[5] VAŠÍČKOVÁ, P., HRDÝ, J., KRÁSNA M., SOVOVÁ, K., GHARWALOVÁ, L., MLEJNKOVÁ, H. *Metodický postup analýzy odpadních vod na přítomnost specifických oblastí genomu viru SARS-CoV-2. Metodický postup*. 2022.

[6] BONANNO FERRARO, G., VENERI, C., MANCINI, P. et al. A State-of-the-Art Scoping Review on SARS-CoV-2 in Sewage Focusing on the Potential of Wastewater Surveillance for the Monitoring of the COVID-19 Pandemic. *Food and Environmental Virology*. 2021. Available from: https://doi.org/10.1007/s12560-021-09498-6

[7] HARRIS-LOVETT, S., NELSON, K. L., BEAMER, P., BISCHEL, H. N., BIVINS, A., BRUDER, A., BUTLER, C., CAMENISCH, T. D., DE LONG, S. K., KARTHIKEYAN, S., LARSEN, D. A., MEIERDIERCKS, K., MOUSER, P. J., PAGSUYOIN, S., PRASEK, S. M., RADNIECKI, T. S., RAM, J. L., ROPER, D. K., SAFFORD, H., SHERCHAN, S. P., SHUSTER, W., STALDER, T., WHEELER, R. T., KORFMACHER, K. S. Wastewater Surveillance for SARS-CoV-2 on College Campuses: Initial Efforts, Lessons Learned, and Research Needs. *International Journal of Environmental Research and Public Health*. 2021, 18, 4455. Available from: https://doi.org/10.3390/ijerph18094455

[8] RUSIÑOL, M., ZAMMIT, I., ITARTE, M. et al. Monitoring Waves of the COVID-19 Pandemic: Inferences from WWTPs of Different Sizes. *Science of the Total Environment*. 2021, 787, 147463. Available from: https://doi.org/10.1016/j.scitotenv.2021.147463

[9] *The New York Times. Health – Coronavirus Sewage*. Available from: https://www.nytimes.com/2021/05/07/health/coronavirus-sewage.html.

[10] ZHU, Y., OISHI, W., MARUO, C., SAITO, M., CHEN, R., KITAJIMA, M., SANO, D. Early Warning of COVID-19 Via Wastewater-Based Epidemiology: Potential and Bottlenecks. *Science of the Total Environment*. 2021, 767, 145124. Available from: https://doi.org/10.1016/j.scitotenv.2021.145124

[11] GONZALEZ, R., CURTIS, K., BIVINS, A., BIBBY, K., WEIR, M., YETKA, K. et al. COVID-19 Surveillance in Southeastern Virginia Using Wastewater-Based Epidemiology. *Water Research*. 2020, 186, 116296. Available from: https://doi.org/10.1016/j.watres.2020.116296

[12] IBRAHIM, N. Epidemiologic Surveillance for Controlling Covid-19 Pandemic: Types, Challenges and Implications. *Journal of Infection and Public Health*. 2020, 13(11), p. 1630–1638. Available from: https://doi.org/10.1016/j.jiph.2020.07.019

[13] BIVINS, A., NORTH, D., AHMAD, A., AHMED, W., ALM, E., BEEN, F. et al. Wastewater-Based Epidemiology: Global Collaborative to Maximize Contributions in the Fight Against COVID-19. *Environmental Science & Technology*. 2020, 54(13), p. 7754–7757. Available from: https://doi.org/10.1021/acs.est.0c02388

[14] MLEJNKOVA, H., SOVOVA, K., VASICKOVA, P., OCENASKOVA, V., JASIKOVA, L., JURANOVA, E. Preliminary Study of Sars-Cov-2 Occurrence in Wastewater in Czech Republic. *International Journal of Environmental Research and Public Health*. 2020, 17, 5508. Available from: https://doi.org/10.3390/ijerph17155508

[15] PALEOLOGOS, E., O'KELLY, B., TANG, C., CORNELL, K., RODRÍGUEZ-CHUECA, J., ABUEL-NAGA, H. et al. Post Covid-19 Water and Wastewater Management to Protect Public Health and Geoenvironment. *Environmental Geotechnics*. 2021, 8(3), p. 193–207. Available from: https://doi.org/10.1680/jenge.20.00067

[16] LOWE, N., BENCKO, V. Using Wastewater Based Epidemiology (WBE) as an Upcoming Tool for Prediction and Control of Covid-19 Disease Outbreaks. *American Journal of Biomedical Science & Research*. 2021, 14(2), p. 182–183/AJBSR.MS.ID.001975. Available from: https://doi.org/10.34297/AJBSR.2021.14.001975

[17] *Doporučení Evropské komise na zavedení systematického monitoringu SARS-CoV-2 v odpadních vodách ze dne 17. 3. 2021* (Commission recommendation of 17 March 2021 on a common approach to establish a systematic surveillance of SARS-CoV-2 and its variants in wastewaters in the EU)

Authors

RNDr. Hana Zvěřinová Mlejnková, Ph.D.[1]
✉ hana.mlejnkova@vuv.cz
ORCID: 0000-0002-3892-6226

Ing. Lucia Gharwalová, Ph.D.[1]
✉ lucia.gharwalova@gmail.com

Mgr. Kateřina Sovová, Ph.D.[2]
✉ katerina.sovova@vuv.cz
ORCID: 0000-0002-2067-7081

Mgr. Petra Vašíčková, Ph.D.[3]
✉ vasickova@vri.cz
ORCID: 0000-0001-6281-5799

Mgr. Jakub Hrdý[3]
✉ hrdy@vri.cz
ORCID: 0000-0002-0890-5811

Mgr. Magdaléna Krásna[3]
✉ krasna@vri.cz
ORCID: 0000-0003-2988-8894

Ing. Věra Očenášková[1]
✉ vera.ocenaskova@vuv.cz
ORCID: 0000-0001-8692-2417

Prof. MUDr. Vladimír Bencko, DrSc.[4]
✉ vladimir.bencko@lf1.cuni.cz
ORCID: 000-003-1935-2228

Prof. MUDr. Milan Tuček, CSc.[4]
✉ milan.tucek@lf1.cuni.cz
ORCID: 0000-0001-6398-5925

RNDr. Milena Bušová, CSc.[4]
✉ milena.busova@lf1.cuni.cz
ORCID: 0000-0003-0668-8769

Ing. Eva Juranová[1]
✉ eva.juranova@vuv.cz
ORCID: 0000-0001-9021-7307

[1]T. G. Masaryk Water Research Institute, Prague
[2]T. G. Masaryk Water Research Institute, Brno
[3]Veterinary Research Institute, Brno
[4]First Faculty of Medicine Charles University, Institute of Hygiene and Epidemiology, Prague

The paper has been peer-reviewed.

DOI: 10.46555/VTEI.2022.01.004

Detection of gully erosion using Global Navigation Satellite Systems in Myjava – Turá Lúka

MICHAELA DANÁČOVÁ, MILICA ALEKSIĆ, MATÚŠ TOMAŠČÍK, ANNA LIOVÁ, ROMAN VÝLETA

Keywords: gully erosion – monitoring – Global Navigation Satellite Systems (GNSS)

SUMMARY

This paper shows the partial outcomes of a study focused on monitoring gully erosion in the Myjava river basin. The study showed the progress of dynamic changes in gully erosion in the location of Turá Lúka using various surveying techniques from 2014 until present. The study shows that selection of the surveying technique depends on various criteria and the aims of the task, where each possesses advantages and disadvantages. In the case of determination of the parameters of gully erosion (volume, length, and position), one of the suitable surveying techniques is Terrestrial Laser Scanning (TLS) as well as Unmanned Aerial Vehicles (UAV), which results in a point cloud. Measurement using Global Navigation Satellite Systems (GNSS) with a GPS device is sufficient for assessing gully erosion in transverse profiles, more complex sections, or in places with built anti-erosion and stabilization dams in a gully. This assumption was confirmed based on results from field measurements of an erosion gully by GNSS technology in 2017–2021. Evaluation of the results is given in this article. The given method of mapping the erosion gully was chosen for the need for detailed profile evaluation of previously identified critical sections (transverse profiles) of the monitored erosion form based on field surveying and area scanning and for simple data processing. The simplicity of this method due to the type of task, staffing, time, and volume of data predetermines and confirms the suitability of its selection for use under the given circumstances. When choosing this measuring technique, the requirements are easy access to the measuring point and a good satellite signal for GPS devices influencing the accuracy of the measurement concerning the surrounding vegetation. Sufficient testing and comparison of available surveying techniques make it possible to efficiently and realistically select suitable effective technology for monitoring erosive forms in the landscape for a predefined purpose. Contributions of this type will help researchers of similar tasks in decision-making when choosing the most suitable landscape surveying technology.

INTRODUCTION

In its acceptable form, soil erosion is a natural process occurring in the landscape; however, in terms of the long-term negative effect on the productive capacity of the soil, this type of soil degradation should be considered as a significant environmental threat [1]. Nevertheless, imprudent anthropogenic activities in the landscape often contribute to an increase in soil erodibility [2]. Water erosion is one of the most significant environmental degradation risks which have a negative influence on the deterioration of basic soil parameters and soil functions in Slovakia. Its unacceptable or accelerated form on agricultural soils not only significantly affects both productive and non-productive soil functions, but it also has high potential to threaten built-up areas in the form of muddy flash floods. These are caused by extreme rainfall falling on a relatively small area of land over a short period of time, when there is concentrated surface runoff and transport of soil particles from higher agricultural areas to areas of lower altitude. This disruption of the soil profile creates indentations (rills and gullies) in the land surface which tend to deepen over time. In addition to the defining characteristics of the relief in terms of soil erosion (i. e., the contributing area and slope conditions), the concentration of surface runoff is often determined by farm roads with fall-line and oblique orientation, interfaces between fields, and furrows left by the wheels of agricultural machinery [3]. The consequence of accelerated and concentrated runoff and erosion processes is the existence and intensive formation of temporary or permanent erosion rills and gullies. In order to solve gully erosion, it is necessary to determine its location, and to measure and monitor the development of its changes and dynamics for the design of elimination or stabilization measures.

Modern advanced technologies, which are associated with experimental field work and data collection, are currently used for the purposes of modelling [4, 5] and monitoring natural erosion-transport processes and their elements in the landscape [6–9]. Progressive monitoring techniques mainly include Terrestrial Laser Scanning (TLS), Light Detection and Ranging (LIDAR), and the use of Unmanned Aerial Vehicles or drones (UAV). They make it possible to obtain information on land use type, morphology, and vegetation cover characteristics [10–13] in a relatively short time, over relatively large areas, and without the need for field work. In some cases, however, the use of these technologies is impractical and cannot be easily applied, either because of the location of the erosion feature (rill or gully) in the landscape, its dimensions, or the vegetation cover. Classic methods and measurement techniques, such as geodetic measurements (tachymetry) or global navigation satellite system (GNSS) methods, can then be used to acquire and collect spatial data of these surface and linear undesirable forms of soil erosion.

This paper aims to summarise the findings and results from field measurements in the form of a case study and to analyse the occurrence and dynamics of the erosion gully development in its critical sections (transverse profiles) within the site of Myjava – Turá Lúka by means of continuous long-term measurements (for 2014–2021) using GNSS technology.

STUDY REGION

The area of the Myjava Hills (Myjavská pahorkatina) is situated in western Slovakia and is characterised by a significant occurrence of erosion rills and gullies, the formation of which is associated with shifting cultivation and colonisation, accompanied to a large extent by deforestation of the area and its subsequent use for agricultural activities. The ruggedness of the terrain, significant slope conditions, large-scale cultivation of land, and specific land use (especially the slopes used for cultivation) create ideal conditions for the formation of erosion-transport and runoff processes, which give rise to a harmful form of soil erosion (erosion rills and gullies).

The monitored erosion gully is situated on a cultivated slope near the residential district of Turá Lúka – Myjava. The slope research area has 0.3 km^2 in the flysch zone with limestone blocks of the White Carpathians and it is located in the geomorphological unit of the Myjava Hills. From the pedological point of view, it is mainly dominated by Cambisols. In terms of climatic conditions, the area belongs to a moderately warm, humid zone with cool to cold winters, with an average annual rainfall of 600–700 mm and an average annual air temperature of 8 °C. From the hydrological point of view, the area is particularly vulnerable in the summer (the highest rainfall was recorded in May–July) and in the winter-spring period when snow and precipitation melt. The combination of hydrometeorological conditions, relief, land use, and low permeability of the bedrock contribute to the development of the erosion gully in the area. At present, the length of the gully is approximately 300 m, and its average longitudinal slope is 10%. Based on military mapping, occurrence of this erosion form was identified in the study region as early as in the 19th century [14]. In the 1990^{s}, the erosion gully was filled in with soil and the area was then used for agricultural purposes. Over time, under the influence of heavy rainfall and snowmelt in the rugged terrain, an erosion rill, which tended to expand into a gully, was re-established in the fall line of the large-scale cultivated slope. Due to development over time and the parameters (length and depth) of the erosion gully, it could no longer be cultivated and was consequently classified as permanent. The gully was left to become overgrown with self-seeded trees and permanent grassland (to aid its stabilisation) and was removed from agricultural use (*Fig. 1*).

Due to the occurrence of muddy floods after torrential summer rains and during spring snowmelt, when extreme surface runoff along with eroded material caused siltation of roads and residences, the erosion gully was included in the project "*Landscape Revitalization and Integrated Watershed Management Programme of the Slovak Republic*" in 2010. Within this project´s implementation, seven small wooden check dams were constructed in the gully as a form of anti-erosion and stabilisation measures (*Fig. 1*).

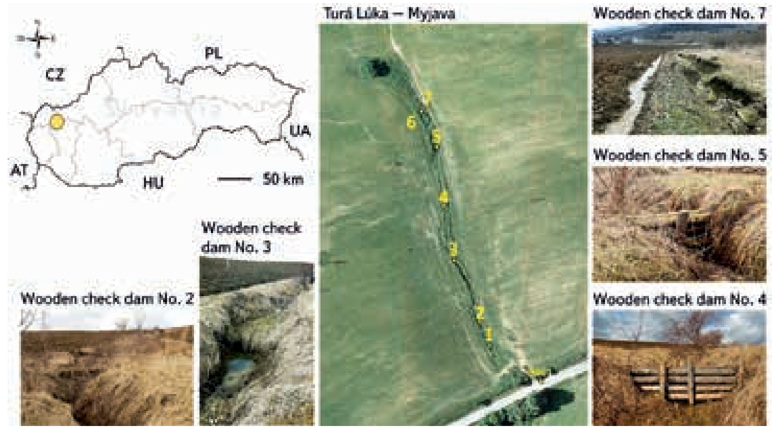


Fig. 1. Location of the study region of the erosion gully with 7 small wooden check dams

Fig. 2. The photo documentation of the erosion gully using GNSS technology from 2017–2021

MATERIAL AND METHODS

The monitoring of the erosion gully site in Myjava – Turá Lúka was closely linked to the RECARE project (2014–2019, implemented under the EU 7th Framework Programme), the results of which were used in the development of EU legislation aimed at soil protection and ensuring sustainable agriculture and food security. Several surveying techniques were applied to measure the erosion gully (in 2014–2021); their selection depended on availability, time demands, accuracy of the measurements, but also on the conditions resulting from the season of the field measurements and the occurrence of vegetation cover. The field measurements were carried out at least once a year and the monitoring has continued until now.

In 2014, the study region was mapped using UAV technology, namely the unmanned aerial vehicle Gatewing X100 with fixed wings. In the spring periods of 2015 and 2016, the erosion gully was measured in detail using TLS technology, namely the Trimble TX5 3D laser scanner with phase shift measurement accuracy of 2 mm/25 m. The application of these modern technologies for landscape surveying was associated not only with the planning and preparation of the measurement, the collection of point data in the field and experimental work, but also the subsequent processing of the measured data and, last but not least, analysis of the results, including evaluation of the territory´s geomorphological characteristics. Partial results of these measurements were published continuously in [15].

The use of modern surveying technologies to monitor erosion features in the landscape requires that the land surface be largely cleared of extensive vegetation (e. g., grassland, shrubs, and self-seeded trees), which is labour and time intensive. That is why, since 2017, the erosion gully has been monitored only using GNSS technology, i. e., a Leica System GS15 GNSS with a connection to the Slovak Real-Time Positioning Service (SKPOS, generating so-called network corrections of geodetic coordinates in real time), because of the presence of full-grown vegetation in the gully. This technology is easy to process the measured data, but data collection requires creation of a point field, i. e., a density of points, where each point has a precise horizontal and vertical position. *Fig. 2* shows the state of vegetation when changes were measured in the erosion gully in 2017–2021.

RESULTS

According to [16], gully erosion was categorised in the past based on the determination of the gully´s basic parameters (length, slope, average depth, and width). These parameters were mostly determined in evenly spaced transverse profiles. In the case of the erosion gully, monitoring was therefore aimed at determining its bottom or axis (main line) and edges in the selected 20 transverse profiles along its length (*Fig. 3*). The reason for this was to detect geomorphological changes of the gully in places where siltation by eroded sediment from higher areas had been proved.

Information on the date of measurement as well as the number of points measured is given in *Tab. 1*.

In [17], the effectiveness of anti-erosion measures in the profiles immediately in front of 7 small wooden check dams was reviewed for the period 2014–2017 (*Fig. 1*), and they were later updated and supplemented in [18]. Geomorphological changes occur along the entire gully, even outside these dams. That is why, in this paper, the analysis of the gully changes was measured on the locations of selected, partly uniformly distributed transverse profiles, regardless of the locations of the dams (*Fig. 3*). As of 2017, points in a total of 20 transverse profiles are being measured using the Leica System GS15 GNSS, but only 18 profiles have been measured in the last 2 years (year 2020–2021). Profiles 19 and 20 have been excluded from monitoring due to their complete siltation by transported sediment and due to the increasing density of vegetation and trees. The problem is access to the site of measurement and shading of the vegetation itself, as in most cases the satellite signal is lost, thus significantly increasing measurement inaccuracy. In such a case, the possibility remains to measure these transverse profiles using a total station. However, this measurement method has not been applied.

Fig. 3. Location of the 20 transverse profiles in the gully erosion: the black arrow shows 9 selected profiles (base map: GKÚ Bratislava, NLC, 2019)

Tab. 1. Overview of measured points in the profiles of the erosion gully using GNSS from 2017–2021

Year/month	Point field
2017/08	191 points
2018/06	248 points
2019/04	164 points
2020/07	153 points
2021/11	210 points

For the purposes of evaluating the erosion gully´s condition, 9 transverse profiles were selected, namely profiles 1, 3, 4, 7, 10, 12, 14, 16, and 18 (*Fig. 3*). Their graphic representation is presented in *Fig. 4*. Profiles 1 and 10 (for 2019, marked as NO DATA) are not shown in the results and comparisons because they were not measured due to unfavourable weather and bad access to the site of measurement, or loss of satellite signal.

Some profiles could not be included because their lines of measurement were not completely identical in each year. They were therefore excluded due to the impaired possibility of correct evaluation of the development of change in the erosion gully´s morphology. It was possible to conclude by visual assessment that expected minor changes had become evident in the head, i. e. the uppermost part of the gully. In this widest part of the gully, there are relatively small depths and several small rills alongside. The minor changes are also caused by a lower slope and a smaller drainage area in this part of the gully. Above the head of the gully, water appears on the ground surface throughout the year. The gully already reaches a depth of more than 1 m approximately 80 m from the head of the erosion gully, i. e. from profile 4. It is seen from the graphic representation of the transverse profile measured in 2019 that it has a different course. This is caused by the fact that the direction of the line of points measured in profile 4 was not maintained as it had been in the other years. Consequently, this year was excluded from the overall comparison of the gully´s shape and parameters in this profile. In the central part of the gully (profiles 7 to 14), in a 100–190 m long section, there was no change of the deepest part, i. e. the axis of the main gully. It varies between 1.5–2 m, but the change in shape, or the formation of secondary ephemeral (temporary) rills, was only apparent in profile 12. This section has the highest slope conditions, with slopes of up to 20%. Siltation by transported particles can be observed in the lower part of the erosion gully (comparison of profiles 16 to 18). A more detailed analysis of gully erosion in this location would require repeated measurements using modern technology (UAV or TLS), as was done in 2014–2016, or using GNSS technology with a much higher number of point measurements, which is significantly more time consuming.

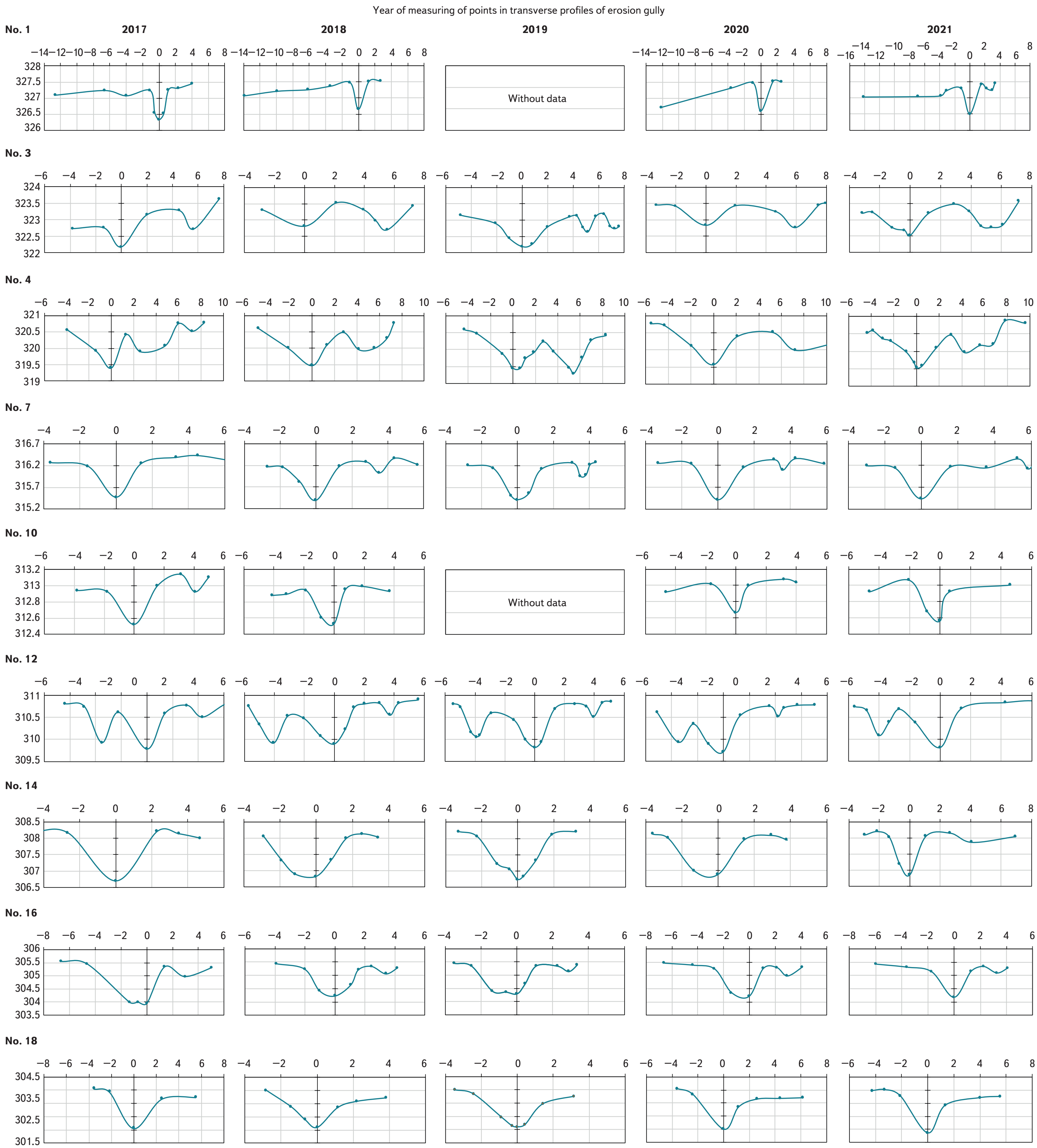


Fig. 4. Selected transverse profiles of erosion gully measured using GNSS technology from 2017–2021

CONCLUSIONS AND DISCUSSION

The paper presents the results of field measurements (2017–2021) of an erosion gully in the locality of Myjava – Turá Lúka. To analyse gully erosion, 9 transverse profiles located along the erosion gully were selected, the points of which were measured using GNSS technology. Their evaluation consisted of comparison of the shape of the transverse profile, change of the maximum depth, which can detect their deepening (incision), bottom silting or erosion, or landslide of the gully´s side slopes. Measurement efficiency is considered to be one of the main advantages of this method, since measurement and subsequent evaluation of the points determining change in the erosion gully´s shape can be carried out by as little as one person. However, care must be taken to measure the points in the same line of the profile so that they can be compared correctly.

Evaluation of the results of field measurements confirmed that the upper part of the erosion gully has a more complex shape, but no significant change occurs in its depth or shape due to the presence of abundant vegetation. In the middle part, slight changes in both horizontal and vertical direction were observed, with the most significant changes occurring in the profiles located in the lower part of the erosion gully, where siltation was expected. It is possible on the basis of long-term monitoring of the erosion gully to review current stabilisation measures as well as the possibility of implementing further protection and stabilisation measures to reduce erosion-transport and runoff processes in the area. Monitoring of the erosion gully is therefore justified and should be continued in the following period, also considering the possible impact of climate change in the form of more extreme torrential rainfall events. ore detailed measurement (e. g. by UAV or TLS technology) would be appropriate every 2–3 years in the spring period due to still undeveloped extensive vegetation, as was the case in 2014–2016. This would ensure evaluation of the position of bed line (the gully´s axis), the gully´s length, and its volume. Point measurements in the profiles in front of the wooden check dams and selected transverse profiles are sufficient once a year. On the other hand, there are several possibilities for field surveying, and it cannot be disregarded that spatial data obtained from Light Detection and Ranging (LIDAR), the Geodesy, Cartography and Cadastre Authority of the Slovak Republic (ÚGKK SR), are now publicly available, too. Data from this source could also be used for this type of task in the future, and it would be interesting to compare them with field measurements.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under contract No. APVV-19-0340 and APVV-18-0347. It was also prepared thanks to the financial support of the grant project VEGA 1/0632/19.

References

[1] LABUDA, M. Hodnotenie recentného stavu mimoprodukčných funkcií poľnohospodárstva (modelový príklad). *Acta Environmentalica Universitatis Comenianae* (Bratislava). 2009, 17(1), p. 53–70 ISSN 1335-0285.

[2] STANKOVIANSKY, M. *Geomorfologická odozva environmentálnych zmien na území Myjavskej pahorkatiny*. Bratislava: UK, 2003. 152 p.

[3] STANKOVIANSKY, M. Vplyv dlhodobého obrábania pôdy na vývoj slovenských Karpát. *Acta geographica Universitatis Comenianae*. 2008, 50, p. 95–116.

[4] NÉMETOVÁ, Z., HONEK, D., KOHNOVÁ, S., HLAVČOVÁ, K., ŠULC MICHALKOVÁ, M., SOČUVKA, V., VELÍSKOVÁ, Y. Validation of the EROSION-3D Model through Measured Bathymetric Sediments. *Water*. 2020, 12(4), 1082. ISSN 2073-4441.

[5] MEINEN, B. U., ROBINSON, D. T. Agricultural Erosion Modelling: Evaluating USLE and WEPP Field-Scale Erosion Estimates Using UAV Time-Series Data. *Environmental Modelling & Software*. 2021, 137, 104962. ISSN 1364-8152. Available from: https://doi.org/10.1016/j.envsoft.2021.104962

[6] WELLS, R. R., MOMM, H. G., BENNETT, S. J., GESCH, K. R., DABNEY, S. M., CRUSE, R., WILSON, G. V. A Measurement Method for Rill and Ephemeral Gully Erosion Assessments. *Soil Science Society of America Journal*. 2016, p. 203–214.

[7] HLAVČOVÁ, K., DANÁČOVÁ, M., KOHNOVÁ, S., SZOLGAY, J., VALENT, P., VÝLETA, R. Estimating the Effectiveness of Crop Management on Reducing Flood Risk and Sediment Transport on Hilly Agricultural Land – A Myjava Case Study, Slovakia. *CATENA*. 2019, 172, p. 678–690. Available from: doi: 10.1016/J.CATENA.2018.09.027

[8] VALENT, P., VÝLETA, R., DANÁČOVÁ, M. A Joint Sedimentation-Flood Retention Assessment of a Small Water Reservoir in Slovakia: A New Hope for Old Reservoirs? *Geosciences*. 2019, 9(4), p. 158. Available from: doi: 10.3390/geosciences9040158

[9] DOUGLAS-MANKIN, K. R., ROY, S. K., SHESHUKOV, A. Y., BISWAS, A., GHARABAGHI, B., BINNS, A., RUDRA, R., SHRESTHA, N. K., DAGGUPATI, P. A Comprehensive Review of Ephemeral Gully Erosion Models. *CATENA*. 2020, 195, 104901. ISSN 0341-8162. Available from: https://doi.org/10.1016/j.catena.2020.104901

[10] CASTILLO, C., PÉREZ, P., JAMES, M. R., QUINTON, J. N., TAGUAS, E. V., GÓMEZ, J. A. Comparing the Accuracy of Several Field Methods for Measuring Gully Erosion. *Soil Science Society of America Journal*. 2012, 76, p. 1319–1332.

[11] ELTNER, A., MULSOW, C. A., MAAS, H.-G. Quantitative Measurement of Soil Erosion from TLS and UAV Data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2013, XL-1/W2, p. 119–124.

[12] NEUGIRG, F., KAISER, A., SCHMIDT, J., BECHT, M., HAAS, F. Quantification, Analysis and Modelling of Soil Erosion on Steep Slopes Using LIDAR and UAV Photographs. *Proceedings of the International Association of Hydrological Sciences*. 2015, 367, p. 51–58.

[13] UYSAL, M., TOPRAK, A. S., POLAT, N. DEM Generation with UAV Photogrammetry and Accuracy Analysis in Sahitler Hill. *Measurement*. 2015, 73, p. 539–543.

[14] DANÁČOVÁ, M., NOSKO, R., VÝLETA, R., KARABOVÁ, B., SZOLGAY, J. Possibilities of Estimating the Gully Erosion Changes on the Myjava Basin. *Acta Hydrologica Slovaca*. 2015, 16, TC 1, p. 167–175.

[15] NOSKO, R., VÝLETA, R., FRAŠTIA, M., ŠKRINÁR, A., DANÁČOVÁ, M. Estimation of Changes in Erosion Gully on a Hillslope. In: *SGEM 2016. 16th International Multidisciplinary Scientific GeoConference. Book 3. Water Resources. Forest, Marine and Ocean Ecosystems: Conference Proceedings. Extended Scientific Sessions. Vienna, Austria, 2–5 November 2016*. 1. vyd. Sofia: STEF 92 Technology, 2016, p. 95–102. ISSN 1314-2704.

[16] ZACHAR, D. *Erózia pôdy*. Bratislava: Vydavateľstvo SAV, 1970. 528 p.

[17] NOSKO, R., VÝLETA, R., MALIARIKOVÁ, M., DANÁČOVÁ, M. Monitoring of the Gully Erosion Technical Measures Efficiency through the Use of Modern Technologies. *Acta Hydrologica Slovaca*. 2018, 19(1), p. 84–92.

[18] DANÁČOVÁ, M., VÝLETA, R., ALEKSIĆ, M., MALIARIKOVÁ, M., NOSKO, R. Comparing Changes over Time: The Permanent Gully Erosion on the Myjava Hill Lands (Slovakia). In: *Public Recreation and Landscape Protection – with Sense Hand in Hand!: Conference Proceedings. 10th–11th May 2021*. (on-line). 1. vyd. Brno: Mendelova univerzita, 2021, p. 84–88. ISSN 2336-6311. ISBN 978-80-7509-779-8.

Authors

doc. Ing. Michaela Danáčová, PhD.
✉ michaela.danacova@stuba.sk
ORCID: 0000-0002-5789-5365

Ing. Milica Aleksić
✉ milica.aleksic@stuba.sk
ORCID: 0000-0001-6332-0851

Ing. Bc. Matúš Tomaščík
✉ matus.tomascik@stuba.sk
ORCID: 0000-0001-7650-4211

Ing. Anna Liová
✉ anna.liova@stuba.sk
ORCID: 0000-0002-7165-2378

Ing. Roman Výleta, Ph.D.
✉ roman.vyleta@stuba.sk
ORCID: 0000-0002-4594-2515

Slovak University of Technology in Bratislava, Faculty of Civil Engineering,
Department of Land and Water Resources Management

The paper has been peer-reviewed.

DOI: 10.46555/VTEI.2022.01.005

Photo: 123rf.com

Changes in precipitation and runoff in river basins in the Czech Republic during the period of intense warming

LADISLAV KAŠPÁREK, ROMAN KOŽÍN

Keywords: increasing air temperature — changes in atmospheric precipitation — changes in runoff from the river basin

SUMMARY

The basic meteorological variables that affect the hydrological regime are atmospheric precipitation and air temperature. Both fluctuate not only in the short term and in the annual cycle, but also in the long term. Long-term changes in both of these variables have the character of periodic fluctuations around the mean values. Since about 1980, there has been a systematic increase in air temperature in the Czech Republic. This article provides information on how the climate fluctuations that this change brings affect the precipitation and runoff regime in our territory.

In the first part of the study, we used long-term observations of flows in the river Elbe in Děčín since 1851 and precipitation in its catchment area and compared the deviations in precipitation and runoff from the period after 1980 with the extremes of fluctuations in the previous period. Fluctuations in forty-year moving averages of annual and seasonal precipitation and annual and seasonal runoff, with the exception of an increase in winter runoff, did not deviate from the range in which they fluctuated in the period 1851–1980.

In the next part, we focused on the assessment of possible deviations in precipitation and runoff during the warming period in seven major river basins from different areas of the Czech Republic. In the period 1981–2019, compared to the previous period 1961–1980, the average annual precipitation in four river basins increased by 2% to 4%, in the Ohře river basin by 7.5%. In the Elbe river basin (above its confluence with the Vltava) the increase was by about 1%. In the Odra river basin the annual rainfall averages decreased by 3%. The increase in annual precipitation was mainly due to increases in winter and autumn precipitation, with significant decreases in spring precipitation in three river basins and summer precipitation in two river basins. The average flow in the period 1981–2019 was lower at all compared gauging stations than in the period 1961–1980, on a relative scale by up to 17% at the Bohumín (Odra river) station and by at least about 2% at Louny (Ohře river).

When comparing the results for the Sázava, Lužnice, Berounka, and Ohře, we found that, from east to west, the decreases from values slightly exceeding 10% change to practically unchanged flow of the Ohře.

INTRODUCTION

The Hydrological Service in the Czech Republic has traditionally related the characteristics of average flows to a specific „representative" period from which data were used to derive them. The principal publication [1] *Hydrological conditions of the Czechoslovak Socialist Republic* was based on the period 1931–1960. A change did not occur until 1980, when the thirty-year period was extended to a fifty-year period of 1931–1980, evaluated in a 1997 study [2]. Further assessment of possible changes in the hydrological regime is contained in [3], which compares the precipitation and flow characteristics from 1981–2010 with those from 1931–1980, which the Czech Hydrometeorological Institute has been using since 2013. The results of this study concluded that there were no significant changes in annual precipitation totals and significant differences in flow characteristics due to natural change in runoff conditions. Immediately after 2013, a multi-year hydrological drought occurred in the Czech Republic, which, according to the study [4], was the longest of all droughts in the Elbe river basin since 1851.

In this study, we try to find out whether using the observed series of precipitation and flows until 2019, which includes the period of drought (precipitation and hydrological), we find the effect of warming on long-term averages of precipitation and flows. In the first part of the study, we took long-term observations of flows of the river Elbe in Děčín since 1851 and precipitation in its catchment area; these were compared with changes in forty-year average precipitation and runoff from the period after 1980 with their fluctuations in the previous period unaffected by intense warming. In the following part, we focused on the assessment of possible changes in precipitation and runoff after 1980 in regional differentiation; that is, we focused on how the average precipitation and runoff in river basins in different areas of the Czech Republic in the period 1981–2019 differ from the averages in the period 1961–1980, in which the air temperature was not yet increasing significantly.

COMPARISON OF PRECIPITATION AND RUNOFF ON THE ELBE RIVER BASIN IN THE PERIOD 1981–2019 WITH THEIR LONG-TERM FLUCTUATIONS

We first dealt with changes in long-term average precipitation and long-term average runoff levels during the warming period compared to their long-term fluctuations between 1851–2019. The choice of the Elbe river basin in Děčín is due to the fact that it occupies a substantial part of Bohemia and a long-term series of average monthly precipitation and runoff from the period 1851–2019 has been prepared for it. Since 1851, water levels have been systematically monitored on the Elbe in Děčín, and later in his work [5] Novotný reconstructed the flows for the historical period. We used flow values supplemented by water

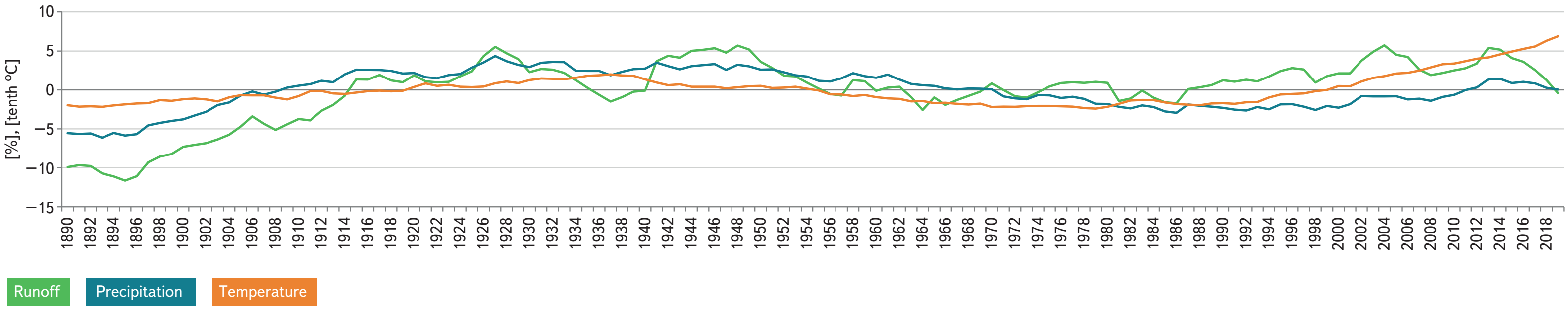


Fig. 1. Relative deviations of forty-year moving averages of average annual precipitation and annual runoff heights in [%] and deviations of forty-year moving averages of average annual air temperatures, scale in tenths of °C

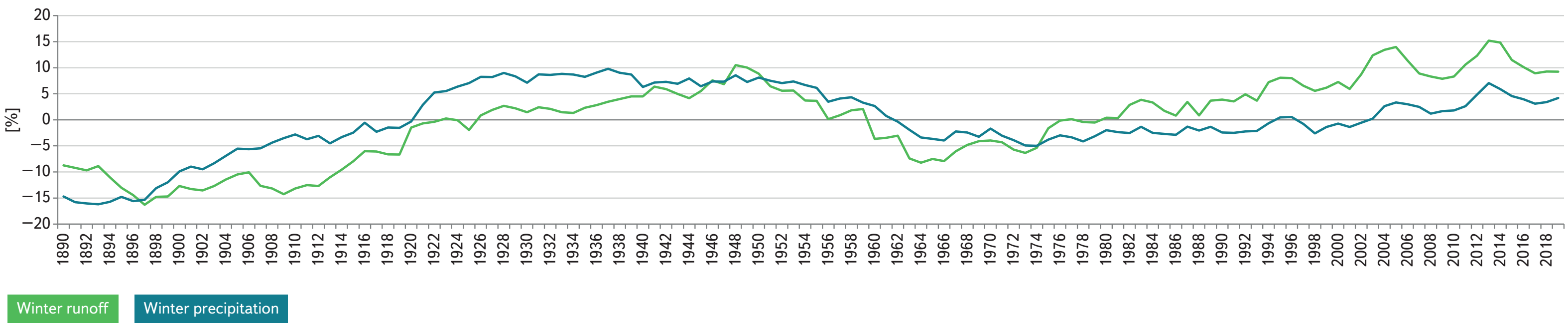


Fig. 2. Relative deviations of forty-year moving averages of average precipitation and runoff heights for the months December to February

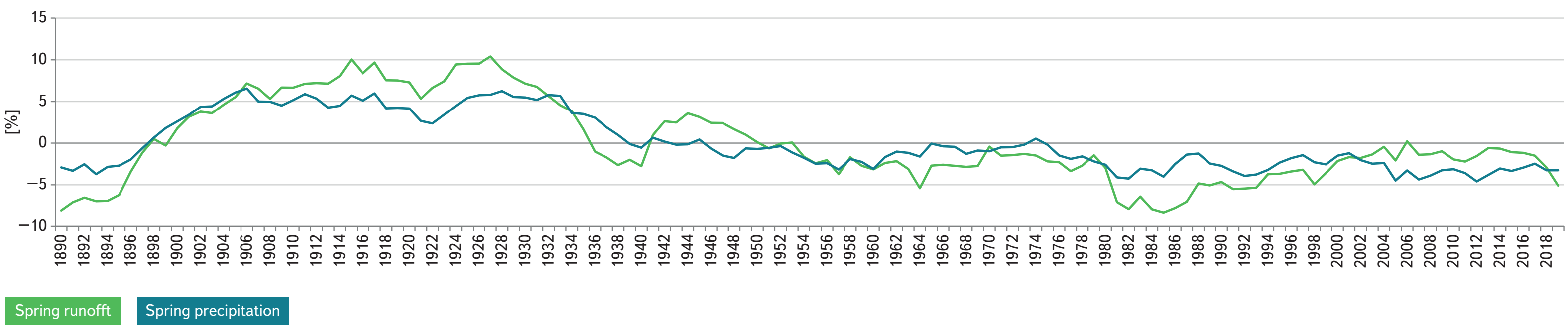


Fig. 3. Relative deviations of forty-year moving averages of average precipitation and runoff heights for March to May

abstraction, wastewater discharge, and activities on water reservoirs in the catchment area. These data have only been available since 1979, which may add additional inaccuracy to the comparison results for seasonal and monthly averages.

Average precipitation in the Elbe river basin in Děčín in 1851–1875 is burdened by considerable uncertainty. Until 1828, it is estimated only from observations from Klementinum; from 1829, observations in Havlíčkův Brod were added, and from 1848, observations in Čáslav were added. Data from 55 stations have been available since 1876 and from 382 precipitation stations since 1880.

Air warming, which is part of global climate change, has been intense in the Czech Republic since 1980. This phenomenon is evident in the display of deviations of moving average air temperatures for a forty-year period in the Elbe river basin in Děčín, calculated by the difference in a number of annual averages from 1851–2019 from the average temperature for this period (see *Fig. 1*). *Fig. 1* also shows the deviations of the forty-year moving averages of average annual precipitation and annual levels of runoff from this river basin in the form of relative values in [%] of averages for the whole period.

Analysis of the longest series of monitored flows in the Czech Republic, for example in the study of long-term fluctuations of Vltava flows in Prague [6], revealed that average flows fluctuated to a significant degree in the past. The fluctuations have periodic components, which is also evident in the data from watercourses worldwide, as demonstrated by Pekárová [7]. This phenomenon must be taken into account when assessing the possible effect of warming on changes in runoff regime.

Fig. 1 shows that, even with a relatively long averaging interval of 40 years, precipitation averages fluctuate around 10% and the fluctuation has a cyclic character, with a wavelength of about 90 to 100 years. If the nature of the fluctuations has not changed, we are currently on the ascending part of the cycle. Květoň and Žák came to the same conclusion [8] during the evaluation of the precipitation series 1808–2019 from the Prague Klementinum station.

Leaving aside the different courses of relative deviations of forty-year moving averages of precipitation and runoff before 1915, which may be related to the uncertainty of precipitation estimates before 1875, we find a similar course of deviations of both quantities until about 1988. Then, until 2013, runoff deviations are relatively greater than precipitation deviations. The following period of drought caused a decrease in runoff; therefore, the forty-year averages of precipitation and runoff for the period 1981–2019 are very close to the averages for the whole period 1851–2019, and thus the effect of warming is not apparent

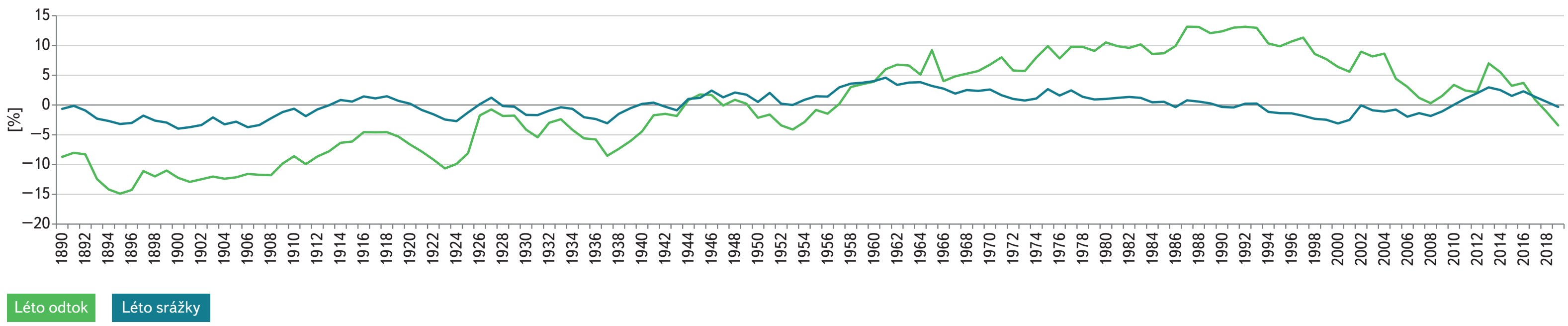


Fig. 4. Relative deviations of forty-year moving averages of average precipitation and runoff heights for the months June to August

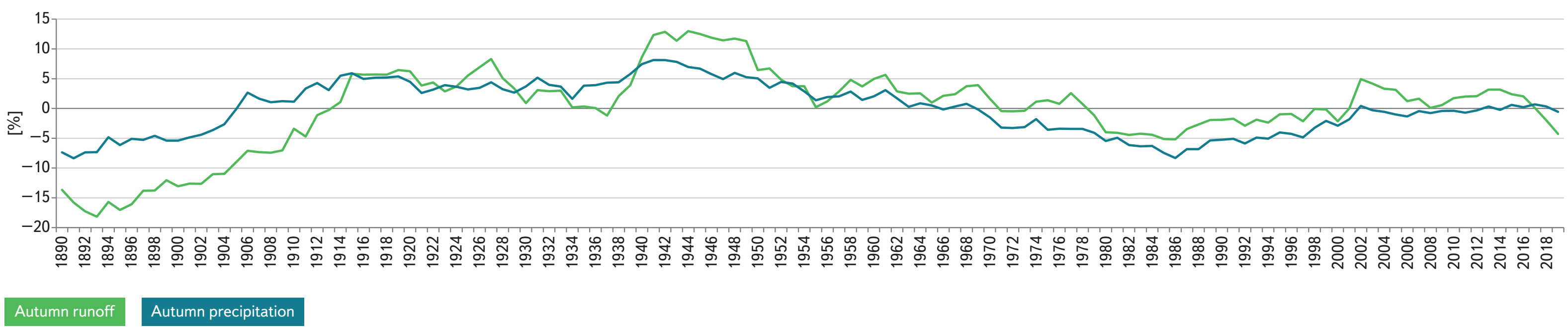


Fig. 5. Relative deviations of moving averages of average precipitation and runoff heights for the months of September to November

in the long-term annual averages of precipitation and runoff from the period of intense warming in the data for the Elbe river basin in Děčín.

To clarify which phases of the annual runoff cycle contributed to the described difference in runoff and precipitation deviations, we created graphs comparing the relative deviations of the forty-year averages of precipitation and runoff from the four seasons. The year is divided into the period December to February (winter), March to May (spring), June to August (summer), and September to November (autumn).

The courses of forty-year moving averages of seasonal average precipitation and runoff show the following:

Winter precipitation and runoff have had an upward trend since about 1975, and runoff has deviated from the range of values that occurred in the previous part of the series since 2002. This can be explained by the fact that due to higher temperatures, more snow will melt during the winter due to increasing precipitation.

Spring precipitation from the above-average level in 1933 decreased by about 10% to the level of 1983, and then i fluctuated only slightly around this level. Runoff from the maximum in 1927 decreased by about 18% by 1980, and then were increasing until 2013. After a short decrease in runoff, the deviations in precipitation and runoff in the forty-year period 1981–2019 almost agreed at the level of −4% to −5%.

On a relative scale, summer precipitation did not fluctuate much in the long run, in contrast to summer runoff; its course deviates significantly from the course of precipitation than in other seasons. In the forty-year periods ending before 1925, the precipitation estimate is probably less accurate. In the following period, until about 1954, the course of runoff deviations and precipitation deviations did not differ much. After 1954, the difference between runoff and precipitation deviations gradually increased. We explain this by the fact that during the summer floods in 1954, 1981, 1997, and 2002, the runoff coefficient from several days of intense precipitation was significantly higher than from a comparable total of less intense precipitation distributed over a longer period of time. After 2002, the relative deviations of runoff were decreasing,

Tab. 1. Relative deviations of annual and seasonal precipitation and runoff in the Elbe river basin in Děčín [%] in the period 1981–2019 with respect to the whole period 1851–2019

	Year	XII–II	III–V	VI–VIII	IX–XI
Precipitation	0.04	3.39	−3.25	0.53	0.32
Runoff	−0.42	9.27	−5.08	−3.42	−1.99

Tab. 2. Shares of averages of seasonal precipitation and seasonal runoff on the annual average [%]

	Winter	Spring	Summer	Autumn
Precipitation	19	24	36	21
Runoff	27	37	19	17

in the forty-year period 1981–2019, after a period of hydrological drought, up to the value of −4%.

Autumn precipitation and runoff were similarly decreasing from the level after 1941 by about 16% until 1988, then again increased similarly to average values; runoff after 2013 decreased to −4%.

The course of the quantities in *Fig. 3* to *5* result in the following findings:

The fluctuations of the forty-year moving averages of seasonal precipitation and runoff, with the exception of the rise in winter runoff in the period after 2002, did not deviate from the range in which they fluctuated in the period 1851–2019.

According to the data from *Tab. 1*, the annual average precipitation in the Elbe river basin in Děčín practically did not change. The increase in winter precipitation and the decrease in spring precipitation are obvious. The changes in runoff are larger on a relative scale; the increase in winter runoff is in contrast to the decrease in other seasons.

When assessing the relative deviations of average seasonal precipitation and runoff, it is necessary to keep in mind that they are related to significantly different values of long-term averages, so that their share in the deviations of annual averages is quite different – see *Tab. 2*, which shows the percentages of averages of seasonal precipitation and seasonal runoff on the annual average.

Although summer precipitation outweighs precipitation from other seasons, summer runoff is only half the spring runoff and exceeds the share of winter runoff from significantly less precipitation.

For the analysis of the trend and changes in the trend in the series of annual and seasonal precipitation and runoff, we also used statistical analysis with the software methodologically described in [9]. The CTPA application allows the use of a series of statistical tests that assess, for example, the following hypotheses: the series has a normal distribution; the members of the series are statistically independent; the series has a change in average; the series shows a trend; there is a change in trend in a series. Several methodologically different tests can be used to verify some hypotheses.

For testing, we first used a series of annual precipitation levels and a series of precipitation levels for the seasons defined above. At the significance level of 0.05, the hypothesis of a normal distribution and independence of members for all tested series was not rejected. A statistically significant change in the average was indicated for the annual series in 1991 and for the winter series in 1993. The overall trend of the annual series is upwards by 0.187 mm/year, for the winter series by 0.174 mm/year; however, it is only statistically significant for the winter series.

The results for the runoff series are more uncertain when using the significance level; the series do not correspond to the normal distribution. There are autocorrelations in many annual values. The algorithm used indicated a change in the trend in 1965 from ascending to declining.

The results of the comparisons can be summarized in the conclusion that, apart from the increase in winter runoff, we did not find any changes that would demonstrate a more significant effect of warming on long-term precipitation and runoff. The forty-year averages of precipitation and runoff did not deviate from the range in which they occurred during a period when the air temperature did not increase intensively for a long time.

COMPARISON OF AVERAGE PRECIPITATION AND RUNOFF IN THE CZECH REPUBLIC

We assessed the variability of precipitation and runoff changes in the Czech Republic according to the deviations of the averages from the period 1981–2019 from the averages from the period 1961–1980. The choice of these periods was influenced by the requirement for available data – synchronous observation of precipitation and runoff at gauging stations. We assessed averages from whole years, seasons and, partly, from individual months. We selected a set of river basins which allows us to assess regional differences in changes in precipitation and runoff. In the first stage, data from the final gauging stations of large river basins were used; later, the assessment was supplemented by stations characterizing the variability of conditions from mountain to lowland river basins.

COMPARISON OF PRECIPITATION AND RUNOFF AVERAGES 1981–2019 AND 1961–1980 FOR THE ELBE RIVER BASIN IN DĚČÍN

The relative deviations of annual and seasonal precipitation and runoff in the Elbe river basin in Děčín [%] in the period 1981–2019 from averages of the period 1961–1980 are shown in *Tab. 3*. In comparison with *Tab. 2*, we find that the significant deviations are similar in both tables; a larger difference in *Tab. 3* is in the decrease in autumn runoff and it probably affects a larger – albeit statistically insignificant – decrease in the annual average.

Tab. 3. Relative deviations of annual and seasonal precipitation and runoff in the Elbe river basin in Děčín [%] in the period 1981–2019 with respect to the period 1961–1980

	Year	XII–II	III–V	VI–VIII	IX–XI
Precipitation	−0.2	6.53	−2.38	−3.09	0.89
Runoff	−1.93	8.05	−3.52	−14.49	−6.88

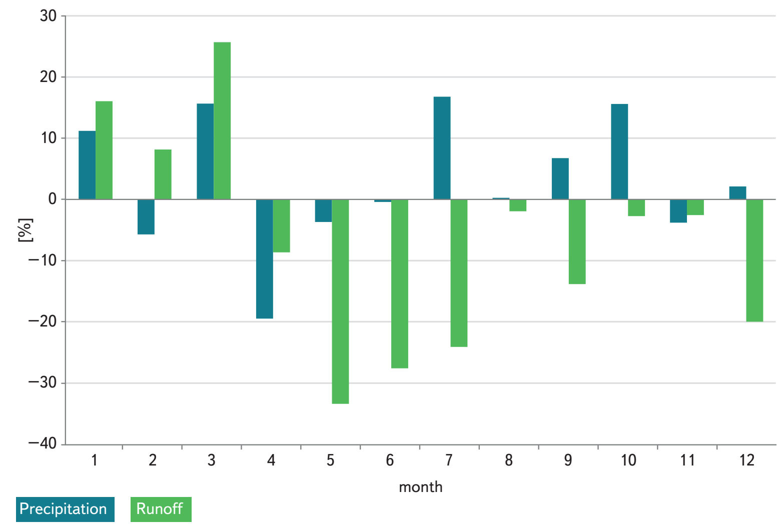


Fig. 6. Relative deviations in average precipitation heights and runoff heights in individual months for the Elbe river basin in Děčín in the period 1981–2019 with respect to the period 1961–1980

A comparison of relative changes in precipitation and runoff levels [%] in individual months for the Elbe river basin in Děčín is shown in *Fig. 6*. There is a continuous increase in precipitation from December to March, with the exception of February. It is worth noting that, after the increase in March, precipitation decreases in April. Decreases in runoff from May to September can be attributed to less precipitation in the spring and more intense evapotranspiration during the growing season due to rising air temperatures.

Comparison of precipitation and runoff averages 1981–2018 and 1961–1980 in large river basins

In the next stage of the calculations, we processed data from the river basins of gauging stations which are close to the lower profiles of the larger river basins of watercourses listed in *Tab. 4*. Relative deviations of average annual and average seasonal precipitation in the period 1981–2019 with respect to the period 1961–1980 are listed in *Tab. 5* and shown in *Fig. 7* and *8*.

Fig. 7 shows that in most river basins in the period 1981–2019, compared to the previous period 1961–1980, the average annual precipitation increased by 2% to 4%, in the Ohře river basin by 7.5%. In the Elbe (above the Vltava confluence), at the Brandýs n. L. station, the annual precipitation averages decreased slightly, and the annual precipitation averages in the Odra river basin decreased significantly.

Fig. 8 and *Tab. 5* show that the increase in annual precipitation was mainly due to increases in precipitation in the winter and autumn months, only in the Ohře river basin and slightly in the Vltava river basin was it also due to summer precipitation. Decreases in spring precipitation are more significant

Tab. 4. List of river basins of gauging stations representing large river basins in the Czech Republic

	Watercourse	Station	Station number	Catchment area [km²]
Bohemia	Labe	Brandýs n. L.	104,000	13,109
	Vltava	Praha Modřany a Chuchle	200,000	26,371
	Ohře	Louny	219,000	4,962
Moravia	Odra	Bohumín	294,000	4,665
	Morava	Olomouc	367,000	3,324
	Bečva	Dluhonice	390,000	1,593
	Dyje	Dolní Věstonice	479,000	11,744

in the Elbe and Odra river basins. Summer precipitation decreased in the Odra and Moravia river basins. Changes in precipitation in the Czech Republic in the warming period, assessed according to average precipitation in selected larger river basins, are clearly different in the river basins in the northern part of the territory from the river basins in the southern and western parts of the Czech Republic.

Changes in average precipitation from individual calendar months listed in *Tab. 6* and shown in *Fig. 9* reach larger values on a relative scale than the deviations of the seasonal averages. The fluctuation of changes in the neighbouring months during the year is confirmed. January averages (excluding the Elbe and the Odra) show increases of over 20%, with slight declines prevailing in February, with the exception of Bečva, where an insignificant increase was recorded. In March, precipitation increased or did not change in all river basins, and decreased (with one exception) from April to June. The July increase (except for the Odra and Morava) is followed by slight and small disparate changes in August. In September, precipitation increased in all river basins in Moravia even above 20%; the increase in October is especially noticeable on the Vltava and Ohře rivers. In November (except Ohře) there is a typical decrease below 10%, in December an increase of 6% to 10%, in Brandýs n. L. only by 1%.

As the changes in precipitation in the neighbouring months have the opposite trend prevailing; in the January–February, March–April, June–July, and November-December pairs in particular, changes in seasonal averages expressed in percentages are levelled to significantly smaller values. The constant decrease in precipitation in the period from April to June is unfavourable for the agricultural sector.

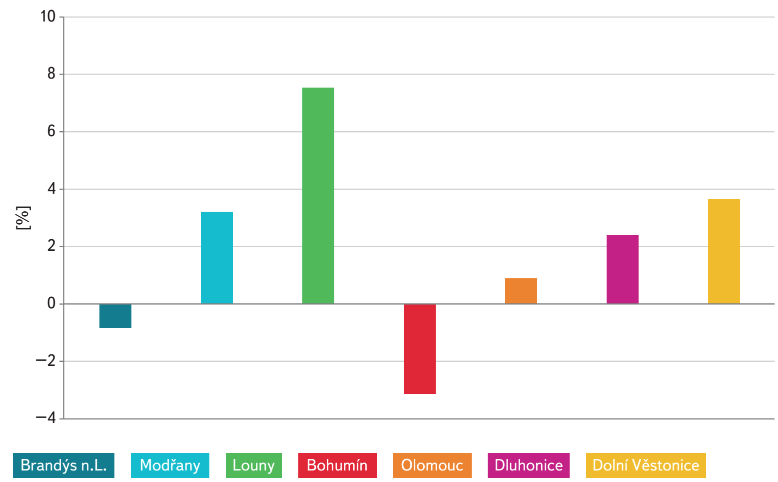


Fig. 7. Relative deviations of annual precipitation averages in the catchment area of gauging stations in the period 1981–2019 with respect to the period 1961–1980

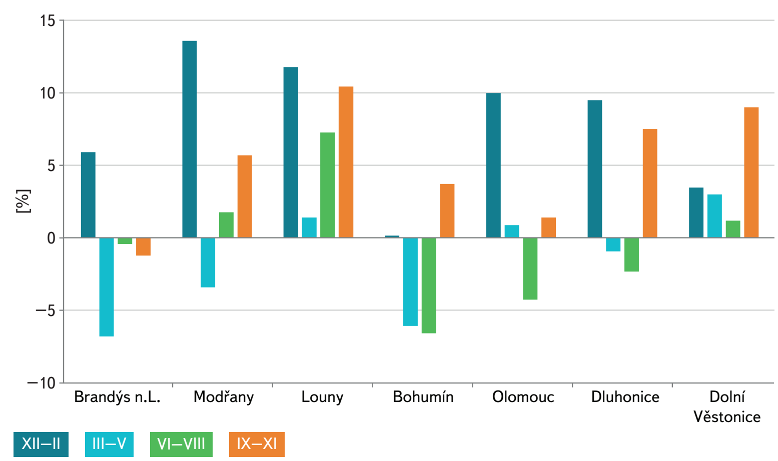


Fig. 8. Relative deviations of seasonal average precipitation in the catchment area of gauging stations in the period 1981–2019 with respect to the period 1961–1980

Tab. 5. Relative deviations of average annual and average seasonal precipitation in the period 1981–2019 with respect to the period 1961–1980 in [%], decreases are highlighted

River basin	Station	Year	XII–II	III–V	VI–VIII	IX–XII
Labe	Brandýs n. L.	−0.84	5.90	−6.81	−0.43	−1.22
Vltava	Praha Modřany	3.22	13.59	−3.41	1.76	5.69
Ohře	Louny	7.55	11.77	1.39	7.26	10.43
Odra	Bohumín	−3.13	0.14	−6.07	−6.60	3.71
Morava	Olomouc	0.91	9.99	0.87	−4.27	1.39
Bečva	Dluhonice	2.42	9.48	−0.93	−2.34	7.50
Dyje	Dolní Věstonice	3.66	3.46	2.99	1.18	9.01

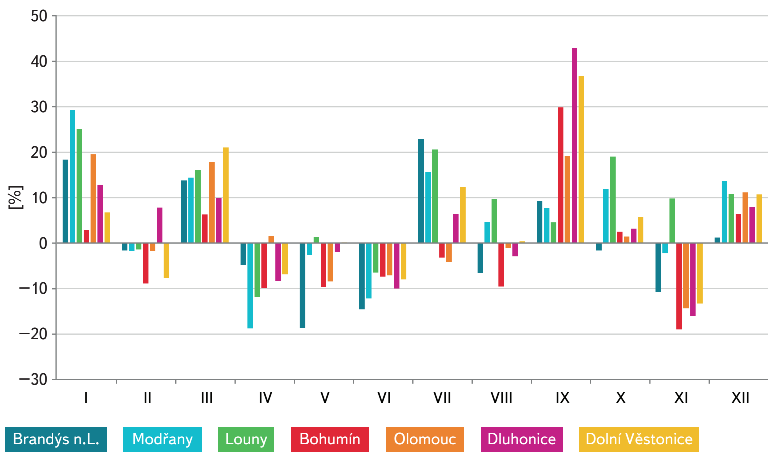


Fig. 9. Relative deviations of monthly precipitation averages in the catchment area of gauging stations in the period 1981–2019 with respect to the period 1961–1980

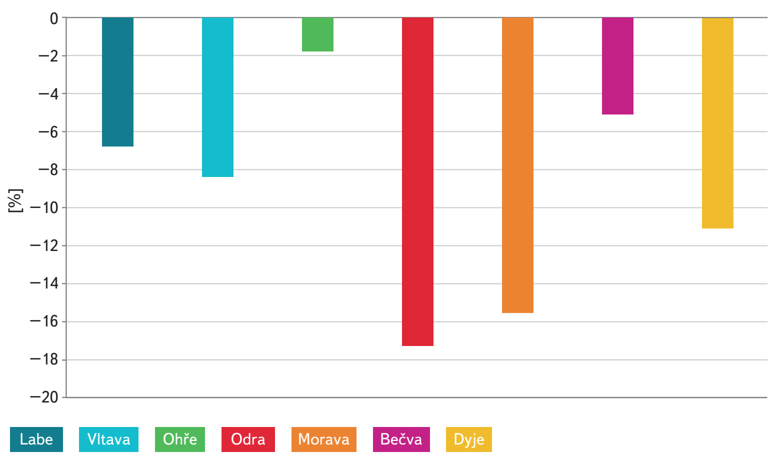


Fig. 10. Relative deviations of average annual flows in the period 1981–2019 with respect to the period 1961–1980

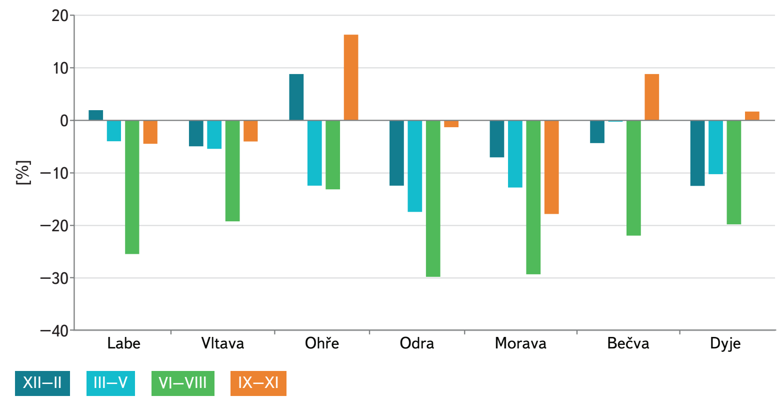


Fig. 11. Relative deviations of seasonal average flows in the period 1981–2019 with respect to the period 1961–1980

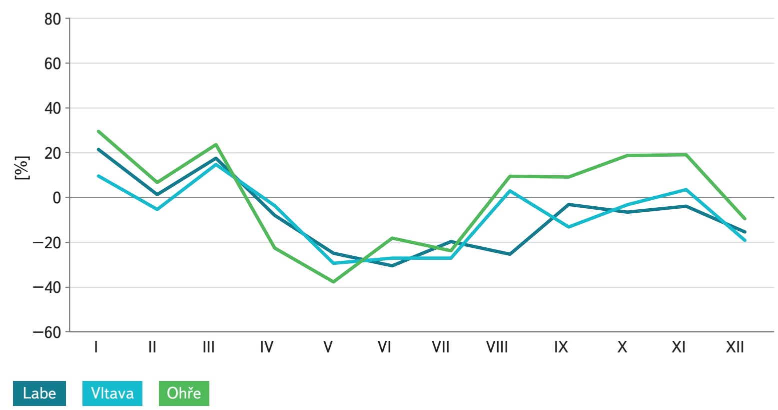


Fig. 12. Relative deviations of monthly average flows in the period 1981–2019 with respect to the period 1961–1980 – river basins in Bohemia

Deviations of annual flow averages in *Tab. 7* and *Fig. 10* show that the average flows in the period 1981–2019 were lower in all compared stations than in the period 1961–1980, on a relative scale by up to 17% at the Bohumín station on Odra, and at least by about 2% in Louny on Odra.

Relative deviations of seasonal average flows are shown in *Tab. 8* and *Fig. 11*. In the winter, the flow averages did not decrease only on the Elbe in Brandýs n. Labem and in Louny. In the spring and summer, the flows at all monitored stations decreased, mostly on the Odra in Bohumín by 17% in the spring and by about 30% in the summer. Autumn flows decreased on the Elbe, Vltava, Odra, and Morava (here more significantly – by about 18%), while the largest increase was recorded on the Ohře.

Relative deviations of the average monthly flows from individual months in the period 1981–2019 with respect to the period 1961–1980 in [%] are listed in *Tab. 8*.

Tab. 6. Relative deviations of average monthly precipitation in the period 1981–2019 with respect to the period 1961–1980 in [%]

Watercourse	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Labe	18.38	−1.65	13.80	−4.82	−18.67	−14.62	22.92	−6.60	9.25	−1.63	−10.82	1.20
Vltava	29.26	−1.83	14.39	−18.80	−2.61	−12.18	15.62	4.64	7.70	11.87	−2.23	13.63
Ohře	25.10	−1.40	16.12	−11.87	1.36	−6.48	20.62	9.69	4.56	19.02	9.82	10.81
Odra	2.90	−8.91	6.27	−9.85	−9.64	−7.40	−3.19	−9.60	29.88	2.52	−18.99	6.32
Morava	19.54	−1.77	17.85	1.48	−8.46	−7.13	−4.14	−1.14	19.21	1.41	−14.36	11.14
Bečva	12.86	7.82	9.90	−8.32	−2.02	−10.04	6.35	−2.95	42.91	3.17	−16.09	7.98
Dyje	6.71	−7.73	21.06	−6.89	0.11	−8.00	12.37	0.38	36.80	5.66	−13.32	10.71

Tab. 7. Relative deviations of average annual and average seasonal flows in the period 1981–2019 with respect to the period 1961–1980 in [%]

River basin	Station	Year	Winter	Spring	Summer	Autumn
Labe	Brandýs n. L.	−6.79	1.94	−3.98	−25.42	−4.43
Vltava	Praha Modřany	−8.36	−4.96	−5.44	−19.20	−4.03
Ohře	Louny	−1.76	8.82	−12.44	−13.14	16.30
Odra	Bohumín	−17.26	−12.43	−17.42	−29.76	−1.28
Morava	Olomouc	−15.53	−7.04	−12.77	−29.28	−17.82
Bečva	Dluhonice	−5.10	−4.31	−0.23	−21.94	8.81
Dyje	Dolní Věstonice	−11.08	−12.49	−10.25	−19.78	1.66

Fig. 12 shows that the change in seasonal distribution of flows in the Ohře is different from the Vltava and Elbe river basins; the changes for the Moravian watercourses differ significantly only in September, see *Fig. 13*.

Variability of changes in average precipitation and runoff in sub-basins

In the following stage, we focused on the variability of changes in average precipitation in 41 sub-basins. We limited the evaluation to annual and seasonal averages. The variability of changes in annual and seasonal precipitation averages is shown in *Fig. 14*.

A slight decrease in annual precipitation in the sub-basins that are part of the Elbe above the Vltava confluence is similar at most stations, namely about 2% to 3%. In the mountain basins (Vestřev – Krkonoše, Týniště n. O. – Orlické hory, Železný Brod – Jizerské hory), the changes in precipitation averages are negligible. In the group of river basins in eastern and central Bohemia, which form a continuous strip from Loučná to Výrovka, a decrease in precipitation ranged from 1.9% to 3.1%. Only the result for Doubrava in Žleby deviates from this. A decrease in precipitation in the lower profile of Brandýs n. Labem by

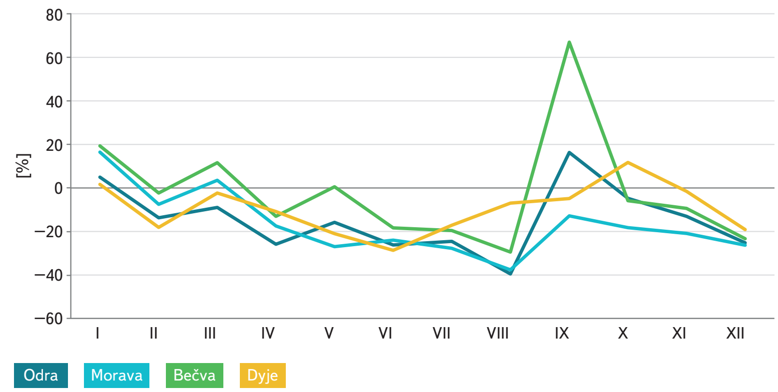


Fig. 13. Relative deviations of monthly average flows in the period 1981–2019 with respect to the period 1961–1980 – river basins in Moravia

0.88% is thus a superposition of unchanged precipitation in mountain areas and decreases in sub-basins at a lower altitude.

In the sub-basins of the Vltava, the average annual precipitation in most stations increases by about 3% to 4%, with the exception of the Malše river basin in Pořešín. On the Ohře, the increase in precipitation decreases from the highest value in Karlovy Vary by almost 10% downstream. According to data for Bílina in Trmice and Ploučnice, this is a decrease towards the north. Decreases in annual precipitation averages of about 2% to 4% in the Odra River Basin are similar in all sub-basins. In the Morava and Dyje river basins, an increase of about 2% to 3% is usually recorded; in particular the data for the Jihlava river basin up to the Ptačov station deviates from this (by about 7%).

In the winter period from December to February, precipitation increased (with one exception) on all river basins. In Bohemia, the increase is greater in the Vltava, Berounka, Ohře, and Ploučnice river basins, generally falling within the range of 10% to 15%. In the period from March to May, precipitation clearly decreased in most tributaries of the Elbe above the Vltava confluence and also in the Odra and Dyje river basins. Changes in precipitation between June and August are mostly, except for the increase in the Ohře and Ploučnice river basins, in the range of −5% to +2%; only in the Odra, Loučná, and Chrudimka river basins are there noticeable decreases in the range of −10%. The distribution of precipitation changes between September and November shows a significant difference between small decreases in the Elbe above the Vltava confluence and increases in the sub-basins of the Vltava, Berounka, and Ohře river basins, ranging from 3% to 10%. The increases in the Odra and Upper Morava river basins are smaller, only up to 5%.

Tab. 8. Relative deviations of average monthly flows in the period 1981–2019 with respect to the period 1961–1980 in [%]

Watercourse	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Labe	21.47	1.36	17.61	−7.89	−24.78	−30.43	−19.67	−25.24	−3.07	−6.47	−3.86	−15.34
Vltava	9.61	−5.31	14.77	−3.57	−29.30	−26.99	−27.06	2.95	−13.12	−3.22	3.61	−19.12
Ohře	29.55	6.79	23.69	−22.49	−37.61	−18.10	−23.72	9.51	9.20	18.74	19.09	−9.52
Odra	4.90	−13.77	−8.98	−25.85	−15.80	−26.23	−24.56	−39.54	16.27	−4.83	−13.04	−25.27
Morava	16.43	−7.60	3.45	−17.45	−26.98	−23.97	−27.81	−37.65	−12.90	−18.23	−20.97	−26.30
Bečva	19.27	−2.36	11.56	−13.08	0.53	−18.39	−19.59	−29.49	66.95	−5.88	−9.47	−23.34
Dyje	1.67	−18.14	−2.36	−10.91	−21.00	−28.69	−17.16	−6.99	−4.89	11.68	−1.54	−19.11

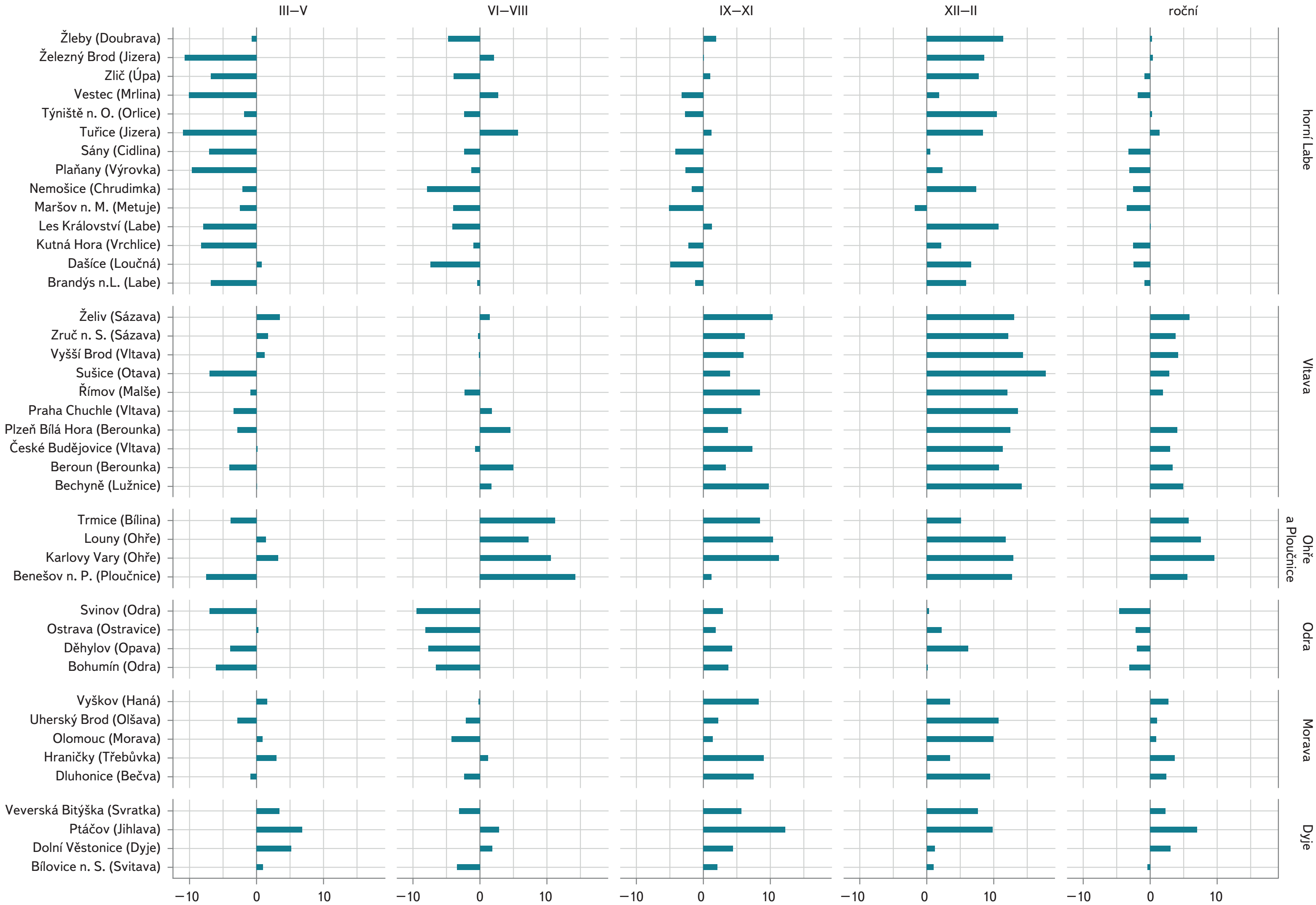


Fig. 14. Deviations of annual and seasonal averages of precipitation in sub-basins in the Czech Republic in the period 1981–2019 with respect to the period 1961–1980

In summary, it can be stated that only in the winter period in the Vltava river basin did precipitation increase slightly above 10%, while in the spring period there was a steady decrease in precipitation in the Elbe river basin. The changes in the summer period are generally small; precipitation has been steadily increasing in the Ohře river basin and slightly decreasing in the Odra river basin. In autumn, precipitation decreased slightly in the Elbe river basin, and increased in the Vltava river basin and in the Ohře river basin. The results show that the relative deviations of the seasonal precipitation averages are usually significantly larger than the deviations of the annual averages. Differences in changes in annual averages are the result of decreases in spring and autumn precipitation in the Elbe and Odra river basins and an increase in autumn precipitation in the Vltava river basin.

The variability of changes in annual and seasonal runoff averages is shown in *Fig. 15*.

The mountain basins of the Upper Elbe and Jizera are characterized by very small changes in annual averages. Decreases in tributaries of the Elbe are changing from about 5% to 10% in the upper stream up to the level of 25% for tributaries of the Middle Elbe; the maximum decrease of about 35% is evaluated in the Mrlina river basin. In the Vltava river basin, the changes in flows are very small at the stations in the Šumava region. When comparing the results for Sázava, Lužnice, Berounka, and Ohře, we find that, from east to west, the decreases change from values slightly exceeding 10% up to a practically unchanged flow of the Ohře. We do not use the increase in the Bílina river basin in this regard due to the uncertainty of elimination of the influence of flows. Stations from the Odra, Morava, and Dyje river basins also show only a very small decrease in flows in mountain river basins (Ostravice, Bečva). Larger river basins, even if they are part of a mountain area, are characterized by clear decreases in the range of about 10% to 15%, with the exception of the Odra in Svinov.

In the period from December to February, in mountain river basins and in the Ohře river basin, the averages increase up to the level of about 15%. In contrast, in the area of tributaries of the Middle Elbe, flows decrease on average by about 15%; in the Odra, Morava, and Dyje river basins this was mostly by 10%. In the spring period from March to May, flows decreased in most stations, slightly in mountain basins, usually in the range of up to 10%; however, in the area of tributaries of the Middle Elbe is was by more than 20%. Summer flows between June and August decreased in all river basins, in the Elbe river basin by more than 30% (the most by 59% in Vestec on Mrlina), in the Odra and Morava river basins usually by about 30%, in the Vltava river basin mostly by about 26%. The results from September to November are more volatile than in other seasons. Areas with constant decreases of more than 15% are tributaries of the

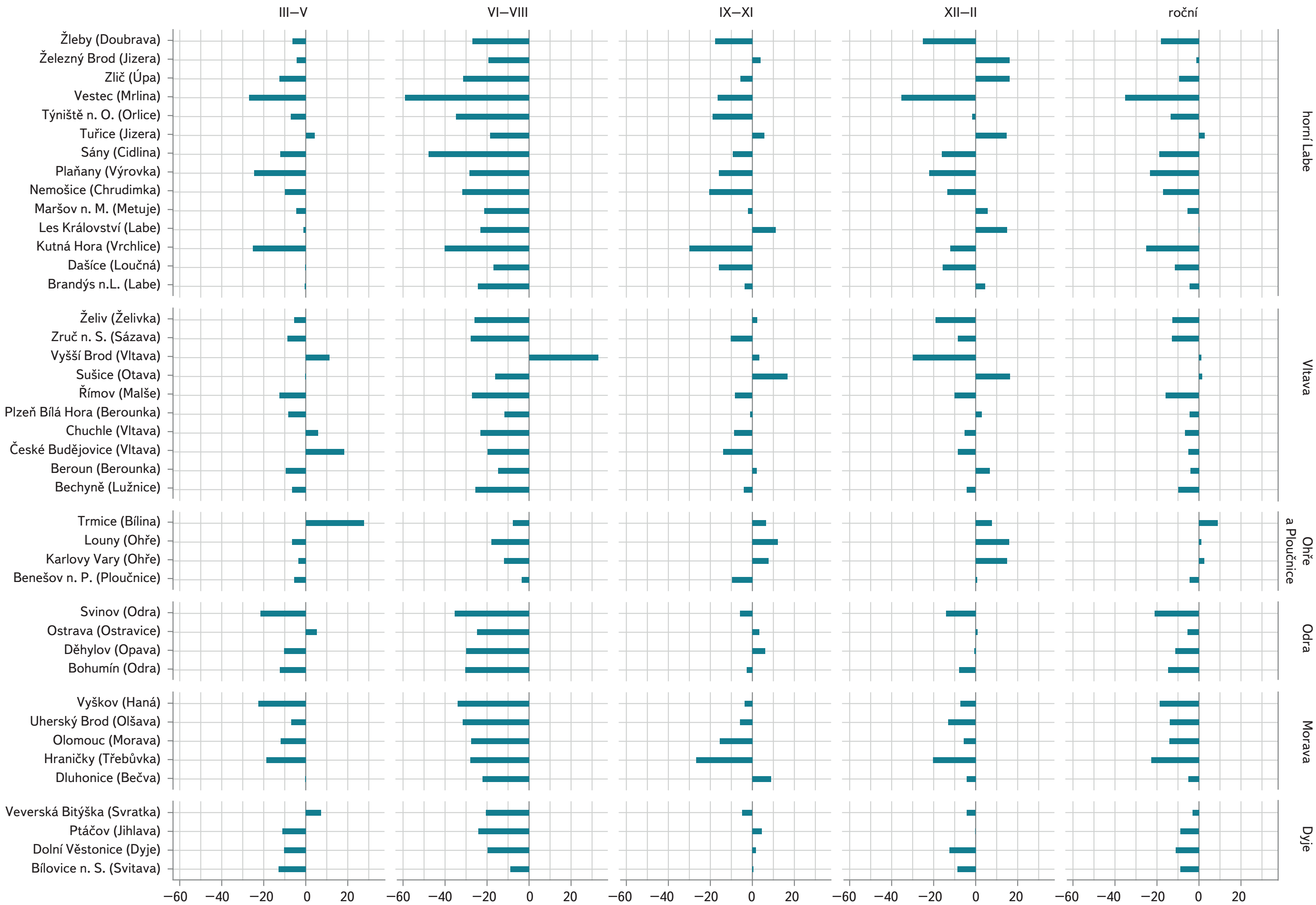


Fig. 15. Relative deviations of average annual and seasonal flows in the period 1981–2019 with respect to the period 1961–1980

Middle Elbe; in other stations, decreases of up to 10% were found. There is also an increase in flows; however, they reach more than 10% only occasionally.

COMPARISON OF CHANGES IN PRECIPITATION AND RUNOFF

Fig. 16 shows deviations of the average annual precipitation and deviations of the average annual runoff in the scale of precipitation and runoff levels in the river basin in mm; it is clear that the runoff decreases show a free dependence on the change in precipitation. The regression relationship between the change in precipitation (dP) and the change in runoff (dR) is shown in *Fig. 17*. The zero change in precipitation during warming in individual river basins, which ranges from 0.68 to 0.94 °C, corresponds to a decrease in runoff of about 30 mm/year, according to the regression relationship.

The relationship between increase in air temperature and change in runoff in individual river basins is very loose; it is characterized by a coefficient of determination of 0.16.

For a general estimate of the decrease in runoff due to the increase in air temperature in the period 1981–2019, we used a calculation based on the assumption that in each of the monitored river basins, the average long-term territorial evaporation is proportional to the long-term average precipitation. Based on the evaporation/precipitation ratio determined from the period 1961–1980, we calculated the evaporation estimate for precipitation from the period 1981–2019. When we subtract from it the value of evaporation in the area, which is given as the difference between the observed precipitation and the observed runoff, we obtain an approximate estimate of the part of the runoff decrease that can be attributed to the effect of warming. The results of this calculation in *Fig. 18* show that the effect of warming varies in the monitored river basins in a fairly wide range. The average value of runoff decreases due to warming is 27 mm.

CONCLUSION

Based on a comparison of the course of forty-year average precipitation in the Elbe river basin in Děčín and runoff levels from this river basin for the period 1951–2019, it can be stated that after 1980 there were no changes deviating from fluctuations in the previous period. This applies to averages from whole years as well as to averages from four seasons. A similar finding applies to fluctuations

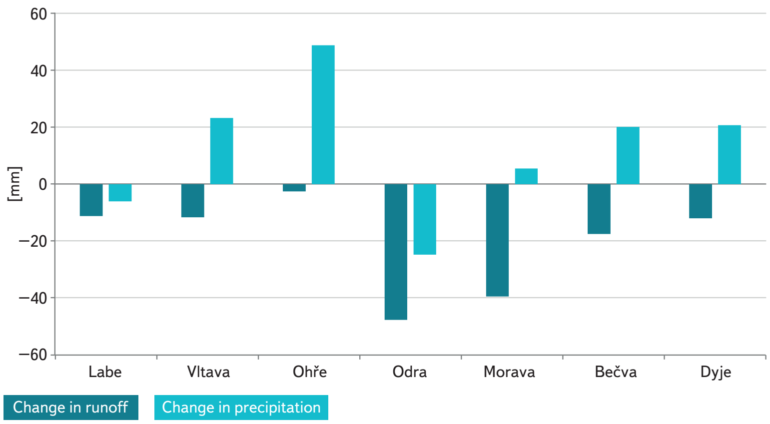


Fig. 16. Deviations of average annual precipitation and average annual runoff heights in the period 1981–2019 with respect to the period 1961–1980

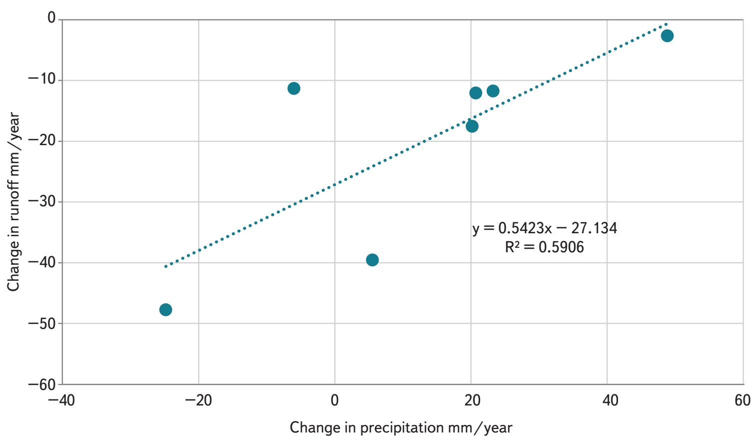


Fig. 17. Correlation relation of the deviations of runoff depending on the deviations of precipitation for the river basin from *Fig. 16*

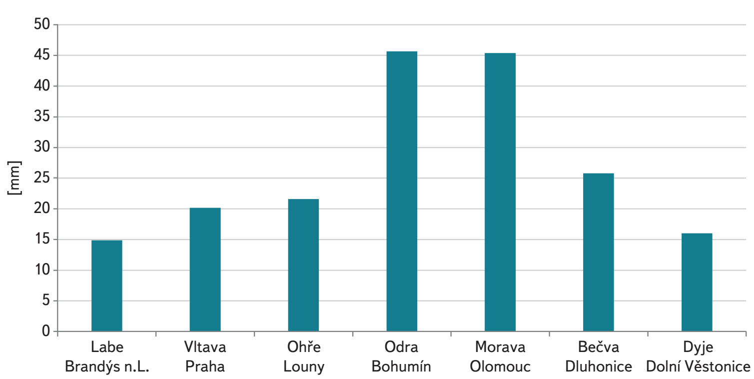


Fig. 18. Estimation of the contribution of warming in the decrease of the average annual runoff in the period 1981–2019 compared to the period 1961–1980

in the forty-year moving averages of annual and seasonal runoff levels from the said river basin, with the exception of the increase in winter runoff.

A comparison of possible changes in precipitation and runoff during the warming period in seven larger river basins of Bohemia and Moravia showed that in the period 1981–2019, compared to the previous period 1961–1980, average annual precipitation in four river basins increased by 2% to 4%, in Ohře river basin by 7.5%. On the other hand, in the Elbe above Vltava confluence and in the Odra river basin, the average annual precipitation decreased by about 1% and 3%, respectively. The increase in annual precipitation was mainly due to increases in precipitation in the winter and autumn months, as there were significant decreases in spring in three river basins and summer precipitation in two river basins. The average flows in the period 1981–2019 were lower in all compared stations than in the period 1961–1980; they decreased on a relative scale, with the exception of the Bečva and Ohře river basins, by 5% to 17%. Changes in runoff levels are regionally different and reach values that affect the flow regime. The annual flows of the Bohemian river basins decreased from April to August or September. In the Moravian river basins, the decrease also begins in April, deepening until August; however, in the autumn months the courses different a lot.

It is worth repeating that these figures are characteristic of the averages over 40 years, when the temperature was increasing with slight fluctuations, not of the conditions at the end of this period.

The summary processing of data from 41 sub-basins showed that the nature of the changes determined on the basis of data from seven large river basins is similar for most of the sub-basins that are a part of them. Exceptions are relative changes in flows in river basins located in mountainous areas, which are very small.

The estimate of the share of warming in the decrease of the average runoff level, determined on the basis of the above-mentioned indicative results, ranges from 15 mm to 45 mm, i.e., on average 30 mm per year. However, these are only indicative results. For more reliable estimates, it will be necessary to use more complex methods describing the relationships between balance sheet quantities.

References

[1] *Hydrologické poměry ČSSR.* Díl III. Praha: Hydrometeorologický ústav, 1970, 305 p.

[2] NOVICKÝ, O., KOLÁŘOVÁ, S., KAŠPÁREK, L. Charakteristiky průměrných denních průtoků a maximálních průtoků ve vodoměrných stanicích v Čechách. *Sborník prací ČHMÚ.* 1992, vol. 41, 136 p.

[3] BUDÍK, L., ŠERCL, P., KUKLA, P., LETT, P., PECHA, M. Odvození základních hydrologických údajů za referenční období 1981–2010. *Sborník prací ČHMÚ.* 2018, vol. 65, 60 p. ISBN 978-80-87577-78-3.

[4] KOŽÍN, R., KAŠPÁREK, L. Extrémní víceletá hydrologická sucha v povodí Labe. *Vodohospodářské technicko-ekonomické informace.* 2021, 63(3), p. 28–32. ISSN 0322-8916.

[5] NOVOTNÝ, J. Dvě stoleté řady průtokové na českých řekách. *Sborník prací Hydrometeorologického ústavu Československé socialistické republiky.* 1963, vol. 2, 40 p.

[6] KAŠPÁREK, L. Dlouhodobé kolísání průtoků Vltavy v Praze. *Vodohospodářské technicko-ekonomické informace.* 2017, 59(5), p. 25–30. ISSN 0322-8916.

[7] PEKÁROVÁ, P. *Dynamika kolísania odtoku svetových a slovenských tokov.* Bratislava: VEDA Bratislava, 2003, 222 p. ISBN 80-224-0780-1.

[8] KVĚTOŇ, V., ŽÁK, M. Výskyt suchých období v pražském Klementinu. *Meteorologické zprávy.* 2021, 74, p. 45–55.

[9] *Identifikace změny v časové řadě.* Praha: Český hydrometeorologický ústav, 1994. 79 p. Práce a studie, sešit 24.

Authors

Ing. Ladislav Kašpárek, CSc.
ladislav.kasparek@vuv.cz
ORCID: 0000-0002-8394-9136

Ing. Roman Kožín
roman.kozin@vuv.cz
ORCID: 0000-0002-5773-6567

T. G. Masaryk Water Research Institute, Prague

The paper has been peer-reviewed.

DOI: 10.46555/VTEI.2022.01.002

Photo: shutterstock.com

Occurrence of pesticides in the Punkva river

TAŤÁNA HALEŠOVÁ, JANA KONEČNÁ, MARTA VÁCLAVÍKOVÁ, PETR KARÁSEK, EVA NOVÁKOVÁ

Keywords: Moravian Karst — water quality — surface and groundwater — triazines — azoles

SUMMARY

The Moravian Karst is the largest and most karstic area in the Czech Republic, and, as such, it is a protected landscape area (PLA). The karst area occupies a strip of Devonian limestone north of Brno. The north part of Moravian Karst is drained by the river Punkva and its headwaters. One of the biggest cave systems in central Europe is located there, Amaterska cave, which is more than 40 km long.

Despite the strict protection measures that are in place in the PLA, the presence of pollutants and potentially hazardous substances has recently been detected in the Punkva river and its catchment. The sources of this pollution are found both within the territory of Moravian Karst PLA and in the river´s catchment, and they are related to anthropogenic activities and land use. This article focuses on the occurrence of pesticides, especially triazine and azole pesticides and their polar metabolites. In 2020, a new significant contaminant, 1,2,4-triazole, a common relevant metabolite of azole pesticides, was found at the site concerned. These substances can have fatal effects not only on the endemic organisms living in the Moravian Karst, but they can also endanger human health because the local groundwater is used as a source of drinking water. Thanks to the studies carried out, the protection zones around the cave system have been extended, reducing the negative effects of agricultural activities in the area of interest.

INTRODUCTION

With an area of over 92 km^2, the Moravian Karst (MK) is the largest and most important karst territory in the Czech Republic. Each karst represents an extremely fragile ecosystem, which is highly sensitive to and easily influenced by human activities, since the transport of nutrients and contaminants from soil to groundwater is accelerated due to specific pedological and geological conditions [1]. One of the possible sources of karst groundwater pollution is agricultural activity [2]. Agrochemicals such as pesticides can be transported from their direct application sites into local streams, rivers and, subsequently, into groundwater in caves. These substances can be fatal not only to the microflora and microfauna, but they also have a negative impact on higher animals´ activity and health [3]. Some pesticides are carcinogenic to humans, while others can cause serious health complications, including metabolic disorders, neurological disorders, and allergic reactions [4].

The Punkva is a subterranean river in the Moravian Karst and the longest underground watercourse in the Czech Republic. It flows through the bottom of Macocha Abyss and the system of Punkva Caves, which it co-created. The Punkva is formed by the confluence of many subterranean headwaters that flow through the limestone area from north and east to the south. These are predominantly the combined waters of the Holštejn White Water (Bílá voda) and the Sloupský Stream, which meet in the labyrinth of Amaterska cave (*Fig. 1*).

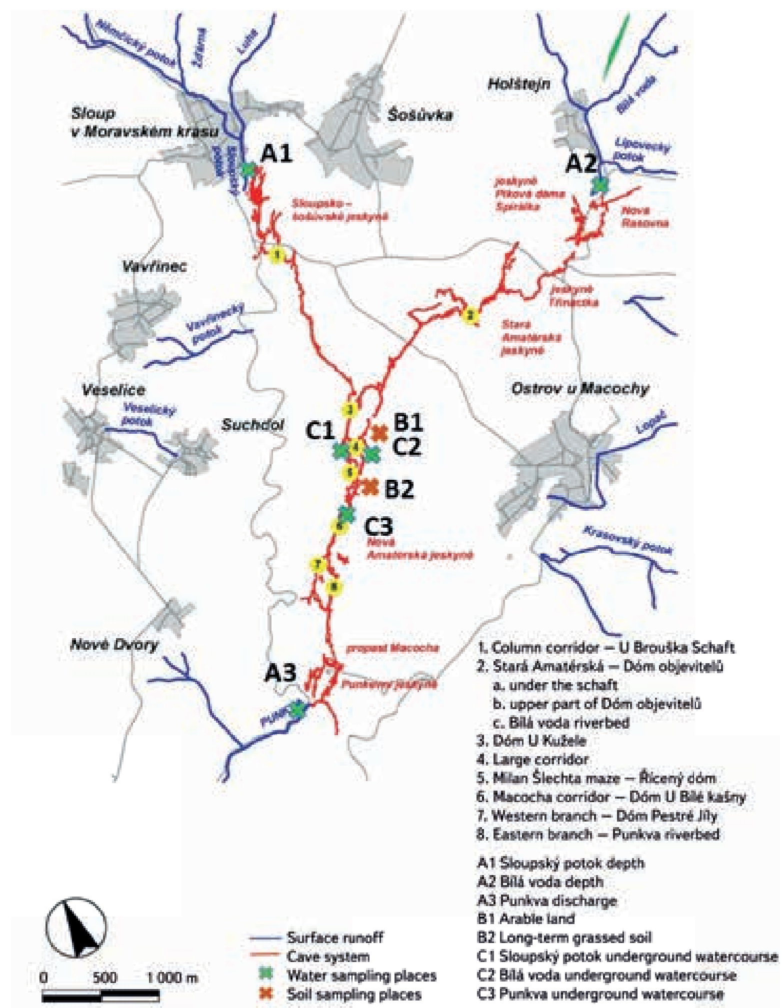


Fig. 1. Map of the Moravian Karst and monitored places (source Cave administration CR)

As PLAs are generally considered to be free of any extraneous substances, pesticide monitoring in the Moravian Karst has not been paid attention to in the past. However, Kotyzová and Halešová [5] confirmed the contamination of waters in the area with these compounds, as well as other xenobiotics. Although the pesticide residue concentrations found were not high enough to pose an acute danger to aquatic animals due to their toxicity, their long-term accumulation, the growing amount of substances used, and the formation of known and unknown metabolites of parent compounds could result in negative impacts on non-target organisms and the entire karst ecosystem.

This study aims at assessing the extent of contamination of the Punkva River with triazine and azole pesticides within the Moravian Karst.

MATERIAL AND METHODOLOGY

For the purpose of this study, water and soil samples were collected at a regular monthly interval, every second week of the month, during the period from April to December in 2018–2020. Surface water and soil samples were always collected on Thursday and subterranean samples (i.e., samples of groundwater in the caves) were collected on the following day, i.e., Friday. The water samples were taken as point samples. Soil samples were prepared as a composite sample from each site, collected using a soil probe from a depth of about 30 cm. All sampling was accredited according to EN ISO/IEC 17025 [6].

The Punkva as well as the White Water (Bílá voda) and the Sloupský Stream, whose confluence gives rise to the Punkva, are partly subterranean watercourses. Therefore, water samples were collected from the three streams, both from the surface section (*Fig. 1* – sampling points A1, A2, and A3) and from the subterranean section (*Fig. 1* – sampling points in the Amaterska cave C1, C2, and C3) of each stream. Soil samples were collected on the surface above the subterranean stream of the emerging Punkva River (*Fig. 1* – sampling sites B1 and B2). The B1 sampling site was located where the application of selected plant protection products (PPPs) was permitted in 2018 and 2019, and the B2 sampling site was a site that has been permanently grassed since 1998. All sampling sites are summarized in *Tab. 1*.

Almost 400 pesticide substances were examined in the water samples and approximately 200 pesticide substances were analysed in the soil samples. The pesticide substances were analysed on the basis of accredited methods using sensitive and selective LC-MS technique in the laboratory of ALS Czech Republic in Prague. The applied analytical methods are accredited according to Czech Standard (ČSN) EN ISO/IEC 17025 [6]. Triazine and azole pesticides and their polar metabolites showed a consistent trend and were therefore subsequently the main focus of attention (*Tab. 2*). Other pesticide substances were more likely to be present in the tested samples due to seasonal application of PPPs and were not present in the next sampling.

Tab. 1. Identification and description of sampling points

Sample type	Sampling point	
	Description	**Identification**
Surface watercourses	Sloupský Stream inflow point	A1
	White Water (Bílá voda) inflow point	A2
	Punkva outflow point	A3
Soil	Above the emerging subterranean Punkva river – arable land	B1
	Above the emerging subterranean Punkva river – permanent grass cover	B2
Subterranean watercourses	Subterranean part of the Sloupský Stream	C1
	Subterranean part of the White Water (Bílá voda) Stream	C2
	Subterranean part of the Punkva	C3

Tab. 2. Parent active substances of azole and triazine pesticide groups and their metabolites monitored in the study

Pesticide class	Parent substance	Metabolite
Azole	Epoxiconazole	1,2,4-triazole
	Cyproconazole	
	Tebuconazole	
	Propiconazole	
Triazine	Atrazine	Atrazine-2-hydroxy
		Atrazine-desethyl
		Atrazine-desisopropyl
		Atrazine-desethyl-desisopropyl
	Hexazinone	
	Metamitron	
	Terbuthylazine	Terbuthylazine-desethyl
		Terbuthylazine-desethyl-2-hydroxy
		Terbuthylazine-hydroxy
	Terbutryn	
	Simazine	Simazine-2-hydroxy

RESULTS AND DISCUSSION

Triazine herbicides and azole fungicides and their polar metabolites were detected in most of the water samples tested. Of the triazine pesticides, metabolites of terbuthylazine and atrazine were the most frequently represented (*Fig. 2*). It is worth noting that neither the parent active substance atrazine nor terbuthylazine were detected in any of the soil samples tested. Atrazine metabolites, especially atrazine-2-hydroxy, were significantly represented only in the B1 sample of agricultural soil. The banned atrazine was present in the surface water and mainly groundwater samples. The use of atrazine has been banned since 2005 [7]. The presence of this persistent active substance, as well as the active substance simazine and subsequently their degradation products (*Fig. 2*), is explained as a consequence of the application of PPPs with the active substance terbuthylazine, since both atrazine and simazine are impurities that are formed during its production. Another cause could hypothetically be the application of illegal protection products [8]. The maximum sum of triazine pesticide substances in surface water samples of the Sloupský Stream and White Water (Bílá voda) for 2018–2020 did not exceed the concentration of 0.1 mg/l; their sum for the whole period was about 0.05 mg/l on average. The main contaminants of surface water of both Punkva tributaries were metabolites of terbuthylazine (terbuthylazine-desethyl) and atrazine (atrazine-desethyl and atrazine-desethyl desisopropyl). Residues of the parent active substances terbutryn, terbuthylazine, and atrazine were also repeatedly detected in the Sloupský Stream in 2018; there were also occasional occurrences of terbuthylazine and atrazine in the White Water (Bílá voda). Contaminants from both surface streams are reflected in the occurrence of the pesticide triazine substances in the Punkva, where the sum was also a maximum of 0.1 mg/l and the average sum of pesticides over

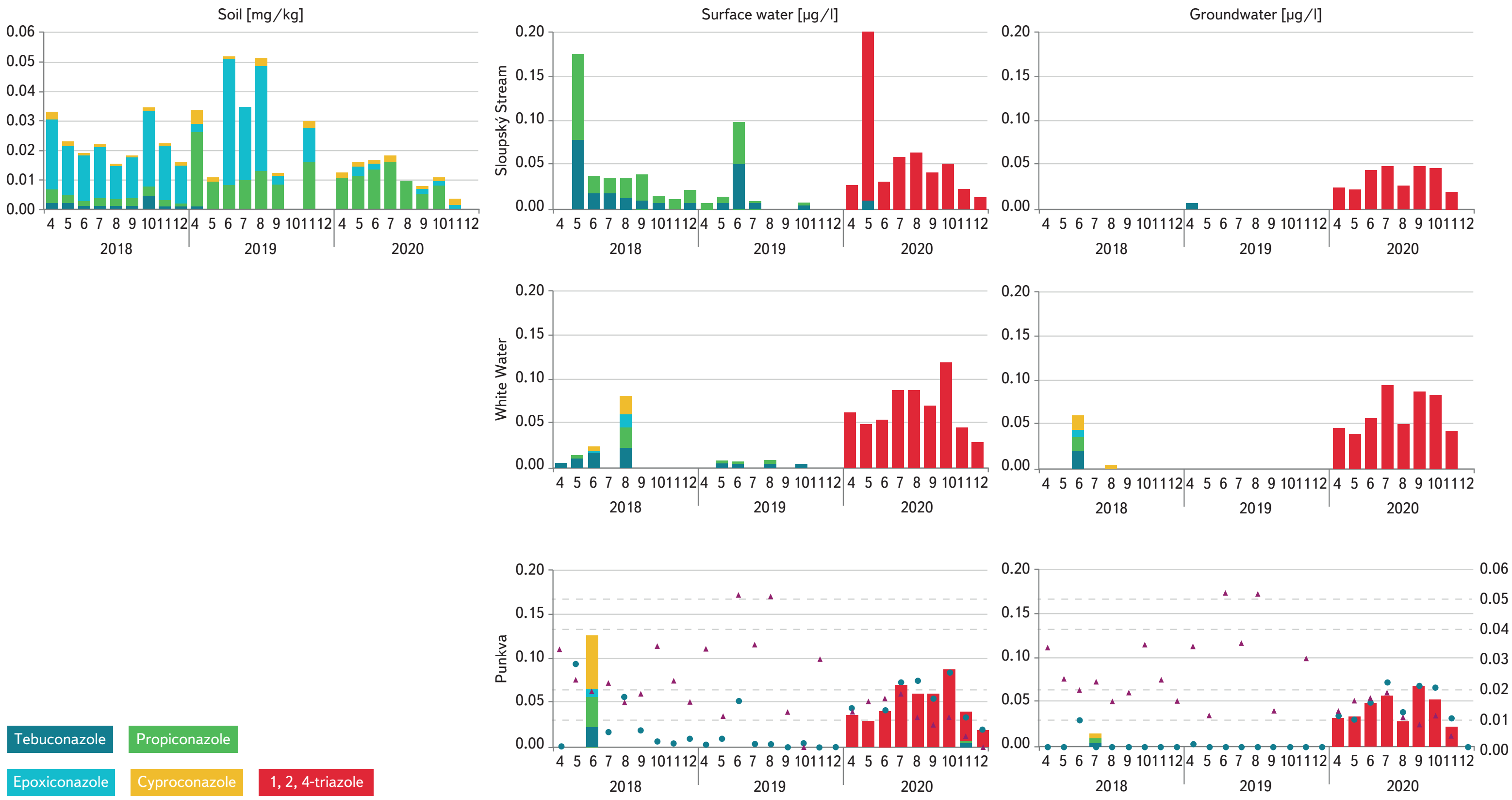


Fig. 2. An overview of triazine pesticides detected in the soil and water samples in the Moravian Karst area

Fig. 3. An overview of azole pesticides detected in the soil and water samples in the Moravian Karst area

the whole period was about 0.05 mg/l. However, the difference is that, after the two tributaries enter the underground space, the decomposition of the metabolites which were previously formed on the surface and now have flowed into the underground continues under local conditions (year-round low temperature, darkness, and dissimilar organisms). Nevertheless, if parent active substances, such as atrazine, enter the karst bedrock, their subsequent decomposition underground is very slow and it leads to their accumulation and gradual transport into the Punkva river, where concentrations are higher, and the load is long-lasting.

Although the problem with triazine pesticides appears to have been eliminated, a new potential risk was discovered within the study, which the authors sought to address. In addition to triazine pesticides, azole fungicides are also widely used to treat plants. Azole pesticides (tebuconazole, propiconazole, cyproconazole, and others) are biodegradable by plants and soil microorganisms, and it is these organisms in the soil matrix that degrade the parent active ingredients to their common metabolite 1,2,4-triazole (124-TRZ), which is highly polar, mobile in soil and, therefore, a potential water contaminant. 124-TRZ is a toxicologically relevant metabolite of azole pesticides, which means that, according to legislation, its presence should be monitored and the concentration in drinking water should not exceed the limit for each individual pesticide/relevant metabolite of 0.1 µg/l. Unlike the parent substances, 124-TRZ is relatively stable in the environment, especially if it reaches groundwater where the rate of degradation is slowed down by the conditions. Its DT50 is more than 300 days, especially in groundwater [9]. Although 124-TRZ is classified as a relevant metabolite, it is quite surprising that it is still not routinely monitored and there is a lack of data and information on this compound, but this is due to the difficulty of its determination [9, 10]. Fisher et al [11] confirmed its widespread occurrence in groundwater in association with intensive agricultural land use.

The results of the azole pesticide analyses are summarised in *Fig. 3*. It is evident that the B1 agricultural soil sample collected in the Moravian Karst was positive for the applied active substances tebuconazole, propiconazole, and epoxiconazole, while surface and groundwater samples were, with some exceptions, negative for these compounds. These results confirm that the parent azole active substances are degraded relatively early by soil microorganisms and are thus not transported into the aquatic and environmental system [12]. The fact that parent active substances of azole pesticides are applied to soil in abundance, yet their residues in water are not detected, contributed to the need for validation of the analysis and subsequent monitoring of the metabolite 124- triazole in water in 2020. The aim is to focus on the analysis of the metabolite in time to avoid future problems with exceeding its drinking water limit, as is the case with metabolites of triazine or chloroacetanilide herbicides in some areas of the Czech Republic (e. g., acetochlor, alachlor, atrazine, terbuthylazine) (e. g. [13]).

The results obtained within this study confirmed our assumptions that the water samples do not contain the parent azole pesticides, whereas their common relevant metabolite 124-TRZ is already present in any water type *(Fig. 3*), and at relatively high concentrations. Although the concentration of 124-TRZ did not exceed the recommended drinking water limit (0.1 µg/l), even in groundwater, it is alarming that all samples tested in this study since 2020 have been positive for presence this relevant metabolite. Continuous and systematic monitoring of this compound should be organised globally to avoid unwanted accumulation in the environment and subsequent elimination problems.

CONCLUSION

According to the above results, it can be concluded that triazine and azole pesticides, and their polar metabolites in particular, are common and abundant contaminants of the aquatic system in the Moravian Karst. Both groups have specific characteristics. Although the application of triazine pesticides is fortunately decreasing, their metabolites are still present to some extent in water samples. Continuous decontamination and complete removal of their residues from the environment should remain a priority. On the other hand, other unexplored and unknown compounds and metabolites are still emerging. In our case, 124-TRZ is a new interesting relevant metabolite that was detected in 2020 in all surface and groundwater samples tested, although the parent azole pesticides were absent. Not much is known about this compound, so global and national monitoring should be encouraged.

Evaluation of the results of the monitoring studies performed in 2019 and 2020 led to the modification of zones in the Moravian Karst PLA and changes in agricultural activities near the sinkholes and areas above the caves [14]. Targeted grassing was completed, which has significantly improved the quality of water infiltrating into the caves and will certainly have further positive impacts on the site in the long term.

Acknowledgements

This paper was prepared thanks to the support of the Ministry of Agriculture of the Czech Republic (within the projects QK1910282 "Options for mitigation of the impacts of extreme hydrological events in small catchments with respect to the demands of sustainable agriculture and pond aquaculture" and RO0218 "Long-term concept of development of the research organization (Research Institute for Soil and Water Conservation) for the period 2018–2022"), the support of the Technology Agency of the Czech Republic (within the project TH03030178 "New methods for assessing plant protection products risks against non-target soil organisms: Assessing risks of xenobiotics contamination on diversity") and also in cooperation with the Moravian Karst Protected Landscape Area Administration.

References

[1] HUANG, H., LIU, H., XIONG, S., ZENG, F., BU, J., ZHANG, B., LIU, W., ZHOU, H., QI, S., XU, L., CHEN, W. Rapid Transport of Organochlorine Pesticides (OCPs) in Multimedia Environment from Karst Area. *Science of the Total Environment*. 2021. 775, 145698. Available from: https://www.sciencedirect.com/science/article/abs/pii/ S004896972100766X

[2] ZAJÍČEK, A., FUČÍK, P., KAPLICKÁ, M., LIŠKA, M., MAXOVÁ, J., DOBIÁŠ, J. Pesticide Leaching by Agricultural Drainage in Sloping, Mid-Textured Soil Conditions – The Role of Runoff Components. *Water Science & Technology*. 2018, 77(7), p. 1879–1890.

[3] SHARMA, A., KUMAR, V., SHAHZAD, B. et al. Worldwide Pesticide Usage and its Impacts on Ecosystem. *SN Applied Sciences*. 2019, 1, 1446. Available from: https://doi.org/10.1007/s42452-019-1485-1

[4] RODRÍGUEZ, A., LÓPEZ, M., CASILLAS, A., LEÓN, J., BANIK, S. Impact of Pesticides in Karst Groundwater. Review of Recent Trends in Yucatan, Mexico. *Groundwater for Sustainable Development*. 2018, 7, p. 20–29. Available from: https://www.sciencedirect.com/science/article/abs/pii/S2352801X18300055

[5] KOTYZOVÁ, M., HALEŠOVÁ, T. Occurrence of Pesticides in Selected Localities of the Moravian Karst with an Impact on Drip Waters. *Protection of the Nature*. 2018, 73(1), p. 22–26.

[6] ČSN EN ISO/IEC 17025:2018. *General requirements for the competence of testing and calibration laboratories.*

[7] HVĚZDOVÁ, M. et al. Currently and Recently Used Pesticides in Central European Arable Soils. *Science of the Total Environment*. 2018, 613–614 (2), p. 361–370.

[8] CHEN, W., ZENG, F., LIU, W., BU, J., HU, G., XIE, S., YAO, H., ZHOU, H., QI, S., HUANG, H. Organochlorine Pesticides in Karst Koil: Levels, Distribution, and Source Diagnosis. *International Journal of Environmental Research and Public Health*. 2021, 18(21), 11589. Available from: https://doi.org/10.3390/ijerph182111589

[9] HALEŠOVÁ, T., VÁCLAVÍKOVÁ, M., TOMEŠOVÁ, D., ERBAN, T. 1,2,4-triazole: (Un) known Relevant Metabolite in Water. *Water management*. 2021, 71(1), p. 4–7.

[10] COWI. *Potential Sources of 1,2,4-triazole in Danish Groundwater.* Danish Environmental Protection Agency, 2019, 32 p. Available from: https://mst.dk/media/ 210522/notat_potential-sources-of-124-triazole-in-danish-groundwater.pdf

[11] FISHER, I., PHILLIPS, P., BAYRAKTAR, B., CHEN, S., MCCARTHY, B., SANDSTROM, M. Pesticides and their Degradates in Groundwater Reflect Past Use and Current Management Strategies, Long Island, New York, USA. *Science of the Total Environment*. 2021, 752, 141895. Available from: doi.org/10.1016/j. scitotenv.2020. 141895

[12] CHEN, Z. F. et al. Typical Azole Biocides in Biosolid-Amended Soils and Plants Following Biosolid Applications. *Journal of Agricultural and Food Chemistry*. 2013, 61(26), p. 6198–6206.

[13] MOULISOVÁ, A., BENDAKOVSKÁ, L., KOŽÍŠEK, F., VAVROUŠ, A., JELIGOVÁ, H., KOTAL, F. Pesticidy a jejich metabolity v pitné vodě. Jaký je současný stav v České republice? *Vodní hospodářství*. 2018, 68(7), p. 4–10. Available from: https://vodnihospodarstvi.cz/pesticidy-a%E2%80%AFjejich-metabolity-pitne-vode/

[14] KOTYZOVÁ, M., HALEŠOVÁ, T. Grassing of the 1st Zone in the Moravian Karst. *Protection of the Nature*. 2021, 76(1), p. 15–18.

Authors

Ing. Taťána Halešová[1]
tatana.halesova@alsglobal.com
ORCID: 0000-0002-3911-860X

Ing. Jana Konečná, Ph.D.[2]
konecna.jana@vumop.cz
ORCID: 0000-0002-7914-428X

Ing. Marta Václavíková, Ph.D.[1]
marta.vaclavikova@alsglobal.com
ORCID: 0000-0001-8460-6218

Mgr. Petr Karásek[2]
karasek.petr@vumop.cz
ORCID: 0000-0002-0991-076X

Mgr. Eva Nováková[2]
novakova.eva@vumop.cz
ORCID: 0000-0002-1013-1659

[1]ALS Czech Republic, Prague
[2]Research Institute for Soil and Water Conservation, Prague

The paper has been peer-reviewed.

DOI: 10.46555/VTEI.2021.12.001

Monitoring changes in the landscape development on the northeastern edge of the Hřebeny Mountains with a focus on wetlands

PAVEL RICHTER, RENÁTA SZTYMONOVÁ

Keywords: archive maps — landscape changes analysis — GIS — wetlands — water in the landscape

SUMMARY

This article deals with changes in wetlands on the north-eastern edge of Hřebeny Mountains in the last 180 years. It assesses the dynamics of these landscape elements in space and time. The cadastral areas of Čisovice, Řitka, Kytín, and Nová Ves pod Pleší were selected, with a total area of 3,785.57 ha. Analysis was carried out on the basis of the Imperial obligatory prints of the maps of the stable cadastre from 1840, an orthophotomap, and field research from 2020; it distinguished wetlands in the monitored area into continuous, extinct and new. The background data were processed in ArcGIS software, version 10.7.1. The area of wetlands decreased from 289.34 ha in 1840 (7.6% of the monitored area) to 39.26 ha in 2020 (1.04% of the monitored area). Based on the study of available data, three types of wetland habitats were classified: wet meadows, wet meadows with woody plants, and ponds.

INTRODUCTION: LANDSCAPE CHANGES IN THE CONTEXT OF WATER MANAGEMENT

The landscape is constantly changing, most often as a result of human activity. The European landscape underwent major changes during the early 19th and during the 20th century – from the intensification of agricultural production, to the construction of urban and suburban zones, to reforestation [1]. The landscape in the Czech Republic is no exception. Over the past 200 years, there has been a permanent loss of meadows and pastures from the landscape, most often in order to create new arable land. In the 19th century, even meadows in floodplain areas were ploughed in this way [2]. Between 1845 and 1948, meadows and pastures were the most common original land used for the creation of new arable land. This trend of steady decline changed in the 1990s, when meadows and pastures were extended, first in mountainous areas and then in the lowlands [3]. During the 19th century, further interventions in the landscape took place on surface waters. For the first time in history, large-scale land reclamation, straightening and regulation of watercourses, infilling of ponds, and construction of the first dams took place [2]. Ponds are man-made wetlands. They were established in Bohemia from the 12th century, but their decline began after the Thirty Years' War, and new pastures and fields were created on dried up areas [4]. In the Czech Republic, the term pond is defined by Act 99/2004 Coll., as *"a body of water, which is a reservoir intended primarily for fish farming, in which the water level can be regulated, including the possibility of its discharge and fish harvesting; a pond consists of a dyke, a reservoir, and other technical equipment"*[5]. One of the most important functions of wetlands in general is the ability to retain surface water, which is then released into groundwater, enriching its supplies. This connectivity between wetlands and groundwater is influenced by the geological subsoil, relief, and soil properties [6]. Replenished groundwater supplies are slowly released into the surrounding watercourses, reservoirs, and the landscape in general, thus providing the environment with a water supply in times of drought [7]. The main goal of the research presented in this article was to assess the spatiotemporal dynamics of wetland habitats.

Monitored area

Brdská vrchovina (The Brdy Highlands) is divided into Hřebeny, central Brdy, and southern Brdy [8, 9]. Brdská vrchovina also include the sub-units Příbramská pahorkatina and Brdy itself, consisting of three districts (Třemošenská vrchovina, Třemšínská vrchovina, and Strašická vrchovina) [9]. Hřebeny, sometimes called Brdské Hřebeny or Hřebeny Brdy, represent a forested belt stretching in the NE-SW direction between Prague and Pilsen, more specifically between the Vltava valley, near Zbraslav, and the Litavka valley. In 2009, Hřebeny Nature Park was designated in the majority of Brdy Hřebeny, covering 184 km² [10].

An up-to-date geomorphological division:

- GMF subsystem: Brdy subsystem
- GMF unit: Brdská vrchovina
- GMF subunit: Brdy, Hřebeny, Příbramská pahorkatina

Hřebeny subunit is located in the north-eastern part of Brdská vrchovina. It is a rugged highland with an area of 125.08 km², a mean height of 440 m, and a mean slope of 7°. It is composed of formations of Cambrian and Ordovician shales, sandstones, greywacke, conglomerates and quartzites, Proterozoic dacites, andesites and tuffs; these form a single wide structural ridge of the SW-NE direction with significant steep marginal slopes (covered with boulder and block rubble on the NW), transversely disturbed by the Vltava valley and Všenorský potok. The highest point is Studený vrch, at 660.30 m above sea level, in Studenská vrchovina [9].

Photo: shutterstock.com

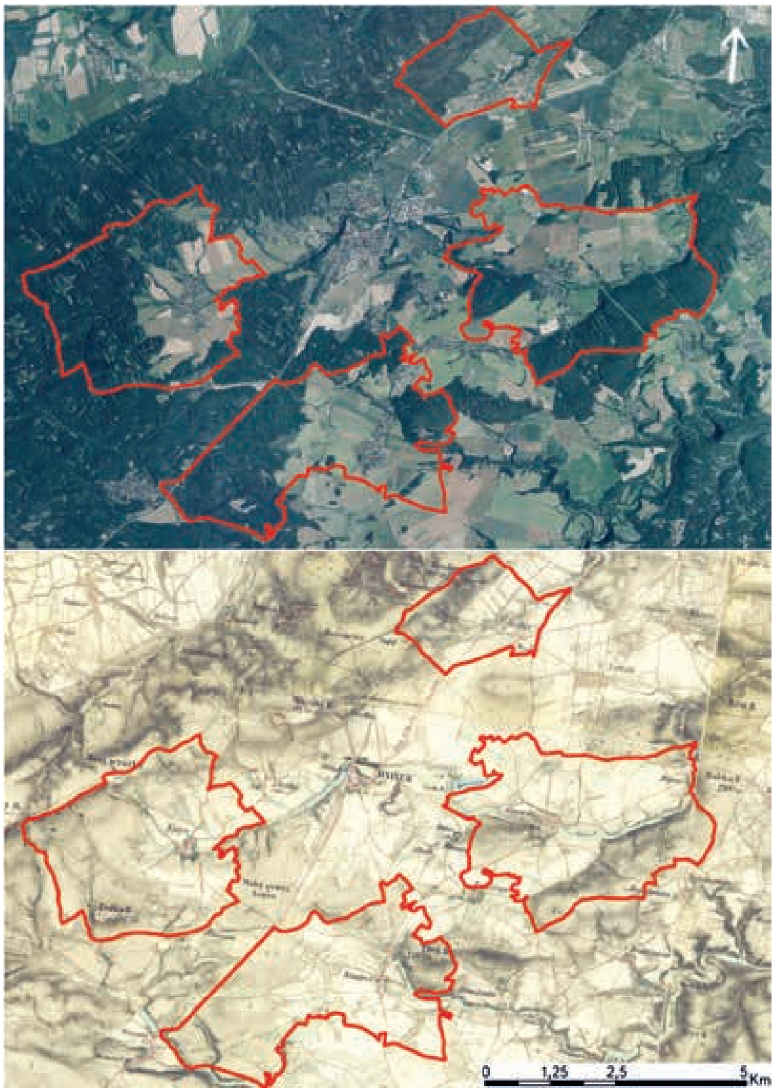


Fig. 1. Monitored area (current borders of cadastral area) on the basis of the current orthophotomap [21] and 2nd military mapping (mapped 1836–1852, 1 : 28,800) [22]

The monitored area was delimited by the boundaries of the current cadastral areas (hereinafter c. a.) (*Fig. 1*). It was chosen to represent predictors of the development of watercourses and wetlands in the landscape area "Dobříšsko-Mníšsko", located on the north-eastern edge of Hřebeny [11]. The main criterion for the selection of the monitored area was its location in the hitherto little-analysed area of Central Bohemia, in the geomorphological subunit Hřebeny. Another criterion was the location of the study area in a moderately cold landscape of hills and highlands [12]. The local landscape is a mosaic of forests, large agricultural fields, and smaller settlements. It also serves as an important leisure facility for the capital city of Prague [13].

Four c. a. were selected, with a total area of 3,785.57 ha [14]. The natural topographical and economic centre of the area, Mníšek pod Brdy c. a., was intentionally omitted from the selection. Mníšek pod Brdy has had the status of a town since the 14th century [15]. Its character does not correspond to the rural type of settlement, and its territory is therefore not suitable for comparison with the surrounding rural regions.

The imaginary axis of the monitored area is the D4 motorway leading from Prague in a south-westerly direction; its route approximately follows the route of the historic Golden Trail. The Golden Trail from Prague to Passau had a major impact on the cultural development of the local landscape. Historically, the area belonged to the prince and later royal states. Continuous forest stands predominated here, in which the royal hunting lodges were located (the current chateau in Mníšek pod Brdy, Vargač in Dobříš, Tři Trubky near Strašice, etc.). A number of plots of land in the vicinity of Mníšek pod Brdy came into the ownership of the church as a prince or royal gift. Monasteries colonized the area and established villages. The monitored area thus belonged to the later colonized areas of the middle Povltaví [16].

Over the past twenty years, new construction has multiplied due to good connections, clean air, and proximity to Brdy Hřebeny. The population almost doubled from the beginning of 2001 to the end of 2020 (Čisovice: 703 inhabitants => 1,104 inhabitants; Řitka: 604 inhabitants => 1,228 inhabitants; Kytín: 331 => 543 inhabitants; Nová Ves pod Pleší: 731 => 1,286 inhabitants) [17].

The original agricultural character of the c. a. in the monitored area was replaced by a residential and recreational function. The historically predominant arable land gave way to new urban and suburban development. At present, a minimum of the population is tied to agriculture, most of them commute to work, and a significant part of the development is used for recreational purposes [11].

Description of the monitored area in terms of geomorphology, climate, vegetation, and water in the landscape

- Geomorphology: weaker layers of loess clays deposited on the gentle slopes of predominantly south-eastern orientation, transferring into slopes. These soils are more fertile, which is why they have been mostly ploughed. The incision of the Vltava tributaries (Bojovský potok, Novoveský potok, Voznický potok) and Berounka tributaries (Všenorský potok) are more pronounced in places [11].
- Climate: the climate is moderately warm and moderately dry. The western half of Central Bohemia lies in the rain shadow of the Brdy Mountains, or the Ore Mountains, and the study areas of interest also lie in the rain shadow of Hřebeny. The climate of the region is also influenced by relatively warm drying winds (slight resemblance to Föhn winds). The average annual air temperature is 7–9 °C, with average annual rainfall of 500–600 mm [18].
- Vegetation: the phytogeographical perimeter of the area is the Bohemian-Moravian Mesophyticum, phytogeographical district 35c Příbramské Podbrdsko – it forms a transition between thermophilous and psychrophilic flora; it includes the supracolinic (hilly) and submontane (foothill, highland) layer [19]. Spruce is the dominant tree species in commercial forests. On the southern slopes of Hřebeny, it suffers from drought in places, which means that it is more exposed to bark beetle attack. Spruce monocultures are supplemented by pine, fir, and larch. Oak, beech, aspen, birch, and maple are represented, individually or in groups, sometimes also in continuous stands [11].
- Water in the landscape: aquatic ecosystems are not an important feature of the landscape. They consist of small and large streams, small to medium-sized ponds, and springs. Streams flowing through the field landscape are often regulated, channelled, and usually with a minimum of riparian vegetation. The streams flowing through the forest landscape were also subjected to channelling and incision, but they mostly retained their near-nature character. Numerous springs in the fields were drained and disappeared. There are few springs in the forests; they are mostly located at the foot of Hřebeny in waterlogged localities. Here, too, many have been drained [11].

METHODOLOGY

The basis for data processing were archival map data, map data from 2020, and field research carried out during 2020. The actual processing of the obtained data took place in 2021.

Documentation for data processing

The basic documents for the creation of a vector layer for the analysis of the development of the monitored area were map sheets of the Imperial Mandatory Imprints of the Stable Cadastre (showing the state of the area in 1840 at a scale of 1 : 2,880) [20] and a coordinated orthophotomap from 2020, ZABAGED® and Basic Map of the Czech Republic 1 : 10,000 (BM 10), all available on the ČÚZK Geoportal [21] as a WMS service.

Programs used and data processing

Georeferencing of archival map sheets of the Imperial Mandatory Imprints of the Stable Cadastre in the S-JTSK East North coordinate system, connection of current documents using the WMS service, and subsequent creation of a polygon layer of the .shp format took place in the ArcGIS environment, in the ArcMAP 10.7.1 program. Each polygon was defined by its identification number, the type of wetland, and the year in which it occurred in the area. The initial data processing took place in a GIS environment. It was a calculation of the area of polygons and line lengths. The resulting values were exported and interpreted in the form of tables in Microsoft Excel 2016. As part of the processing of these map and tabular outputs, the article presents results concerning the change in area and location of individual types of wetlands. According to stability, wetlands were differentiated as continuous, defunct, and new (*Tab. 1*). Based on available data, three types of wetland habitats were classified: wet meadows, wet meadows with woody plants, and ponds (*Tab. 3*); it was thus possible to identify them in both monitored periods.

Tab. 1. Wetland classification according to stability occurrence in individual periods

Wetland type	1840	2020	Code
Defunct	1	0	**d**
Continuous	1	1	**c**
New	0	1	**n**

Tab. 2. Total proportion of wetlands in individual periods in absolute [ha] and relative [%] values

Cadastral areas / wetlands	1840 [ha]	1840 [%]	2020 [ha]	2020 [%]
Čisovice (1,200 ha)	116.29	9.69	19.73	1.64
Řitka (393 ha)	13.08	3.33	3.98	1.01
Kytín (1,089 ha)	88.55	8.13	6.92	0.64
Nová Ves p. P. (1,102 ha)	71.43	6.48	8.63	0.78
Area in question (3,784 ha)	**289.34**	**7.65**	**39.26**	**1.04**

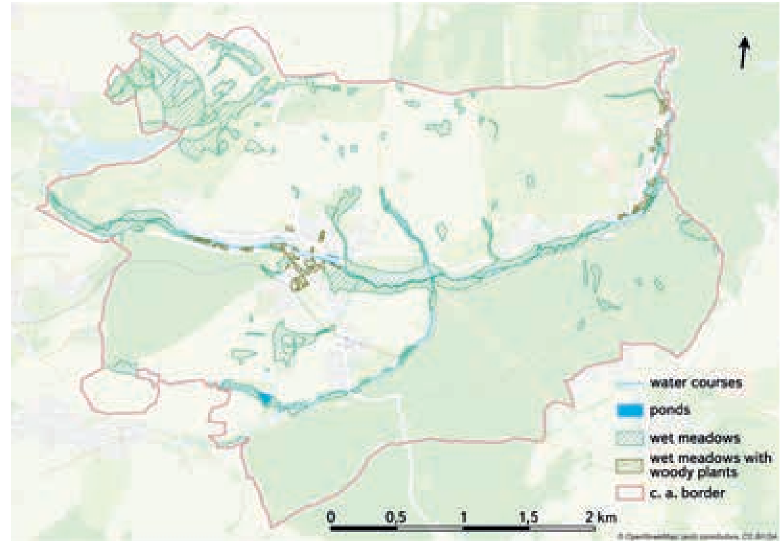


Fig. 2. Location of wetland habitats in the Čisovice cadastral area in 1840. Background data OpenStreetMap [23]

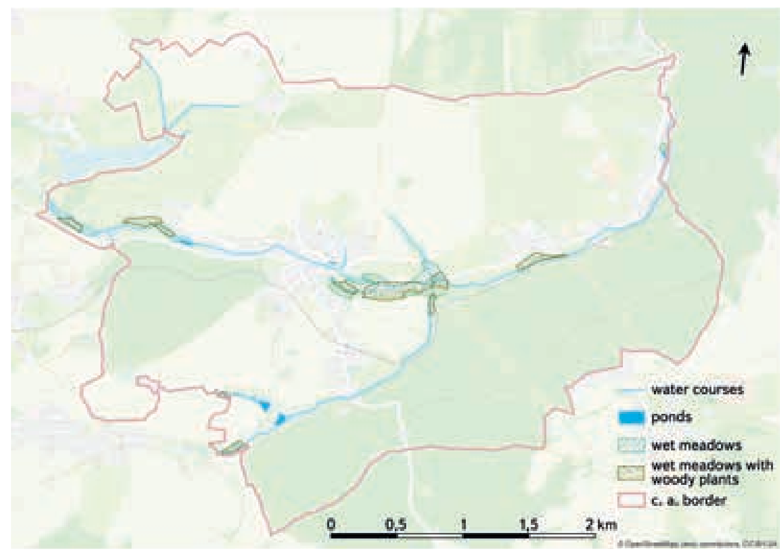


Fig. 3. Location of wetland habitats in the Čisovice cadastral area in 2020. Background data OpenStreetMap [23]

Determining the hypothesis of landscape changes in the monitored area and the expected driving forces

A hypothesis of a significant decrease in wetlands was established in connection with the change of land use from purely agricultural to predominantly urban, and to the intensification of agriculture in the remaining cultivated areas. The set of impulses that leads to such changes in the landscape is called the driving forces. The concept of land use driving forces is the basic term used to explain the reasons for landscape changes [24]. A characteristic feature of driving forces is their interconnectedness, diversity, and difficulty in defining them [25]. However, despite this diversity, driving forces tend to be divided into different categories. The basic division of driving forces is into two categories, depending on the relationship of their origin to human society, namely social driving forces and natural conditions [26]. Subsequently, social driving forces can be divided into four basic categories: economic, technological, political,

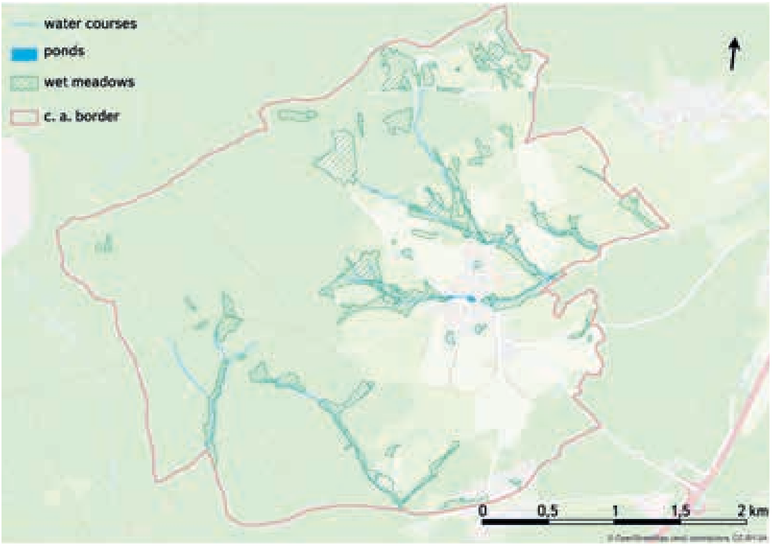


Fig. 4. Location of wetland habitats in the Kytín cadastral area in 1840. Background data OpenStreetMap [23]

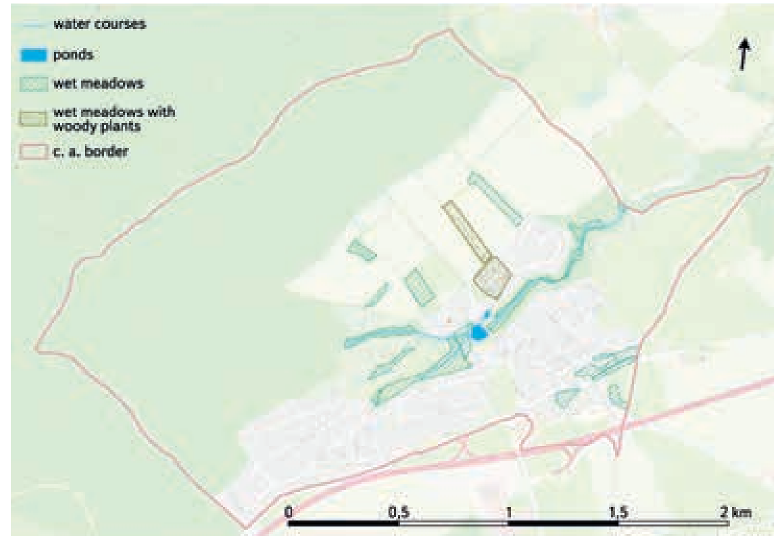


Fig. 6. Location of wetland habitats in the Řitka cadastral area in 1840. Background data OpenStreetMap [23]

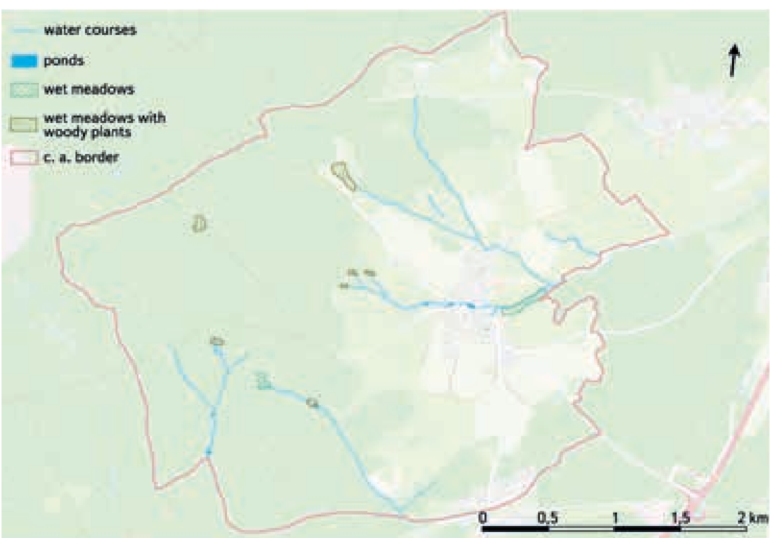


Fig. 5. Location of wetland habitats in the Kytín cadastral area in 2020. Background data OpenStreetMap [23]

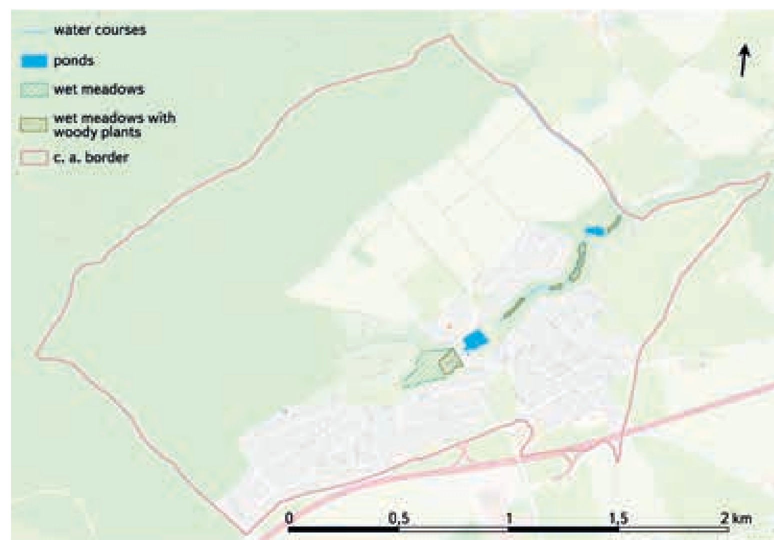


Fig. 7. Location of wetland habitats in the Řitka cadastral area in 2020. Background data OpenStreetMap [23]

and cultural [27]. The assumption was that the intensification of agriculture and urbanization in this area was the result of the first three above-mentioned driving forces; urbanization, due to the recreational use of the area, was also influenced by cultural driving forces.

RESULTS

A common feature of all studied c. a. is a significant decrease in the total area of wetlands – it decreased from 289.34 ha in 1840 (7.6% of the monitored area) to 39.26 ha in 2020 (1.04% of the monitored area) (*Tab. 2*, *Fig. 2–9*). The most dominant wetland type (out of all types according to stability, i. e. including defunct wetlands) in the monitored area are wet meadows – they cover 283.87 ha, i. e. they make up 89.35% of wetland types. Wet meadows with woody plants and ponds are located only on 27.92 ha, or 5.91 ha, i. e. it makes up 8.79%, or 1.86% of wetland types.

Wet meadows according to stability significantly predominate – the defunct ones have an area of 271.57 ha (95.67%), while continuous and new meadows occupy 9.49 ha (3.34%), or 2.81 ha (0.99%).

On the other hand, minor wetland types (i. e. wet meadows with woody plants and ponds) record an increase in their total area over time; however, due to their small proportion in the monitored area, they cannot reverse the overall trend for wetlands given by predominant wet meadows.

According to stability, new wet meadows with woody plants predominate – on an area of 22.39 ha (80.19%); in contrast, defunct ones occupy 5.53 ha (19.81%). As a continuous type of wetland according to stability, wet meadows with woody plants do not occur. According to stability, ponds are mostly represented by new ones – on an area of 3.16 ha (53.47%), continuous and defunct ones occupy 1.41 ha (23.86%), or 1.34 ha (22.67%).

In all four c. a., the results and trends are similar to those in the entire monitored area, i. e. the largest area of defunct wetlands and the smallest area of continuous wetlands. However, there are minor differences; for example, in Řitka and Kytín c. a., wet meadows with woody plants occur only as new wetlands. As a continuous type,

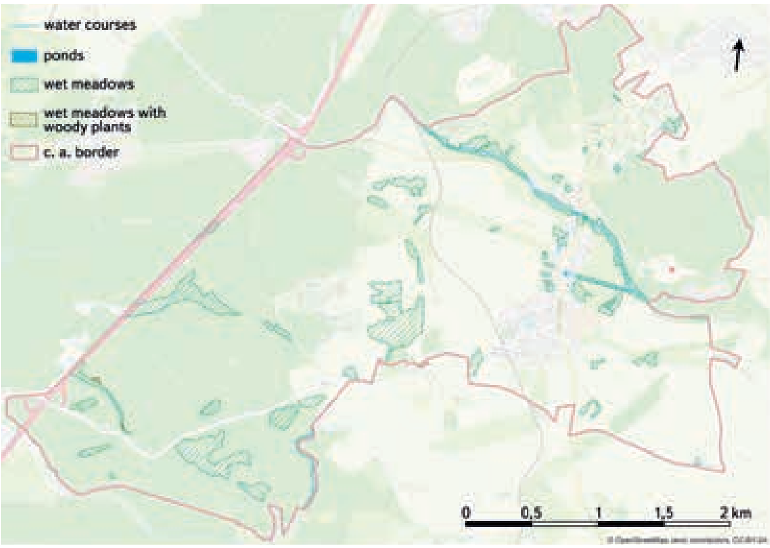


Fig. 8. Location of wetland habitats in the Nová Ves pod Pleší cadastral area in 1840. Background data OpenStreetMap [23]

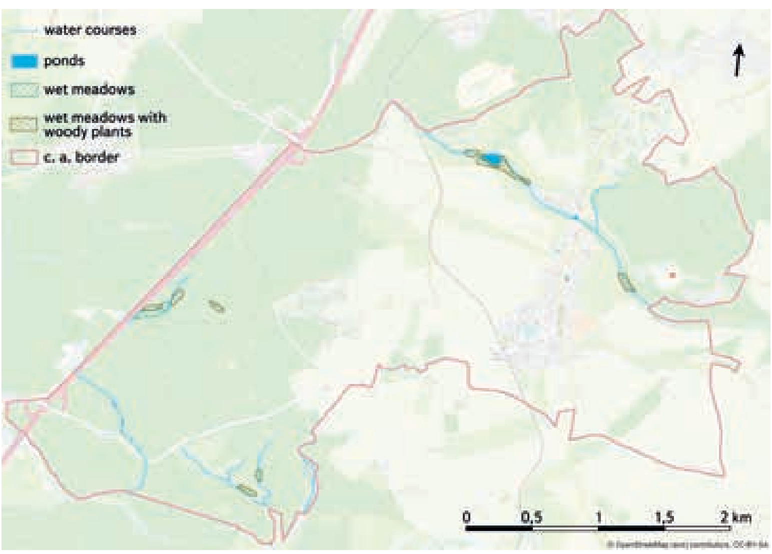


Fig. 9. Location of wetland habitats in the Nová Ves pod Pleší cadastral area in 2020. Background data OpenStreetMap [23]

wet meadows are almost non-existent in Řitka c. a. and have a smaller area than new wet meadows. The same applies to ponds in Nová ves pod Pleší c. a. In Řitka c. a., the total area of wetlands according to stability is considerably smaller than in other c. a. (4.7 times smaller than in Nová Ves pod Pleší c. a., 5.6 times smaller than in Kytín c. a. and 7.9 times smaller than in Čisovice c. a.). The entire area of Řitka c. a. is about 3 times smaller in relation to all other individual c. a. (*Tab. 3, Fig. 2–9*).

On defunct areas of wet meadows, i. e. the predominant wetland habitat, in Kytín c. a., permanent grasslands (42%), forest and shrubs (18 and 17%, respectively) currently occur most frequently; in Nová Ves pod Pleší c. a., the same applies for permanent grasslands (38%), arable land and forest (30 and 27%, respectively), and in Čisovice c. a., the same applies for permanent grasslands and arable land (40 and 28%, respectively); however, forest and development, including gardens on the site of defunct wetlands, also account for a significant share (14 and 13%, respectively). In Řitka c. a., on the site of wet meadows there are permanent grasslands (35%), forest and development, including gardens (both 27%), arable land (12%) and also a relatively significant area of defunct wet meadows with woody plants. On their site, arable land and development, including gardens, are equally represented.

Tab. 3. Proportion of individual classification types of wetland habitats according to stability in the monitored area and in individual c. a. [ha]

Čisovice (1,200 ha)	**d [ha]**	**c [ha]**	**n [ha]**	**total [ha]**
Wet meadows	105.35	4.86	1.33	111.54
Wet meadows with woody Plants	5.27	0	12.1	17.37
Ponds	0.21	0.59	0.85	1.65
Total wetlands	**110.83**	**5.45**	**14.28**	**130.56**
Řitka (393 ha)	**d [ha]**	**c [ha]**	**n [ha]**	**total [ha]**
Wet meadows	12.53	0.04	1.45	14.02
Wet meadows with woody Plants	0	0	1.48	1.48
Ponds	0.08	0.43	0.58	1.09
Total wetlands	**12.61**	**0.47**	**3.51**	**16.59**
Kytín (1,089 ha)	**d [ha]**	**c [ha]**	**n [ha]**	**total [ha]**
Wet meadows	85.64	2.57	0.03	88.24
Wet meadows with woody Plants	0	0	3.68	3.68
Ponds	0.08	0.26	0.38	0.72
Total wetlands	**85.72**	**2.83**	**4.09**	**92.64**
Nová Ves p. Pleší (1,102 ha)	**d [ha]**	**c [ha]**	**n [ha]**	**total [ha]**
Wet meadows	68.05	2.02	0	70.07
Wet meadows with woody Plants	0.26	0	5.13	5.39
Ponds	0.97	0.13	1.35	2.45
Total wetlands	**69.28**	**2.15**	**6.48**	**77.91**
Area in question (3,784 ha)	**d [ha]**	**c [ha]**	**n [ha]**	**total [ha]**
Wet meadows	271.57	9.49	2.81	283.87
Wet meadows with woody Plants	5.53	0	22.39	27.92
Ponds	1.34	1.41	3.16	5.91
Total wetlands	**278.44**	**10.9**	**28.36**	**317.7**

Fig. 10. Wet meadow in the locality Andělské schody in the Nová Ves pod Pleší cadastral aea

Fig. 11. The wide floodplain of the Bojovský creek in the Čisovice cadastral area classified as a wet meadow

Fig. 12. The floodplain of the Chouzavá creek in the Kytín cadastral area classified as a wet meadow with woody plants

Fig. 13. The littoral zone of the Mlýnec pond in the Řitka cadastral area

Fig. 10–13 present examples of wetland habitat types from field research in the monitored area.

DISCUSSION

Selected sites in the monitored area are characterized by a specific attribute – their area is almost 50% forested and, due to its location at the foot of Hřebeny, it serves as springs for part of the Lower Vltava and Berounka river basins. Thus far, Brdy forests have been systematically examined only irregularly (with the exception of Brdy Protected Landscape Area). Therefore, this paper could not completely objectively assess the historical locations of forest wetlands. However, it did monitor the declining trend in the occurrence of wetlands in the current forest and non-forest area of the monitored area. The chosen method of wetland detection in the landscape is of limited use due to a certain inaccuracy of the maps of the stable cadastre (mainly due to insufficient historical interception of waterlogged forests) [28]. However, with regard to the availability of historical data on the topic, it is a good means of obtaining the basis for subsequent analysis. Due to the temporal and spatial extent of this research, the used method is relatively quick. The verification results revealed shortcomings in the location of historic wetlands; however, the combination of field research together with the ZABAGED® layer, BM 10 and the current orthophotomap is sufficiently objective to identify the current wetlands.

In terms of temporal stability of wet meadows, analysis of their trajectories in the monitored area showed that, historically, they were in the most widespread wetland category (281.06 ha in 1840). Simultaneously, their representation in the current landscape of the monitored area decreased significantly (to 12.3 ha). In the category of defunct wetlands, they are the most common type (*Tab. 3*). This fact also corresponds to the findings of similar studies in the Czech Republic and abroad [29–32].

Ponds show the highest stability and continuity over time. Based on the analysis of their dynamics, it is clear that we can also attribute the highest increase in area due to their historical size (from 2.75 ha in 1840 to 4.57 in 2020), despite the fact that they represent only 0.95% of the total wetland area in the maps of the stable cadastre. With regard to the decrease in the area of other types of wetland habitats, the share of ponds in the total area of wetlands has risen to 11.64%.

Ponds as a type of wetland did not need to be considered. From the point of view of landscape ecology and water management, the ponds are classified as water areas. However, they also meet the definition of wetlands [5]. On the maps of the stable cadastre, all water surfaces in the monitored area are generally classified as ponds. At present, according to map data and field research, the situation in the monitored area is similar (*Fig. 13*).

An interesting phenomenon was found when comparing the decrease in wet meadows with the increase in wet meadows with woody plants; this wetland type shows the highest detected dynamics of trajectories. Wet meadows with woody plants, which in the maps of the stable cadastre cover only 5.53 ha, and only on the territory of Čisovice and Nová Ves pod Pleší c. a., have increased their area to 22.42 ha by 2020 and are now found in all four c. a. This means an increase from 1.91% to 57.03% of the area of all wetlands in the monitored area (*Tab. 3*). A possible explanation lies in the historical abandonment of wet meadow mowing and their subsequent overgrowth with successional trees, but also in the afforestation of less fertile localities [33, 34].

Permanent grasslands predominate in the areas of defunct wetlands, and forest also occupies a significant share. Arable land also forms a significant area of the original and now defunct wetlands, with the exception of Kytín c. a., where, in contrast to the rest of the monitored area, shrubs occur to a large extent. Development, including gardens, occupies a significant share only in Řitka and Čisovice c. a. Thus, the driving forces in the whole territory were the abandonment of economically used areas and their overgrowth with forest, or drainage of waterlogged localities within the intensification of agriculture, i. e. transformation of "wet" meadows into "dry" meadows. In Kytín c. a., there was a different composition of land use on the areas of historic wetlands, as there is almost no development or arable land. This is due to the recreational use of this area; there is no pressure to convert the site for economic use. On the other hand, development, including gardens, occurs on the site of historic defunct wetlands basically only in Řitka and Čisovice c. a.; currently, there is pressure on their important residential function for development– proximity to the countryside and easy transport accessibility to Prague.

In possible follow-up studies, it would be interesting to perform more detailed hydrological measurements to determine the direct impact of deforestation on the state of springs, and thus the entire area at the foot of Hřebeny. The results could be compared with other foothill areas in the Czech Republic and abroad.

CONCLUSION

In the monitored area, there was a significant decrease in the total area of wetlands from 289.34 ha in 1840 to 39.26 ha in 2020, which means 7.6%, or 1.04% of the monitored area. The most dominant wetland type in the area according to stability, including defunct wetlands, are wet meadows, covering 283.87 ha, i. e. making up 89.35% of wetland types. Wet meadows with woody plants and ponds occupy an area of only 27.92 ha, or 5.91 ha, i. e. they make up 8.79%, or 1.86% of wetland types.

Wet meadows in the monitored area are classified mainly as defunct on an area of 271.57 ha (95.67% of wet meadows according to stability); continuous and new wet meadows are on an area of 9.49 ha (3.34%), or 2.81 ha (0.99%).

On the other hand, other wetland types – wet meadows with woody plants and ponds – show a slight increase in their total area in 2020 compared to 1840; however, due to their negligible area compared to wet meadows in the monitored area, they cannot reverse the global trend of strong decline in total wetland area as such.

The results presented in this article should create a practical basis for subsequent monitoring of water features in the region in order to return water to the landscape. They can be helpful for the restoration of defunct wetlands and, at the same time, for the care of current wetlands; it is these landscape elements that are the solution to adapting to the challenges posed by current climate change. A vibrant and diverse landscape makes a significant contribution to water retention and maintaining a stable climate.

References

[1] BENDER, O., BOEHMER, H. J., JENS, D., SCHUMACHER, K. P. Using GIS to Analyse Long-Term Cultural Landscape Change in Southern Germany. *Landscape and Urban Planning*. 2010, 70(1-2), p. 111–125.

[2] LIPSKÝ, Z. *Sledování změn v kulturní krajině*. Kostelec nad Černými lesy: Lesnická práce, 1999. 71 p.

[3] BIČÍK, I., JELEČEK, L., ŠTĚPÁNEK, V. Land-Use Changes and their Social Driving Forces in Czechia in the 19th and 20th Centuries. *Land Use Policy*. 2001, 18, p. 65–73.

[4] SÁDLO, J., POKORNÝ, P., HÁJEK, P., DRESLEROVÁ, D., CÍLEK V. *Krajina a revoluce: Významné přelomy ve vývoji kulturní krajiny* českých *zemí*. Malá Skála, Praha 2008. 255 p.

[5] MŽP – *Významné krajinné prvky – rybník* [on-line]. [accessed December 3, 2021]. Available from: https://www.mzp.cz/cz/rybnik_definice

[6] ČÍŽKOVÁ, H., KVĚT, J., VLASÁKOVÁ, L. *Mokřady: ekologie, ochrana a udržitelné využívání*. České Budějovice: Jihočeská univerzita, 2017. 631 p.

[7] KUMAR, A., KANAUJIA, A. Wetlands: Significance, Threats and their Conservation. *Environ*. 2014, 7, p. 1–24.

[8] ČÁKA, J. *Toulání po Brdech*. 3. vyd. Praha: Mladá fronta, 2011. 336 p.

[9] DEMEK, J., MACKOVČIN, P. (eds.). *Zeměpisný lexikon – Hory a nížiny*. Praha: Agentura ochrany přírody a krajiny ČR; VÚKOZ, 2006. 583 p.

[10] MĚSTO HOSTOMICE – *Přírodní park Hřebeny* [on-line]. [accessed December 3, 2021]. Available from: https://www.hostomice.cz/prirodni-park-hrebeny.html

[11] STŘEDOČESKÝ KRAJ – *Vyhodnocení krajinného rázu Středočeského kraje* [on-line]. [accessed December 18, 2021]. Available from: https://www.kr-stredocesky.cz/

[12] ROMPORTL, D., CHUMAN, T., LIPSKÝ, Z. New Method of Landscape Typology in the Czech Republic. Landscape Classification – Theory and Practice, The Problems of Landscape. *Ecology*. 2008, 20, p. 315–320.

[13] GEOGRAFICKÁ SEKCE PřF UK – *Zaniklé krajiny* [on-line]. [accessed October 12, 2021]. Available from: http://www.zaniklekrajiny.cz/

[14] *Geoportál* ČÚZK *– přístup k mapovým produktům a službám resortu* [on-line]. [accessed December 18, 2021]. Available from: http:// geoportal.cuzk.cz/

[15] DAVID, P., SOUKUP, V. *Brdy známé i neznámé*. Praha: Euromedia Group, a. s., 2016.

[16] KREJČÍ, J. *Z historie farnosti sv. Václava v Mníšku pod Brdy* [on-line]. 2012. [accessed August 3, 2021]. Available from: http://farnost.mnisek.cz/historie/mnisek-pod-brdy/

[17] Český statistický úřad – *Počet obyvatel v obcích – k 1. 1. 2021* [on-line]. [accessed October 15, 2021]. Available from: https://www.czso.cz/csu/czso/pocet-obyvatel-v-obcich-k-112021/

[18] Český hydrometeorologický ústav – *Atlas podnebí* Česka [on-line]. [accessed October 16, 2021]. Available from: https://www.chmi.cz/files/portal/docs/meteo/ok/images/sra6190.gif

[19] SKALICKÝ, V. Regionálně fytogeografické členění. In: HEJNÝ, S., SLAVÍK, B. (eds.). *Květena* České *socialistické republiky*, 1. Praha: Academia, 1988, p. 103–121.

[20] *Archivní mapy* Ústředního *archivu zeměměřictví a katastru* [on-line]. [accessed October 10, 2021]. Available from: https://ags.cuzk.cz/archiv/

[21] Geoportál ČÚZK – *Prohlížecí služby – WMS* [on-line]. [accessed September 29, 2021]. Available from: https://geoportal.cuzk.cz/(S(lcsguqwsq1my1rvbg3qy5suw))/Default.aspx?mode=TextMeta&side=wms.verejne&text=WMS.verejne.uvod&head_tab=sekce-03-gp&menu=311

[22] Národní geoportál INSPIRE – *WMS služby* [on-line]. [accessed November 23, 2021]. Available from: https://geoportal.gov.cz/web/guest/wms>

[23] *OpenStreetMap* [on-line]. [accessed November 25, 2021]. Available from: https://www.openstreetmap.org

[24] PLIENINGER, T. et al. The Driving Forces of Landscape Change in Europe: A Systematic Review of the Evidence. *Landscape Research*. 2016, 35(7), p. 204–214.

[25] PEÑA, J. et al. Driving Forces of Land-Use Change in a Cultural Landscape of Spain. In Koomen, E. et al. (eds.). *Modelling Land-Use Change*. Dordrecht: Springer, 2007, p. 97–115.

[26] BIČÍK, I. et al. *Vývoj využití ploch v* Česku. Edice Geographica 3. Praha: ČGS, 2010. 250 p.

[27] SKOKANOVÁ, H., FALŤAN, V., HAVLÍČEK, M. Driving Forces of Main Landscape Change Processes from Past 200 Years in Central Europe – Differences between Old Democratic and Post-Socialist Countries. *Ekológia* (Bratislava). 2016, 35(1), p. 50–65. ISSN (on-line) 1337-947X. Available from: doi: 10.1515/eko-2016-0004

[28] RICHTER, P. Problematika interpretace archivních mapových podkladů v případě mokřadních biotopů. *Vodohospodářské technicko-ekonomické informace*. 2021, 63(5), p. 32–38. ISSN 0322-8916.

[29] GIMMI, U., LACHAT, T., BÜRGI, M. Reconstructing the Collapse of Wetland Networks in the Swiss Lowlands 1850–2000. *Landscape Ecology*. 2011, 26(8), p. 1071–1083.

[30] BRAŠNA, V. *Změny ve vývoji mokřadů v krajině – trajektorie, příčiny. Diplomová práce*. Praha: Česká zemědělská univerzita; Fakulta životního prostředí, katedra aplikované ekologie, 2016. (Nepublikováno).

[31] SKALOŠ, J., RICHTER, P., KEKEN, Z. Changes and Trajectories of Wetlands in the Lowland Landscape of the Czech Republic. *Ecological Engineering*. 2017, 108, p. 435– 445.

[32] RICHTER, P. Trajektorie vývoje mokřadů v horní části povodí Výrovky za uplynulých 180 let. *Vodohospodářské technicko-ekonomické informace*. 2020, 62(6), p. 20–26. ISSN 0322-8916.

[33] POLENO, Z., VACEK, S. *Teoretická východiska pěstování lesů*. Kostelec nad Černými lesy: Lesnická práce, s. r. o., 2007.

[34] *Mokřady – ochrana a management* [on-line]. [accessed January 12, 2022]. Available from: http://www.mokrady.wbs.cz

Authors

Ing. Pavel Richter, Ph.D.
✉ pavel_richter@vuv.cz
ORCID: 0000-0001-6338-3481

Ing. Renáta Sztymonová
✉ renata.szt@seznam.cz
Řitka

T. G. Masaryk Water Research Institute, Prague

The paper has been peer-reviewed.

DOI: 10.46555/VTEI.2022.01.003

Comparison of hydrological characteristics of *M*-day discharges of the reference period 1981–2010 and the considered reference period 1991–2020

PAVEL KUKLA

Keywords: hydrology — basic hydrological data — long-term mean discharge — *M*-day discharges — reference period

INTRODUCTION

According to the Czech technical standard ČSN 75 1400 *Hydrological data of surface waters*, *M*-day discharges are a part of the Basic hydrological data [1]. The values of *M*-day discharges in water gauging stations are derived from time series of observed mean daily discharges over a defined reference period. The reference period 1981–2010 is currently used for design purposes [2]. With the end of the second decade of the 21st century, a change in the reference period for 1991–2020 is being considered. In the past, the Czech Hydrometeorological Institute (CHMI) provided hydrological data for the reference periods 1931–1940, 1931–1960, and 1931–1980.

Reference period 1981–2010

The hydrological characteristics of *M*-day discharges for the period 1981–2010 were calculated in CHMI for gauging profiles after 2010; in the following years, the characteristics of *M*-day discharges for unmonitored profiles were derived using new mathematical and statistical tools. The data processing used a significantly wider database with evaluated mean daily discharges from the network of water gauging stations than in the previous reference period 1931–1980. The calculations made it possible to include available data on the influence of the natural flow regime on water abstraction, on wastewater discharges, and on activities at hydraulic structures in the entire reference period. During the derivation, a new layer of watersheds of basic hydrological basins was used, at a scale of 1 : 10,000, as well as other current GIS data layers [3].

Comparison of selected hydrological characteristics of the period 1981–2010 with the considered reference period 1991–2020

The basic hydrological data characterizing the runoff conditions of a watercourse are the long-term mean discharge *Qa* and the quantiles of *M*-day discharges *QMd*. 304 CHMI water gauging stations, which were continuously monitored between 1 November 1980 and 31 October 2020, passed the statistical analysis of changes in hydrological characteristics. *Tab. 1* shows the percentage change in the long-term mean discharge and selected quantiles of *M*-day discharges derived for the period 1991–2020 and for the period 1981–2010 for 35 selected water gauging stations. To highlight the magnitude of the change in individual characteristics, the cells were colour-coded in shades of red (decrease in characteristics in 1991–2020 compared to 1981–2010) and blue (increase in characteristics in 1991–2020 compared to 1981–2010). At first glance, it is clear that red shades predominate in the table for all hydrological characteristics. With a few exceptions at several anthropogenically affected gauging stations, the runoff characteristics decreased mainly in the period 1991–2020.

To compare the development of water bearing during the period 1981–2020, the percentages of each mean annual discharge in the long-term mean discharge for the period 1981–2010 were calculated for 304 water gauging stations. These percentages were then averaged for each hydrological year and this value serves as a characteristic expressing the percentage of the runoff of that year in the long-term mean discharge (see graph in *Fig. 1*). The graph shows that when comparing the decades 1981–1990 and 2011–2020, which differ between the current and newly considered reference periods, most of the years 2011–2020 were part of a multi-year dry period that began in 2014 and in some regions lasted until 2019. In the 1980s, only 1984 and 1990 were significantly below mean (< 0.8), the other years were close to the long-term mean 1981–2010 or even above mean. This fact explains the negative changes in the long-term mean discharge at most water gauging stations.

The magnitude of the change in the long-term mean discharge calculated for the period 1991–2020 compared to the period 1981–2010 in the set of 304 water gauging stations ranges from –27% in the Želízy profile on the Liběchovka river to +31% in the significantly anthropogenically influenced profile of the Žermanice profile on the Lučina river. The map in *Fig. 2* shows the magnitude of the percentage change in the long-term mean discharge *Qa* in selected water gauging stations in the period 1991–2020 compared to the period 1981–2010. The average value of the change in the long-term mean discharge calculated in the set of 304 water gauging stations is equal to –7.3%. From a regional point of view, there are the smallest changes in the size of the long-term mean discharge in the Malše and Odra river basins; on the contrary, the largest decreases were recorded at water gauging stations in the upper part of the Berounka, Ploučnice, Svratka, Jihlava and Dyje river basins. From the overall view of the map, it is clear that the reduction in long-term mean discharge is almost across the board.

Tab. 1. Percentage change of selected quantiles of M-day discharges derived for the period 1991–2020 compared to the period 1981–2010 in selected water gauging stations

Profile	Watercourse	Catchment area [km^2]	Change of [%] Qa and QMd [1991–2020/1981–2010]			
			Q_a	Q_{30d}	Q_{180d}	Q_{355d}
Jaroměř	Labe	1,224.10	–11.2	–13.1	–10.0	–22.1
Týniště nad Orlicí	Orlice	1,554.17	–11.2	–7.7	–12.5	–21.1
Přelouč	Labe	6,437.52	–9.7	–11.5	–9.6	–20.0
Železný Brod	Jizera	791.26	–8.4	–10.9	–5.6	–15.5
Roudné	Malše	962.21	–1.6	–0.7	–3.9	–2.1
Bechyně	Lužnice	4,057.02	–4.8	–5.9	–4.0	–11.7
Písek	Otava	2,913.70	–5.5	–4.5	–8.7	–9.9
Zruč nad Sázavou	Sázava	1,420.68	–5.4	–5.3	–0.3	–12.8
Kácov	Sázava	2,814.42	–10.5	–14.1	–4.5	–13.1
Lhota	Radbuza	1,181.82	–11.1	–13.6	–8.8	–27.9
Štěnovice	Úhlava	892.84	–7.8	–10.3	–4.0	–15.2
Plzeň-Bílá Hora	Berounka	4,017.46	–12.3	–14.9	–9.2	–14.3
Beroun	Berounka	8,286.23	–9.1	–11.2	–6.3	–16.0
Karlovy Vary-Drahovice	Ohře	2,857.03	–12.1	–10.3	–13.1	–17.7
Louny	Ohře	4,979.76	–9.7	–9.1	–13.9	–19.0
Trmice	Bílina	923.17	–13.5	–8.1	–16.6	–24.6
Benešov nad Ploučnicí	Ploučnice	1,156.73	–12.6	–11.3	–12.6	–15.5
Děčín	Labe	51,120.34	–8.7	–10.5	–7.8	–10.4
Svinov	Odra	1,613.70	–0.8	–1.6	1.1	–20.3
Děhylov	Opava	2,037.55	–0.8	–4.8	0.3	10.6
Ostrava	Ostravice	820.02	–1.0	–0.7	0.3	–14.0
Bohumín	Odra	4,663.74	–1.4	–2.9	–0.7	–3.0
Věřnovice	Olše	1,075.59	–2.6	–2.6	–0.9	–10.2
Moravičany	Morava	1,561.19	–8.4	–9.3	–8.3	–14.0
Olomouc-Nové Sady	Morava	3,323.59	–7.4	–5.7	–9.0	–18.6
Dluhonice	Bečva	1,592.84	–3.5	–5.1	–1.5	–14.4
Kroměříž	Morava	7,013.27	–7.0	–6.9	–6.5	–8.0
Strážnice	Morava	9,144.83	–7.7	–8.1	–7.3	–12.1
Podhradí nad Dyjí	Dyje	1,755.48	–10.8	–8.4	–11.2	–19.2
Trávní Dvůr	Dyje	3,535.06	–10.9	–20.4	–8.5	–12.1
Veverská Bítýška	Svratka	1,479.76	–10.5	–11.7	–5.2	–11.7
Bílovice nad Svitavou	Svitava	1,119.98	–10.3	–12.2	–8.7	–3.9
Židlochovice	Svratka	3,938.12	–7.2	–9.1	–3.8	–2.9
Třebíč-Ptáčov	Jihlava	962.71	–7.8	–7.6	–5.5	–11.2
Ivančice	Jihlava	2,679.98	–11.9	–19.1	–12.9	–4.0

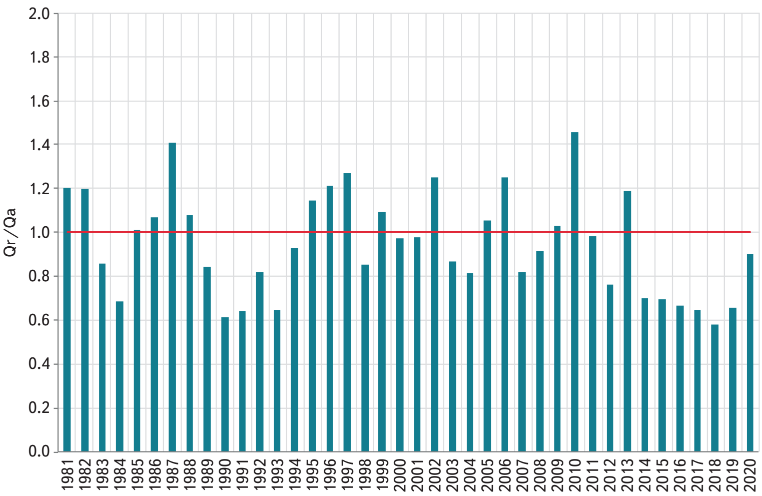


Fig. 1. Mean annual shares of *Qr* in the long-term mean discharge *Qa* for the period 1981–2010 in 304 gauging stations ($Qa_{1981–2010} = 1$)

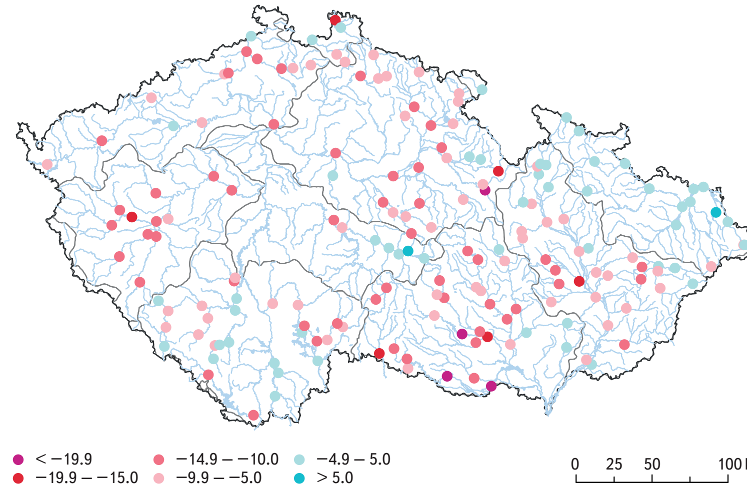


Fig. 3. Percentage differences between Q_{30d} discharges at selected gauging stations for the periods 1991–2020 and 1981–2010

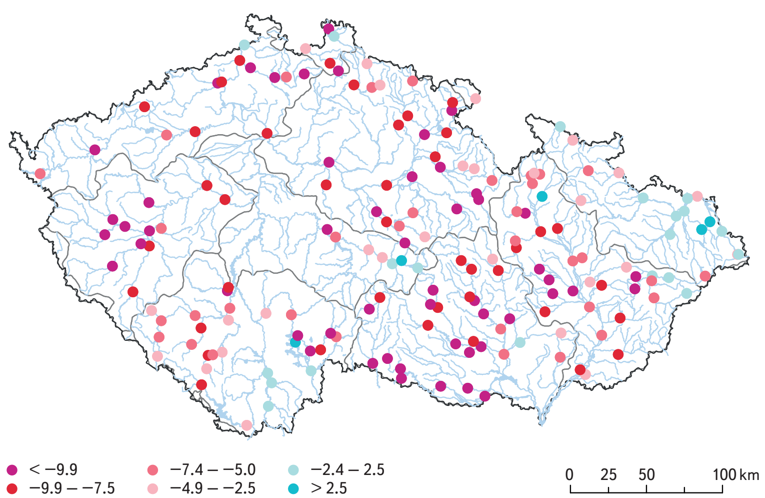


Fig. 2. Percentage differences between long-term mean discharges Q_a at selected gauging stations for the periods 1991–2020 and 1981–2010

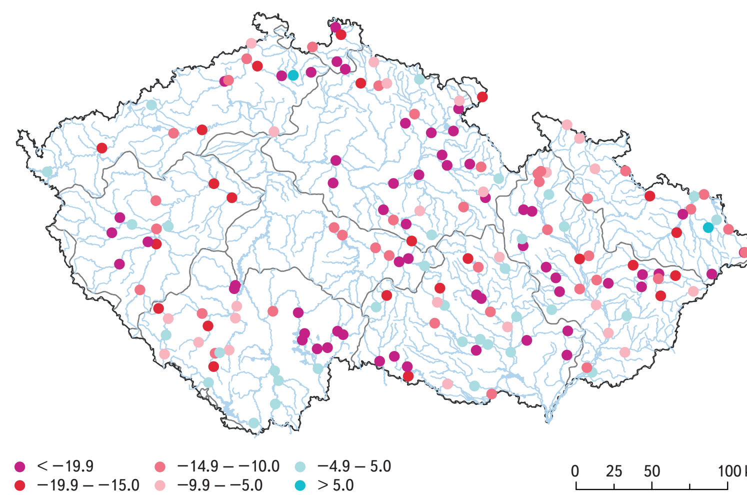


Fig. 4. Percentage differences between Q_{355d} discharges at selected gauging stations for the periods 1991–2020 and 1981–2010

A largely similar spatial distribution also appears in the results of the calculation of the percentage change in the 30-day discharge $Q_{30}d$ when comparing this characteristic for the period 1991–2020 with the period 1981–2010 (see *Fig. 3*). As the highest water bearing years from the second half of the 1990s to 2010 are common to both reference periods, the comparison of the decade of the 1980s and the last decade 2011–2020 is again decisive in the case of the magnitude of the change in the 30-day discharge $Q_{30}d$. In general, the period 1981–1990 was more aqueous than the period 2011–2020, so the average value of the change in the 30-day discharge $Q_{30}d$ in the set of 304 water gauging stations is based on −7.2%.

The map in *Fig. 4* shows the magnitude of the percentage change of the 355-day discharge $Q_{355}d$ in selected gauging stations in the period 1991–2020 compared to the period 1981–2010. Due to the long-lasting hydrological drought in the period 2014–2019, which continued in certain parts of the country until 2020, the values of the minimum discharge quantiles decreased at most gauging stations. Long-term periods of minimum discharges have been observed during long-lasting precipitation-free periods during the dry years. This caused the average magnitude of the change in 355-day discharge $Q_{355}d$ in the set of 304 gauging stations to be −13.4%.

The above-described changes in the size of selected *M*-day discharge quantiles affected the shape of the *flow duration curves of mean daily discharges* at gauging stations. The graphs in *Fig. 5–7* show the flow duration curves of mean daily dischargesin the period 1981–2010 and in the period 1991–2020 for selected final gauging stations. In the graph in *Fig. 5*, which shows the flow duration curves of mean daily dischargesfor the Děčín profile on the Elbe river, it is evident that the water bearing decreased throughout the flow duration curve of mean daily discharges. The flow duration curve of mean daily discharges for the period 1991–2020 copies the curve for the period 1981–2010. The shape of the flow duration curve of mean daily discharges for the Děčín profile is influenced by activities on hydraulic structures; the Vltava Cascades reservoirs have the greatest influence on the shape of the flow duration curve of mean daily discharges.

The graph in *Fig. 6* shows the flow duration curves of mean daily dischargesfor the profile of the Bohumín water gauging station on the Odra river. The graph shows that the flow duration curve of mean daily discharges for the period 1991–2020 has almost the same shape as the curve for the period 1981–2010. The reason is the fact that the Odra river basin was the least affected by drought during the 2014–2020 dry season and, simultaneously, there are large reservoirs on the Odra tributaries, operations on which can improve the flows in the watercourses below the hydraulic structures.

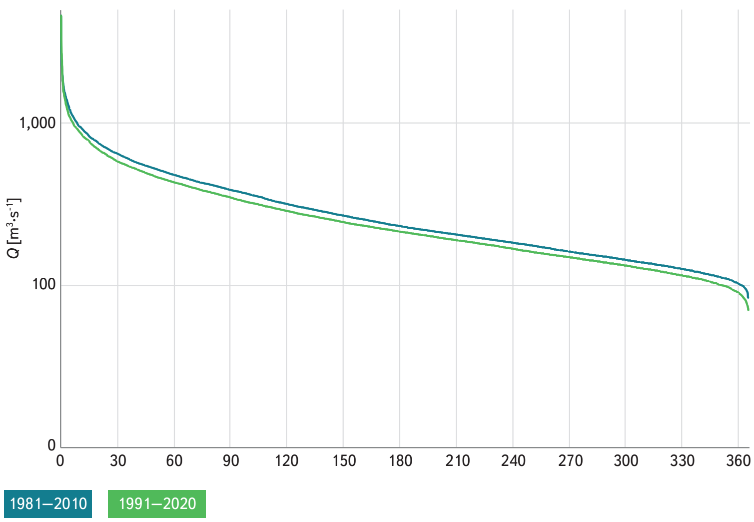


Fig. 5. Flow duration curves at the Děčín gauging station on the Labe River for the periods 1981–2010 and 1991–2020

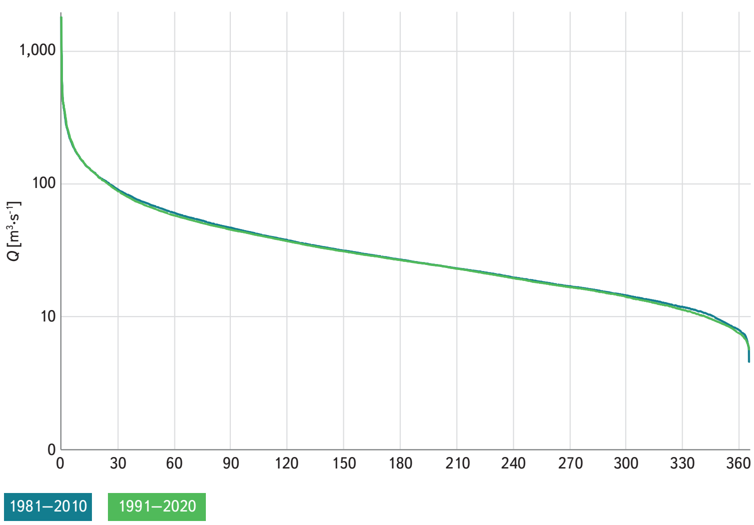


Fig. 6. Flow duration curves at the Bohumín gauging station on the Odra River for the periods 1981–2010 and 1991–2020

The graph in *Fig. 7* shows the flow duration curves of mean daily dischargesfor the Strážnice water gauging station on the Morava river. The Morava river basin and its tributaries was severely affected by the drought. The value of the 30-day discharge $Q_{30}d$ decreased in Strážnice in the period 1991–2020 by 8.1% and the 355-day flow decreased by 12.1%.

CONCLUSION

The results of the comparison of *M*-day discharges for the reference period 1981–2010 and the considered reference period 1991–2020 show that the quantiles of *M*-day discharges decreased at most gauging stations. In the set of 304 water gauging stations, the average change in the long-term mean discharge *Qa* reaches –7.3% and the average change in the 355-day discharge $Q_{355}d$ is –13.4%. The change in the reference period of the hydrological characteristics is made in order to ensure that the hydrological data derived for the reference period best reflect the current hydrological regime.

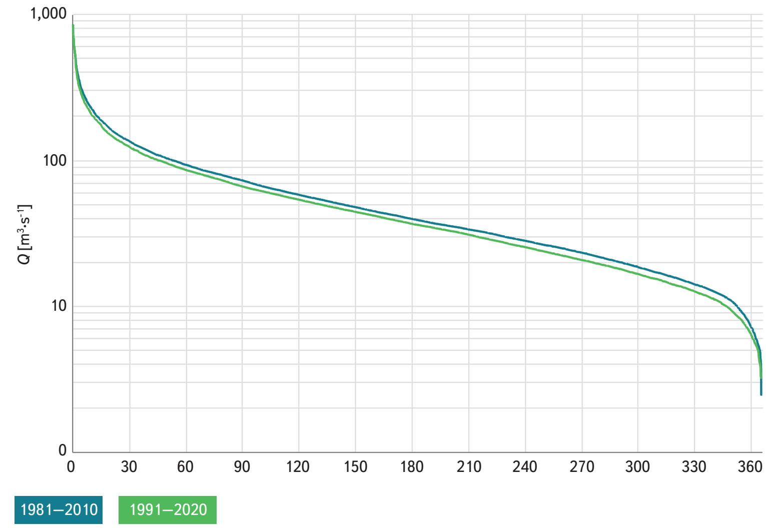


Fig. 7. Flow duration curves at the Strážnice gauging station on the Morava River for the periods 1981–2010 and 1991–2020

References

[1] ČSN 75 1400:2014. *Hydrologické* údaje *povrchových vod*. Česká technická norma. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví, Praha

[2] ŠERCL, P., KUKLA, P. Porovnání základních hydrologických údajů za referenční období 1931–1980 a 1981–2010. *Hydrologická ročenka* České *republiky* 2014. Praha: Český hydrometeorologický ústav, 2015.

[3] BUDÍK, L., ŠERCL, P., KUKLA, P., LETT, P., PECHA, M. Odvození základních hydrologických údajů za referenční období 1981–2010. In. *Sborník prací* Českého *hydrometeorologického* ústavu, vol. 65. Praha: Český hydrometeorologický ústav, 2018.

Author

RNDr. Pavel Kukla
✉ pavel.kukla@chmi.cz
Czech Hydrometeorological Institute, Prague

Photo: shutterstock.com

The Authors

doc. Ing. Michaela Danáčová, PhD.

Slovak University of Technology in Bratislava,
Faculty of Civil Engineering

✉ michaela.danacova@stuba.sk
www.svf.stuba.sk

Doc. Ing. Michaela Danáčová, Ph.D., works at the Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology in Bratislava. She completed her engineering studies in the study programme Water Management and Water Structures at the Faculty of Civil Engineering, Slovak University of Technology, where she was also awarded the degree of *Philosophiae Doctor* in Hydrology. She specializes in hydrological modelling of floods in watercourse beds, analysis of fluctuations in series of hydrological variables, as well as in erosion-transport processes in the landscape. She participates in several research projects and assignments.

Ing. Taťána Halešová

ALS Czech Republic, Ltd., Project Section Supervizor

✉ tatana.halesova@alsglobal.com
https://www.alsglobal.cz/vyzkumne-projekty-v-als

Majoring in Food Chemistry and Biotechnology, she graduated from the Faculty of Chemistry at Brno University of Technology in 2006. She worked at the Analytical Laboratory of Post-Registration Control of Plant Protection Products at the State Phytosanitary Administration in Brno in 2006–2009. Since 2009, she has worked at ALS Czech Republic, Ltd., where she has been focusing on monitoring pesticide substances in various environmental compartments (water, soil, biota) in long terms. In 2014, the independent Project Department was established under her leadership through which ALS Czech Republic participates in grant projects awarded by various government and private entities. Since 2018, she has been a member of the Czech Water Association (CzWA), the group specialising in drinking water treatment, which also deals with pesticides, pharmaceuticals and other micropollutants. She has co-operated in several projects, e.g., LIFE2Water "*Verification and assessment of technologies for tertiary treatment of municipal wastewater*", TA CR TH03030118 "*Decontamination methods and detection of legislatively controlled persistent chloracetanilide pesticides and their metabolites*", and TA CR TH03030178 "*New methods for assessing plant protection products risks against non-target soil organisms: Assessing risks of xenobiotics contamination on diversity*".

Ing. Ladislav Kašpárek, CSc.

TGM WRI, p. r. i., Prague

✉ ladislav.kasparek@vuv.cz
www.vuv.cz

Ing. Ladislav Kašpárek, CSc., has worked in the field of hydrology since 1968, starting at the Czech Hydrometeorological Institute. He focused mainly on the development of methods for evaluating hydrological phenomena, including extreme ones, and on the development of hydrological balance models. He has been working at TGM WRI since 1987. In recent years, he has been involved in evaluating the ongoing global warming influence on the hydrological regime of surface water and groundwater, and processing hydrological data for projects that will be implemented in the conditions of climate change in the coming decades.

RNDr. Pavel Kukla

Czech Hydrometeorological Institute, Prague

✉ pavel.kukla@chmi.cz
www.chmi.cz

RNDr. Pavel Kukla graduated from the Faculty of Science of Charles University in Prague in the field of Physical Geography and Geoecology. Since 2009 he has been working as a hydrologist at the Czech Hydrometeorological Institute (CHMI) in the Department of Surface Waters. His main task is to derive basic hydrological data (*M*-day discharges) and other hydrological characteristics of surface waters. He is also involved in the implementation of grant projects, is a member of the research team of the PERUN grant project (Prediction, Evaluation and Research for Understanding National sensitivity and impacts of drought and climate change for Czechia), and is a researcher of the "Long-term development concept of the CHMI research organization" dealing with the derivation of *M*-day discharges for the reference period 1991–2020.

Ing. Pavel Richter, Ph.D.

TGM WRI, p. r. i., Prague

✉ pavel.richter@vuv.cz
www.vuv.cz

Ing. Pavel Richter, Ph.D., has been an employee of the Department of Water Protection and Informatics at TGM WRI, p. r. i., since 2007. In 2008, he completed the Regional Environmental Administration study programme at the Faculty of Environment of the Czech University of Life Sciences in Prague in the Landscape Engineering Master's degree programme. In 2015, he successfully completed the field of study Applied and Landscape Ecology in the Environmental Sciences doctoral study programme. He focuses on the issue of water retention in the landscape and the development of the landscape based on the interpretation of archival map data, especially on landscape changes in wetlands, water surfaces, and watercourses, including their floodplains. Within the operation of the Hydroecological Information System, he mainly deals with ISVS-VODA records and records of administrative divisions, protected areas, watercourses, water surfaces, and hydrological river basins.

RNDr. Hana Zvěřinová Mlejnková,Ph.D.

TGM WRI, p. r. i., Prague

✉ hana.mlejnkova@vuv.cz
www.vuv.cz

RNDr. Hana Zvěřinová Mlejnková, Ph.D., graduated from the Faculty of Science of Masaryk University in Brno (formerly J. E. Purkyně University), majoring in General Biology, specialization Microbiology. Since 1992 she has been employed at TGM WRI, p. r. i., in Brno, Department of Hydrobiology. In 2016, she moved to the Prague branch of TGM WRI, p. r. i., where she worked in the Department of Water Quality Protection and since 2018 in the Department of Analysis and Evaluation of Environmental Components as the head of the Department of Water Microbiology and Hydrobiology. Her research activity is focused on projects in the areas related to water quality assessment, microbiology, and hydrobiology. Apart from that, she also does expert activities for the Czech-Austrian Commission for Boundary Waters, as well as consulting, assessment, and pedagogical activities. She is the author and co-author of a number of publications in international and domestic professional journals, several monographs, certified methodologies, and specialized maps. She is currently working on the use of wastewater as a diagnostic medium for monitoring epidemiological situations.

Interview with Ing. Bc. Anna Hubáčková, Minister of the Environment

Minister, I have a question for you to start with. What was Anna Hubáčková like as a little girl? Good grades, a diligent student, or bruised knees and occasional disobedience?

What a question! So – good grades, a diligent student, and occasional naughtiness and a bruised knee.

After secondary school, you joined the Faculty of Civil Engineering of the Brno University of Technology, where you chose the field of water management. Why civil engineering and water?

That was a big coincidence. I originally applied to the Czech Technical University in Prague – construction economics (I don't remember the name exactly). Although I was accepted, at the same time I was offered a transfer to another subject so that a more influential student could be accepted on that course. I was told when I was already on the so-called student summer activity. There I met a great group of students – all from the field of hydraulic engineering. Well, it was decided. If I were to choose another field, then water and Brno University of Technology.

Your first job, if I'm not mistaken, was a position at Vodovody a kanalizace Hodonín, where you were in charge of water source protection. Do you remember your first project from that time?

My first project was also my diploma thesis. It was supply of drinking water to the south-eastern area of Hodonín district. Ing. Stanislav Košacký, the then Deputy of Vodovody a kanalizace, was my consultant. After I joined VaK Hodonín, it was a wonderful discovery for me that my project was not put on a shelf, but it was used: the entire water supply system was built according to it and still works.

My first project as a water manager of VaK Hodonín was the design of water source protection zones. At this point, I don't remember exactly which one it was, but I gradually did them all and I really enjoyed it.

After that, you started to pursue your career as an official. First in the position of head of the environmental office at the District Office in Hodonín and then for a long time as head of the environmental department of the Regional Office of the South Moravian Region. What led you to leave the "technology" and move to the "office" career?

The protection of water sources was the biggest motive. I had ready proposals for buffer zones, and the announcement seemed like an unnecessarily long process. I kept urging the then head of the department until he offered me a job. So, I started to announce them myself! And it was another beautiful job with people, and also the first great experience with persuading people about the necessity to treat water better, protect its quality, etc.

Then you transferred to the Regional Office of the South Moravian Region, where you spent many years. From my personal experience, no one called you other than "our Anička". I took it as eloquent proof of your popularity, which is unprecedented for an official. However, you left office unexpectedly quickly. Is there anything that can be said about this now?

I liked working with my colleagues in the South Moravian Region. We managed a lot, except for the final months, which I chose to forget. Some other regional politicians came up with different ideas about environmental protection, in which my style of communication and work did not fit. I left straightaway, but whenever I return to the South Moravian Region, even after many years, I am welcome. Unlike them.

The positive perception of your personality by the public was also reflected in your clear victory in the Senate elections in 2016. What were your feelings then?

These were unimaginably strong positive emotions, great joy, and perhaps a little sense of satisfaction.

But then also great responsibility.

During your professional career, you have dealt with many interesting and unusual cases. Which one do you remember the most – for better or worse?

In the field of the environment, you will experience many unique cases and events. It is not the beautiful and successful ones, but mostly the crisis ones that will be etched in your memory the most. Floods, accidents, drought effects, bark beetle outbreaks, mosquito outbreaks, cyanobacteria outbreaks, and others. But even in disasters, you will experience beautiful moments. We went to Podhradí, where people experienced two floods in one year, to explain why it happened. It was, of course, very sensitive, because people were flooded twice in quick succession. Most of the citizens naturally spoke to us very sharply, but there was also a couple whose marriage and family was actually saved by the flood and the trauma they experienced.

You are now the Minister of the Environment. If someone had told you fifteen years ago that one day you would run an entire environmental department, what would you say?

I would have laughed a lot. I would never have admitted that I could become a mayor or a senator, let alone a minister. These are big coincidences, opportunities, and challenges and I just take them.

As Minister of the Environment for the Czech Republic, you are negotiating with the Polish side over a long-running dispute between the Czech Republic and Poland over the effects of mining at Turów lignite mine. This is a difficult task at the outset in the position of Minister. Can this case be compared to something you have experienced and dealt with in the past?

This is a case with an international impact, which I have not experienced often. The South Moravian Region is bordered by two states, Slovakia and Austria, so in joint negotiations about some issues, most often on operations on the Morava and Dyje rivers during floods, I was present, of course; it was this experience that helped me during negotiations in Poland about the activities at Turów mine. It is always about balancing our legitimate interests, our law and, at the same time, respecting international law and the law of another country. It's not easy even when you do nice projects together, for example to protect the landscape, let alone when damage or harm is being addressed.

The topic of sustainable development has been present in our country for thirty years, since the time of the Federal Minister of the Environment Josef Vavroušek. However, many ordinary citizens may feel that not enough has been done in this field.

There are a lot of people around us like Josef Vavroušek, and I feel that there are more and more. I really appreciate all of them, especially the young ones. Yes, we still have many challenges ahead of us, but climate change is also helping to change our thinking, and I firmly believe that change in our landscape and our environment will be faster.

Some time ago, in our magazine, we interviewed Mr. Pavel Fošumpauer (Deputy Head of the Department of Hydraulic Engineering, Faculty of Civil Engineering, CTU – Editor's note), on the topic of "development of education in the field of water management". I'll ask you the same – how do you see the current state of education and would you, as Minister of the Environment, like to ensure that practical ecology becomes part of the curriculum in primary and secondary schools?

Definitely. In cooperation with the Ministry of Education, I will try to get ecology into the framework school programmes of primary schools. As we say in Czech, what you learn in your youth, you will find useful in old age – it will always be true. We will pay more attention to ecological awareness raising and education at our Ministry.

One of your announced priorities is the protection of drinking water. What exactly does that mean for you? What would you adjust/change in the position of Minister of the Environment in this regard?

For me as a Minister, this means presenting legislation that will protect water more – I am already working on presenting a draft amendment to the Constitution. And then also the preparation of subsidy titles which will strengthen returning water to the landscape, protecting its quality, retaining water in the landscape, supporting the construction of new water sources, wastewater treatment, etc. Naturally, I need to do a lot of awareness raising myself, together with the whole Ministry.

In conclusion, I would like to ask a "light-hearted" question. You have a beautiful Czech first name Anna, associated with many Czech sayings and weather lore. Do you believe – as a graduate of two universities – in these traditions and wisdom of our ancestors?

Our ancestors treated nature much better than we did, they knew it better and I trust and honour their heritage in the form of weather lore and traditions.

Vršovická Street, where the Ministry of the Environment is located, is lined with Japanese cherry trees, which bloom beautifully in spring. I hope that you enjoy the view of that street in bloom as often as possible. Thank you for the interview.

Ing. Josef Nistler

Ing. Bc. Anna Hubáčková

Minister of the Environment

Ing. Bc. Anna Hubáčková was born in Hodonín. She is a graduate of water management at the Brno University of Technology and Public Administration at the Faculty of Law of Masaryk University. She worked at the company Vodovody a kanalizace Hodonín, where she was in charge of water resource protection; later she worked as the head of the environmental office at the District Office in Hodonín and the head of the environmental department of the Regional Office of the South Moravian Region. In 2005, she received the Minister of the Environment Award for her work and cooperation with non-governmental organizations. In her position, she was also a member of the crisis staff involved in resolving crisis situations, as well as the chairwoman of the flood commissions. In 2014–2018, she held the position of mayor of Ratíškovice and since 2016 she has been a senator for the Hodonín Region. In 2020, she was elected a representative of the South Moravian Region and served as chairwoman of the Commission for the Environment and Agriculture. She is married and has two adult sons and three grandchildren.

Balance evaluation of selected water quality indicators on the tributaries of Vranov reservoir

Most of the reservoirs in the Czech Republic have been built as multifunctional reservoirs, with the basic functions being storage and protection. The way the catchment area upstream of a reservoir is used has a significant impact on water quality. Pollution sources can be divided into point, area, and diffuse sources. Being continuous or recurrent, point pollution is not significantly influenced by meteorological factors and it is linked to narrowly delimited areas such as settlements, wastewater treatment plants (WWTPs), industrial plants, agricultural facilities, etc. Area pollution is difficult to observe as it is irregular and depends on meteorological, soil, morphological, and vegetation characteristics [4]. The category of diffuse sources usually includes small diffuse point sources of pollution, namely municipal, agricultural, industrial, as well as traffic pollution, leachates from landfills, etc.

A number of reservoirs are currently facing the problem of eutrophication. This is considered a process of complex changes in natural waters caused by nutrient enrichment. It leads to the development of toxin-producing cyanobacterial bloom. In eutrophicated waters, the accumulated biomass collapses and, at the same time, the oxygen concentration in the water decreases, which in turn leads to fish deaths. Phosphorus and nitrogen are nutrients of concern in terms of eutrophication, with phosphorus being the predominant nutrient in most surface waters in the Czech Republic. At present, about 70% of active phosphorus comes from point sources (mainly municipal), while in the case of nitrogen this figure is only 20% [2]. Nowadays, the consumption of mineral fertilisers and the application of manure fertilisers have a lesser impact on phosphorus pollution. The amount of phosphorus input to agricultural land has decreased over the last 25 years, but wastewater from WWTPs remains a risk [2].

Specific pollutants such as pesticides, pharmaceuticals, microplastics, and personal care products are also a current problem in relation to surface water pollution. They often do not degrade in water, but they have do a negative impact on aquatic organisms. Drinking waters are also burdened with specific pollutants [1].

VRANOV WATERWORKS

Vranov hydraulic structure on the river Dyje was put into operation in 1934. The hydrological catchment area of the reservoir is 2,211.8 km^2, almost half of which is in Austria. In the Czech Republic, the catchment area is 1,159 km^2 in four districts and three regions. In terms of land use, it is comprised of agricultural land (60.2% of the catchment´s total area), forest land (31%), water areas including the actual floodplain (2.5%), urban areas (0.9%), and other land (5.4%) [6].

This major waterworks is multi-purpose and that is why there are often conflicts of interest. Its main functions include flood protection, power generation, recreation, sport fishing, navigation, as well as drinking water supply, which was not its primary function at the beginning because the water intake was not built here until 1982. The collection structure is located on a floating pontoon 3.9 km from the dam. The joint-based connection between the pontoon and the bank allows the movement of the reservoir surface to be followed, thus allowing the optimum depth for raw water intake to be used (*Fig. 6*). The drawn raw water is then treated at Štítary treatment plant, with a capacity of 200 l/s. The group water supply system leading from the Štítary plant currently supplies drinking water to more than 80,000 inhabitants in the adjacent regions of South Moravia and the Highlands. The water reservoir is administered by the Morava River Basin Authority (Povodí Moravy). The raw water collection device is the property of the Water Supply and Sewerage Association of Municipalities, based in Třebíč, and the operator of the group water supply system, including the water intake and water treatment plant, is VAS, Co. [7].

The balance evaluation of selected water quality indicators was carried out for the Dyje and its largest tributary the Želetavka (in the profiles Dyje Podhradí and Želetavka) for the period 2014–2018. The following parameters were evaluated: ammonia nitrogen, nitrate nitrogen, orthophosphates, total phosphorus, and selected pesticides and their metabolites: terbuthylazine, metolachlor ESA, metazachlor ESA, metazachlor OA. Data on the concentrations of the selected water quality parameters were provided by the Morava River Basin Authority (Povodí Moravy), and the flow rate values for the period concerned were provided by the Czech Hydrometeorological Institute. Annual average concentrations were calculated for the monitored indicators and compared with the limits according to Government Decree 401/2015 Sb., as amended. The average annual flow rates on the Dyje and the Želetavka were calculated from the daily flows. Balances were then expressed on the basis of the average annual flow rates and concentrations for the monitored water quality indicators for 2014–2018.

RESULTS

The limit for the average annual concentration of ammonia nitrogen is 0.23 mg/l, according to Government Decree 401/2015 Sb. This limit has been neither reached nor exceeded in any year on the Dyje or the Želetavka. The highest detected concentrations were up to 0.12 mg/l. A more significant difference in concentrations between the Dyje and the Želetavka was found only in 2016, when the annual average concentration was almost twice as high on the Želetavka. In the other years, there were no significant differences between the two watercourses. The ammonia nitrogen balance evaluation is shown in *Fig. 1.* The results show that significantly more ammonia nitrogen flows into the Vranov reservoir through the Dyje Podhradí profile than through Želetavka profile, which is caused by much higher flows on the Dyje.

The average annual concentration of nitrate nitrogen was always higher on the Želetavka than on the Dyje. The limit value of 5.4 mg/l was exceeded only once in the period concerned, namely in 2016, when the average annual concentration on the Želetavka was almost 6 mg/l (*Fig. 2*).

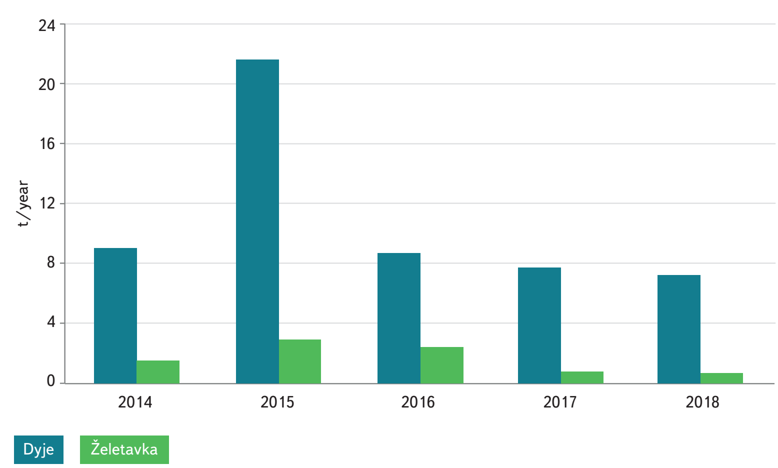


Fig. 1. Ammonia nitrogen balance evaluation 2014–2018

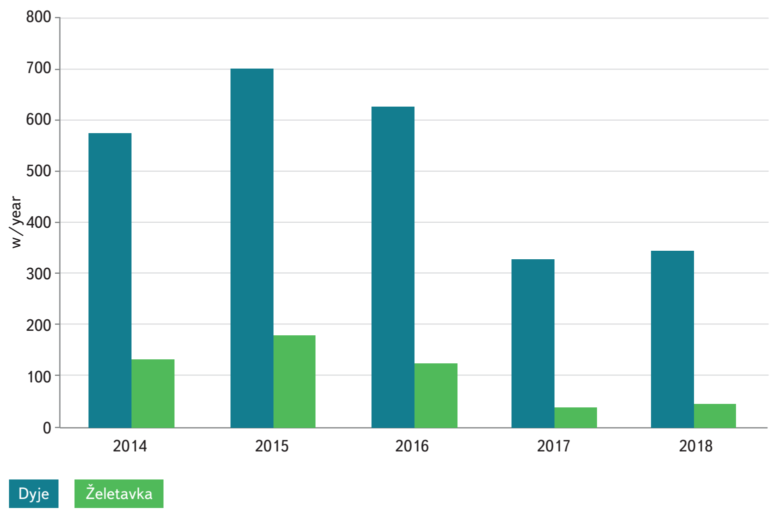


Fig. 2. Nitrate nitrogen balance evaluation 2014–2018

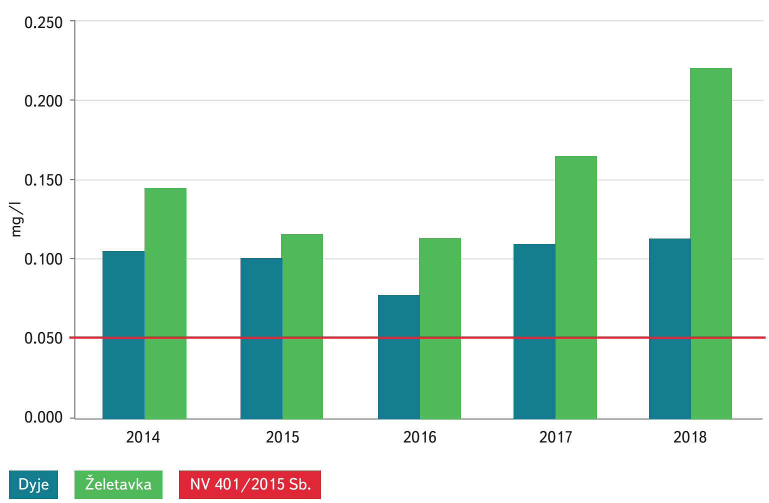


Fig. 3. P_{total} annual average concentration (from monthly measurement) according to Government Decree 401/2015 Sb.

Phosphorus appears to be a problematic water quality indicator. According to Government Decree 401/2015 Sb., the limit for average annual concentration of total phosphorus is 0.05 mg/l for bathing water and water to be used as tap water. The graph in *Fig. 3* shows that this limit was significantly exceeded in both watercourses during the whole monitoring period; there were always higher concentrations in the Želetavka. The water in the Dyje is diluted by cleaner water from Austria. The monitored parameters also include orthophosphates. However, legislation does not specify limit values for this, although it is an important indicator in the context of eutrophication (a useful source of phosphorus for algae and cyanobacteria). For both total phosphorus and orthophosphates, concentrations were always higher in the Želetavka, almost doubled in the dry years of 2017 and 2018.

The following graph in *Fig. 4* shows how many tonnes of total phosphorus flowed into the reservoir from the Dyje and the Želetavka rivers during the period concerned. *Fig. 3* and *Fig. 4* show the drought problem in 2017 and 2018. Despite the high average annual concentration in these years (*Fig. 3*), not as many tonnes of total phosphorus flowed into the reservoir as in previous years due to lower flow rates (*Fig. 4*). The impact of the drought was also obvious for ammonia nitrogen and nitrate nitrogen (*Fig. 1* and *Fig. 2*).

Concentrations of selected pesticides and their metabolites were not monitored regularly. The limits according to Government Decree 401/2015 Sb., the

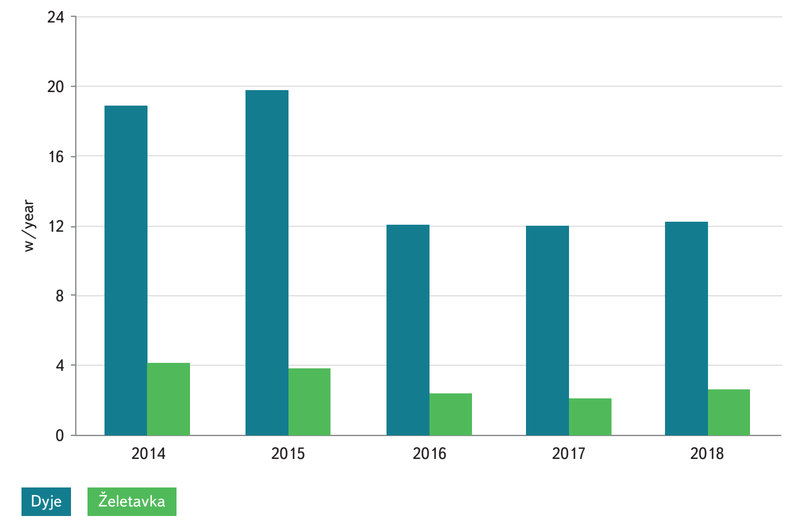


Fig. 4. P_{total} balance 2014–2018.

average annual concentrations of terbuthylazine, metolachlor ESA, metazachlor ESA and metazachlor OA on the Dyje Podhradí profile were not exceeded. On the Želetavka profile the limit value was only exceeded in 2018 for metazachlor ESA. Regarding the balance of monitored pollutants, most data were available for terbuthylazine and metolachlor ESA. For the monitoring period 2014–2018, 5–10 kg/year of terbuthylazine got into the reservoir from the Dyje and 1–4 kg/year from the Želetavka. Metolachlor ESA was also monitored on the Dyje throughout the monitoring period; here, the balance ranged from 5 to 12 kg/year. On the Želetavka, metalachlor ESA was only monitored in 2016 and 2018, with a balance of 3 kg/year and 1 kg/year, respectively.

In 2017, 24 kg of metazachlor ESA were brought into the reservoir by the Dyje; in 2018 it was 32 kg by the Dyje and 6 kg by the Želetavka. In 2017 it was 5 kg of metazachlor OA (Dyje); in 2018 it was 6 kg by the Dyje and 2 kg by the Želetavka.

The results show that the most problematic water quality indicators include the presence of pesticides and total phosphorus, which causes excessive eutrophication of the reservoir (*Fig. 5*). The main source of pesticides is agricultural activity in the catchment upstream of the reservoir.

According to the above results, the balance values of P_{total} for 2014–2018 range from 12 to 20 t/year on the Dyje, with an average annual concentration of 0.110 mg/l, and from 2 to 4 t/year on the Želetavka, with an average annual concentration of 0.1514 mg/l. Hanák [3] focuses on the years 2009–2013 and reports that the Dyje brings to the reservoir on average 30.6 t of P_{total} per year, with an average annual concentration of 0.110 mg/l; the Želetavka brings 5.3 t of P_{total}, with an average annual concentration of 0.135 mg/l. In 2014–2018, the phosphorus contribution is lower, which may be mainly due to the fact that the flow rates were lower than those in previous years. Hanák also states that area sources of pollution (agricultural land) are not a significant source of phosphorus in the Vranov hydraulic structure catchment. The main polluters are point sources (79%), compared to area sources (21%). There are no intensive breeding ponds in the catchment and industry does not have a significant impact on water quality either. The main source of phosphorus is wastewater. There are 27 WWTPs in the Vranov catchment, but most of them lack phosphorus precipitation [3].

There are almost 5,000 buildings used for recreation in the wider area of the reservoir, and almost 1,000 in the immediate vicinity of the reservoir; however, sanitary sewerage systems are only located at the Vranov and Bítov reservoirs. Some buildings that lack connection to the sewerage system are not accessible for a gully emptier. As a result of wastewater disposal, detailed procedures and the principle of precautionary protection of the water resource are part of the management regime in water resource protection zones if an owner of a building is interested in its repair, reconstruction, extension, etc.

Fig. 5. Algal bloom in Bítov Bay

Fig. 6. Collection structure located on a floating pontoon

In the context of recreation, another risk to water quality is the handling of petroleum products, not only by vehicles on access roads and farm tracks, but also directly on the surface of the reservoir by public and private shipping. There are also a lot of chainsaws, lawnmowers, power generators, etc., that create this risk, which would be marginal in many other cases, but significant in view of the developed recreational sector and the number of buildings in use.

CONCLUSION

The measures to reduce phosphorus concentrations must be based on building sewerage in communities where it is lacking, reconstruction of existing leaking sewerage systems and cesspools, and design of new WWTPs or upgrading of existing ones (with phosphorus precipitation included). However, it should be stressed that all existing WWTPs meet the limits set for the P_{total} in the discharge of wastewater to surface waters. This is due to the weak legislation which does not set P_{total} limits for all sizes of municipal WWTPs, but only for those with a population equivalent of more than 2,000.

The issue of pesticides and their metabolites is not only a problem in the Vranov reservoir; their findings can also be documented, for example, in groundwater sources or water supply reservoirs [5].

Water intake (*Fig. 6*) from the Vranov multipurpose reservoir is promising and irreplaceable; however, the reservoir is the only case of such an enormous multipurpose character in the Czech Republic. That is why it is necessary to adapt the protection of the yield, quality, and safety – of this source to its uniqueness.

Acknowledgements

The authors thank the Povodí Moravy State Enterprise for providing data.

References

[1] DURAS, J., POTUŽÁK, J., VAŠEK, P. VN Karhov – Co na nás chystají acidifikované nádrže? In: *Vodárenská biologie*. Chrudim: Vodní zdroje EKOMONITOR, s. r. o, 2010, p. 127. ISBN 978-80-86832-48-7.

[2] FIALA, D. Boj o fosfor. *Vodní hospodářství*. 2016, 66(5), p. 1–4. ISSN 1211-0760.

[3] HANÁK, R. *Studie zlepšení jakosti vod ve VD Vranov: Průvodní zpráva*. Brno: Povodí Moravy, s. p., 2014.

[4] KVÍTEK, T. *Retence a jakost vody v povodí vodárenské nádrže Švihov na Želivce: význam retence vody na zemědělském půdním fondu pro jakost vody a současně i průvodce vodním režimem krystalinika*. Praha: Povodí Vltavy, s. p., 2017. ISBN 978-80-270-2488-9.

[5] LIŠKA, M., FUČÍK, P., DOBIÁŠ, J., WILDOVÁ, P., KOŽELUH, M., VÁLEK, J., SOUKUPOVÁ, K., Zajíček, A. Problematika výskytu pesticidů v povrchových vodách. In: OPPELTOVÁ, P. *Problematika znečišťování a ochrany vodních zdrojů v souvislosti se zemědělstvím*. Brno: Mendelova univerzita, 2018, p. 52–60. ISBN 978-80-7509-604-3.

[6] NOVÁK, J., OPPELTOVÁ, P. Příprava dokumentace pro změnu ochranných pásem vodního zdroje povrchové vody Vranov. In: *Pitná voda: Zborník prednášok z XIV. konferencie s medzinárodnou účasťou*. Bratislava: VodaTím, 2015, p. 171–176. ISBN 978-80-971272-3-7.

[7] NOVÁK, J., OPPELTOVÁ, P. Optimalizace ochranných pásem vodního zdroje Vranov ve smyslu platných právních předpisů a praktických zkušeností. *Sovak: Časopis oboru vodovodů a kanalizací*. 2014, 23(12), p. 22–25. ISSN 1210-3039.

Authors

Ing. Petra Oppeltová, Ph.D.[1]
✉ oppeltova@mendelu.cz
ORCID: 0000-0001-6875-9919

Ing. Ondřej Ulrich[1,2]
✉ ondrej.ulrich@centrum.cz, xulrich@mendelu.cz
ORCID: 0000-0003-2562-3071

Jana Svobodová Navrátilová[1]
✉ jani.svobo@gmail.com

[1]The Institute of Applied and Landscape Ecology, Mendel University, Brno
[2]Department of Water Management Projects, ENVIPARTNER, Ltd., Brno


Photo: 123rf.com

The AdaptaN II Project — from words to action

Over the last few years we have seen – let's not be afraid to say it – a flurry of different adaptation strategies, action plans, and other documents describing what to do to prepare for various problems, especially the impacts of climate change. It is therefore time to start fulfilling the ideas of the above-mentioned documents and putting them into practice.

The project *"Integrated Approaches of the Moravian-Silesian Region Landscape to Climate Change Adaptation"* (abbreviated as AdaptaN II), which was launched in July 2021 and will last until 30 June 2024, also aims to contribute to the implementation of one of the above documents, namely the *Adaptation Strategy of the Moravian-Silesian Region to the Impacts of Climate Change*. This international Project is funded by the Norway Grants, „Bergen" call for proposals, i.e. support for the implementation of selected nature-related adaptation and mitigation measures (the programme is administered by the State Environmental Fund of the Czech Republic).

The main research institution is the Faculty of Civil Engineering at Brno University of Technology. The Project also involves T. G. Masaryk Water Research Institute, ARVEN – Rural Development Academy, and two foreign partners: Norwegian Institute of Bioeconomic Research and Slovak University of Agriculture in Nitra.

In accordance with the National Action Plan on Adaptation to Climate Change in the Czech Republic (NAP CR), the Project responds to the requirements of the territory´s adaptation to the negative impacts of all climate change manifestations in the temperate zone, i.e. extreme meteorological phenomena (heavy rainfall, extreme wind, extreme temperatures), long-term drought, and floods (including flash floods). The Project aims to support implementation of selected nature-related adaptation and mitigation measures in the Moravian-Silesian Region.

The Project´s solutions and outcomes are directed to the open landscape and suburban zones, i.e. it mainly focuses on integrated adaptation approaches in non-development areas as well as in interaction with built-up areas (the cities of Ostrava and Opava). A special part of the Project deals with the urbanised landscape of Pohornice (between the cities of Havířov, Karviná, and Orlová). The last active mines are now awaiting closure in this area, which was heavily affected by coal mining in the past.

The Project will describe and model the implementation process of adaptation for the open landscape in the Moravian-Silesian Region. State and local government authorities in the region, watercourse administration bodies, forestry and agricultural enterprises, the non-profit sector, and the interested public will receive a detailed description of the implementation process, an overview of possible adaptation measures, monitoring patterns and effect calculations, as well as precise identification of their territory´s vulnerability in the form of territorial studies in order to target the follow-up adaptation measures. Examples of good practice and demonstration of sample measures to reduce the negative impacts of climate change will also be implemented. In the pilot area of Lichnov municipality, a system of retention swales will be constructed, including stabilisation of the concentrated runoff pathway, and the addition of linear accompanying greenery; these are the interaction elements which fulfil protective functions with an alternative use for strengthening biodiversity functions linked to the territorial system of ecological stability. In addition, wetlands and pools will be created in the pilot areas of Lichnov and Větřkovice.

AdaptaN II
Norway grants
Státní fond životního prostředí České republiky
Společně pro zelenou Evropu

The AdaptaN II Project is a follow-up of the previous, successfully completed project *„AdaptaN I – the Complex Planning, Monitoring, Information and Educational Tools for Adaptation of Territory to the Climate Change Impacts, with the Main Emphasis on Agricultural and Forestry Management in the Landscape"* (No. EHP-CZ02-OV-1-039-2015), which was implemented in 2015–2016 and was supported by EEA and Norway Grants (more at https://www.adaptan.net/).

Authors

Mgr. Pavla Štěpánková, Ph.D.
pavla.stepankova@vuv.cz
ORCID: 0000-0003-2079-9078

Ing. Karel Drbal, Ph.D.
karel.drbal@vuv.cz
ORCID: 0000-0002-5595-2493

T.G. Masaryk Water Research Institute, Brno

VTEI/2022/2

Since 1959

VODOHOSPODÁŘSKÉ
TECHNICKO-EKONOMICKÉ INFORMACE

WATER MANAGEMENT
TECHNICAL AND ECONOMIC INFORMATION

A scientific bimonthly journal specialising in water research. It is included in the List of Peer-Reviewed Non-Impacted Periodicals Published in the Czech Republic.

Volume 64

VTEI.cz

Published by: the TGM Water Research Institute,
Podbabská 2582/30, 160 00 Prague 6

Sources of photographs for this issue:
VÚV, Shutterstock.com, 123RF.com

Graphic design, typesetting and printing:
ABALON s. r. o., www.abalon.cz

Number of copies: 700 ks
Since 2022, the VTEI journal has been published in English at https://www.vtei.cz/en/

The next isuue will be published in June 2022.
Instructions for authors are available at www.vtei.cz

ISSN 0322-8916
ISSN 1805-6555 (on-line)
MK ČR E 6365

SANDSTONES ENCHANT

Suchá Bělá is a typical small watercourse in Labské pískovce (Labe sandstones). It flows when there is plenty of water, it dries up in the summer. This is due to the sandstone subsoil, which can absorb a large amount of the water from Suchá Bělá. The river rises in the wetlands of Jelení louže near the border with Saxony. Close to the village of Hřensko, it flows into the Kamenice and then with it immediately into the Elbe river. *Text and photo provided by Václav Sojka, www.vaclavsojka.cz.*

VÝZKUMNÝ ÚSTAV
VODOHOSPODÁŘSKÝ
T. G. MASARYKA
veřejná výzkumná instituce

VTEI.cz