ACTA VET. BRNO 2026, 95: 187–194; https://doi.org/10.2754/avb202695020187

Assessment of mercury contamination in fish from the rivers Morava and Dyje in relation to river environmental conditions

Kamila Novotná Kružíková, Nikola Dundáčková, Elina Zavisha, Petr Linhart,
Jana Jozefová, Zdeňka Svobodová

University of Veterinary Sciences Brno, Faculty of Veterinary Hygiene and Ecology,
Department of Animal Protection and Welfare and Veterinary Public Health, Brno, Czech Republic

Received January 23, 2026
Accepted May 4, 2026

Abstract

A total of seven species of fish were caught in the lower reaches of the rivers Morava and Dyje: round goby, white-finned gudgeon, gudgeon, perch, chub, Prussian carp and roach. The total mercury (THg) contents in the muscle tissue and liver were measured using atomic absorption spectrometry with an AMA 254 analyser. The non-native round goby showed no significant difference in mean mercury (Hg) content in muscle tissue compared to a fish species at the same trophic level (gudgeon). Although the age and weight of chub, perch, and round goby were similar, THg concentrations in muscle and liver of chub, perch, and round goby were significantly higher in the river Dyje (Thaya) compared to fish from the river Morava ($P < 0.01$). Although there is no known source of industrial contamination in the rivers Morava and Dyje, higher values of chemical oxygen demand (COD_{Cr}), chloride (Cl^-), sulphate (SO_4^{2-}), orthophosphate as phosphorus ($P\text{-}PO_4^-$) and total phosphorus (total P), together with oxygen deficits were found in the Dyje, which may lead to greater Hg accumulation in bottom sediments.

Total Hg, COD_{Cr}, chub, perch, round goby

Due to its toxicity and persistence in sediments, mercury is considered to be a major pollutant in the aquatic environment. Mercury bioaccumulates in aquatic organisms and biomagnifies in the food chain (Mason et al. 2000). The mercury content in aquatic organisms depends on species differences, with the highest content observed in predatory fish. Mercury bioaccumulates with increasing trophic level (Maršálek et al. 2006; Jurajda et al. 2020; Doležal et al. 2025). Accumulation of mercury can be affected by environmental conditions. Kružíková et al. (2011) reported higher mercury concentrations in fish in the period 15–20 years after flooding in newly constructed reservoirs, even though no industrial source of mercury contamination was present at the study site. After subsequent change in environmental conditions, there was a significant decrease in mercury content. Non-native species may create new pathways of mercury bioaccumulation, which has been investigated by e.g. Hogan et al. (2007), who found that the goby invasion in Lake Erie created a new mercury bioaccumulation pathway, where contaminants originally restricted to the benthos began to enter the food chain after the invasion of gobies. According to Lusk et al. (2010), the occurrence of the round goby was first detected in the river Morava in 2008, thus it is a non-native fish species in Czech rivers. The round goby is a benthic fish feeding on mussels, small bivalves, crustaceans, insects or small fish. Jurajda et al. (2020) published data on mercury content in round goby and gudgeon from the rivers Dyje (Thaya) and Labe (Elbe); however no data regarding mercury concentrations in fish from the Morava are available.

The aim of the study was to evaluate the total mercury (THg) content in fish from the rivers Morava and Dyje in relation to various environmental conditions, such as the values

Address for correspondence:
Kamila Novotná Kružíková
Department of Animal Protection and Welfare and Public Veterinary Health
Faculty of Veterinary Hygiene and Ecology
University of Veterinary Sciences Brno
Palackého tř. 1946/1, Brno 612 42, Czech Republic

E-mail: novotnak@vfu.cz

of chemical oxygen demand (COD_{Cr}), chloride (Cl^-), sulphate (SO_4^{2-}), orthophosphate ($P\text{-}PO_4^-$) total phosphorus (P), and oxygen deficits in water, and to assess the mercury (Hg) content in the non-native species round goby.

Materials and Methods

Sites

The study focuses on two rivers in the Czech Republic: the lower reaches of the rivers Morava and Dyje before their confluence (Plate XV, Fig. 1). The Dyje originates at the confluence of the Austrian Dyje and the Moravian Dyje in Lower Austria. It flows through the town of Znojmo and receives two tributaries, the rivers Jihlava and Svratka at the Nové Mlýny reservoir (a complex of three reservoirs constructed between 1972 and 1989). In certain sections, the Dyje exhibits a slower flow with numerous reservoirs and pools, resulting in higher sedimentation rates. Its valley is characterised by a meandering canyon incised into the Bohemian Massif.

The river Morava rises near Mount Králický Sněžník and flows through the city of Olomouc. Compared to the Dyje, the Morava has a higher discharge and higher flow velocity which leads to lower accumulation of organic sediments. There is no known source of industrial contamination in the rivers Morava and Dyje. The water quality indicators of both rivers are shown in Table 1.

Table 1. Water quality indicators in the rivers Morava and Dyje (median and Q25 + Q75).

Indicator	Dyje median (Q25; Q75)	Morava median (Q25; Q75)	*P*
COD_{Cr} (mg/l)	21.50 (19.30; 24.90)	15.50 (12.50; 19.10)	0.0000*
Cl^- (mg/l)	54.50 (45.10; 69.30)	32.30 (26.90; 42.90)	0.0000*
SO_4^{2-} (mg/l)	101.50 (90.60; 110.00)	51.10 (47.40; 61.70	0.0000*
Insoluble substances (mg/l)	11.00 (5.40; 15.00)	18.50 (11.00; 26.00)	0.0006*
$P\text{-}PO_4^-$ (mg/l)	0.15 (0.07; 0.31)	0.05 (0.02; 0.07)	< 0.01*
P total (mg/l)	0.16 (0.11; 0.35)	0.10 (0.07; 0.13)	< 0.01*
Dissolved oxygen (mg/l)	10.70 (8.70; 12.40)	10.10 (8.20; 12.40)	0.2659
	2.90–14.00**	7.60–14.40**	
BOD_5	1.65 (1.25; 2.90)	2.25 (1.40; 2.90)	0.3100
$ANC_{4.5}$ (mmol/l)	2.90 (2.70; 3.10)	2.60 (2.30; 3.10)	0.0672
$ANC_{8.3}$ (mmol/l)	0.08 (0.08; 0.08)	0.08 (0.08; 0.08)	0.6362
$N\text{-}NO_2^-$ (mg/l)	0.03 (0.02; 0.03)	0.02 (0.02; 0.03)	0.3027
$N\text{-}NO_3^-$ (mg/l)	1.75 (0.53; 3.80)	1.95 (1.50; 2.80)	0.7999
$N\text{-}NH_4^+$ (mg/l)	0.08 (0.04; 0.10)	0.07 (0.04; 0.13)	0.8881
	mean ± SD	mean ± SD	
THg (mg/kg)***	0.21 ± 0.08	0.15 ± 0.06	0.0439*

Q25; Q75 = 25% and 75% quartiles; COD_{Cr} = chemical oxygen demand (dichromate method); Cl^- = chloride; SO_4^{2-} = sulphate; $P\text{-}PO_4^-$ = orthophosphate as phosphorus; P total = total phosphorus; BOD_5 = biochemical oxygen demand; $ANC_{4.5}$ = acid neutralizing capacity to pH 4.5; $ANC_{8.3}$ = acid neutralizing capacity to pH 8.3; $N\text{-}NO_2^-$ = nitrite nitrogen; $N\text{-}NO_3^-$ = nitrate nitrogen; $N\text{-}NH_4^+$ = ammonium nitrogen; THg = total mercury

*Significant differences between the rivers Morava and Dyje; **min-max; ***alluvial sediment

Fish

In cooperation with the Institute of Vertebrate Biology of the Czech Academy of Sciences (permit MZE-68283/2022-16232), seven fish species were sampled using an electrofishing equipment in rivers Morava and Dyje in August and September 2023: round goby (*Neogobius melanostomus),* white-finned gudgeon (*Romanogobio albipinnatus)*, gudgeon (*Gobio gobio)*, perch (*Perca fluviatilis)*, chub (*Leuciscus cephalus)*, roach (*Rutilus rutilus)*, and Prussian carp (*Carassius gibelio).* The fish were stunned (by a strong blow to the top of the head using a blunt object) and subsequently killed by spinal transection. Basic morphometric and weight data of the captured fish are presented in Table 2. Scales, muscle, and liver were obtained from the fish by autopsy. The age of the fish was determined from scales by visual inspection using an optical instrument Meoflex RI 21 (Meopta, Přerov, Czech Republic). Liver samples in many cases could not be collected or there was not enough tissue for analysis.

Table 2. Fish species, their characteristics and numbers captured in the rivers Morava and Dyje.

				Median (Q25–Q75)		
Fish species	Latin name	River	N	Age (year)	Weight (g)	Total length (cm)
Round goby	*Neogobius*	Morava	14	2 (2–3)	20.4 (17.4–25.6)	9.15 (8.6–9.9)
	melanostomus	Dyje	9	2 (1–2)	18.0 (10.4–23.7)	10.4 (8.5–11.2)
Perch	*Perca fluviatilis*	Morava	11	2 (2–3)	19.6 (16.3–77.7)	11.1 (10.9–16.5)
		Dyje	10	2 (2–2)	27.3 (21.7–32.4)	12.7 (11.8–13.4)
Chub	*Leuciscus*	Morava	11	2 (2–2)	20.8 (15.4–23.8)	12.6 (11.6–13.3)
	cephalus	Dyje	12	2 (2–2.5)	32.1 (26.8–36.0)	14.8 (13.9–15.0)
White-finned gudgeon	*Romanogobio albipinnatus*	Morava	10	2 (2–2)	7.3 (6.9–8.3)	9.6 (9.4–9.8)
Gudgeon	*Gobio gobio*	Morava	7	2 (2–3)	11.4 (10.7–12.3)	10.5 (10.0–10.7)
Roach	*Rutilus rutilus*	Morava	11	2 (1–2)	19.2 (17.7–24.7)	12.0 (11.7–13.4)
Prussian carp	*Carassius gibelio*	Dyje	22	2 (1–2)	39.6 (18.0–46.2)	13.0 (10.4–14.0)

N = number of fish; Q25–Q75 = 25% and 75% quartiles

Mercury analysis

The THg content in the muscle and liver tissues was determined using the method of atomic absorption spectrometry on the AMA 254 analyser (Altec, Prague, Czech Republic). It was measured at least twice in each sample (the relative deviation of the measurement did not exceed 10%) and then the THg content in the sample of fresh muscle was determined. Each sample was thawed and weighed (analytical scales Precisa 125A, Dialab Prague, Czech Republic), then approximately 50 mg of the sample was placed into a combustion boat and inserted into the AMA 254 without any further preparation. The analysis was conducted under the following conditions: drying at 120 °C for 60 s, thermal decomposition at 550 °C for 150 s under oxygen flow. The AMA 254 operates across two ranges, with an automatic switch-over between lower and higher concentrations (0.05 to 40 ng and 40 to 500 ng; $R^2 = 0.9922$, limit of detection = 0.18 µg/kg). The standard reference material NIST–2976 (muscle tissues, National institute of Standards and Technology) was used for validation.

Statistical analysis was performed using statistical software StatSoft Inc. (2014) STATISTICA, version 12. (Tulsa Oklahoma, USA). Normality was tested using Shapiro-Wilk test. The homogeneity of variances was tested using Levene's test. The Hg concentrations between individual fish species were compared using Kruskal-Wallis ANOVA. The Hg concentrations in muscle tissue were compared between localities using unpaired *t*-test. Body weight and length of individuals between localities were compared using Mann-Whitney test. The relationship between Hg concentrations in individual tissues and age, weight, and length of individuals was analysed using Pearson's correlation coefficient or Spearman's rank correlation coefficient. The significance level was set at 0.05.

Results

Total mercury content in individual fish species in the rivers Morava and Dyje

A comparison of mean THg concentrations in individual fish species from the monitored rivers is shown in Tables 3–6. On the Morava, a negative correlation between muscle THg content and length ($r_s = -0.7026$; $P < 0.01$) and muscle THg content and weight ($r_s = -0.7113$; $P < 0.01$) in herbivorous fish and a positive correlation between muscle THg content and length in predators ($r_s = 0.6166$; $P < 0.01$) was found. In the Dyje, a strong correlation in the THg content between muscle and liver ($r_s = 0.8244$; $P < 0.01$) in predator fish was found.

Comparison of mercury content in fish from the rivers Morava and Dyje

Fish from the rivers Morava and Dyje (Table 2) did not show differences in age ($P > 0.05$). Fish in this study did not show differences in weight ($P > 0.05$) and body length ($P > 0.05$) either, except for chub ($P < 0.05$). Therefore, it was possible to compare the difference in Hg content in the muscle tissue between individual fish species from both rivers.

To compare the monitored rivers and their Hg load, the same fish species caught in both rivers were evaluated. A comparison of muscle THg in the round goby, perch, and chub is shown in Fig. 2. From the graphs, it is evident that all three fish species in the Dyje had higher ($P < 0.01$) THg content compared to the Morava. The THg in the liver was also significantly higher in fish from the Dyje compared to the Morava for the same fish species ($P < 0.01$) (Tables 4, 6).

Table 3. Total mercury content in fish muscle from the river Morava.

Fish species	N	THg (mg/kg) median (Q25–Q75)	Chub	Roach	Round goby	White-finned gudgeon	Gudgeon	Perch
Chub	11	0.021(0.017–0.024)			**	**	**	**
Roach	11	0.0224 (0.019–0.030)			**	**	**	**
Round goby	14	0.050 (0.041–0.067)	**	**				
White-finned gudgeon	10	0.053 (0.051–0.068)	**	**				
Gudgeon	7	0.056 (0.054–0.060)	**	**				
Perch	11	0.061 (0.055–0.073)	**	**				

N = number of muscle samples; THg = total mercury; Q25–Q75 = 25% and 75% quartiles

** Significant difference in THg content between the fish species ($P < 0.05$)

Table 4. Total mercury content in fish liver from the river Morava.

Species	N	THg (mg/kg) median (Q25–Q75)	Round goby	Perch
Round goby	8	0.038 (0.034–0.051)		**
Perch	11	0.105 (0.093–0.115)	**	

N = number of liver samples; THg = total mercury; Q25–Q75 = 25% and 75% quartiles

** Significant difference in THg content between the fish species ($P < 0.05$)

Table 5. Total mercury content in fish muscle from the river Dyje.

Fish species	N	THg (mg/kg) median (Q25–Q75)	Chub	Round goby	Perch	Prussian carp
Chub	12	0.047 (0.038–0.060)		**	**	
Round goby	9	0.109 (0.104–0.131)	**			
Perch	10	0.181 (0.170–0.209)	**			**
Prussian carp	23	0.062 (0.043–0.092)			**	

N = number of muscle samples; THg = total mercury; Q25–Q75 = 25% and 75% quartiles

** Significant difference in THg content between the fish species ($P < 0.05$)

Table 6. Total mercury content in fish liver from the river Dyje.

Fish species	N	THg (mg/kg) median (Q25–Q75)	Chub	Round goby	Perch	Prussian carp
Chub	5	0.047 (0.024–0.056)				
Round goby	9	0.087 (0.072–0.105)				**
Perch	10	0.177 (0.153–0.236)				**
Prussian carp	19	0.009 (0.008–0.032)		**	**	

N = number of muscle samples; THg = total mercury; Q25–Q75 = 25% and 75% quartiles

** Significant difference in THg content between the fish species ($P < 0.05$)

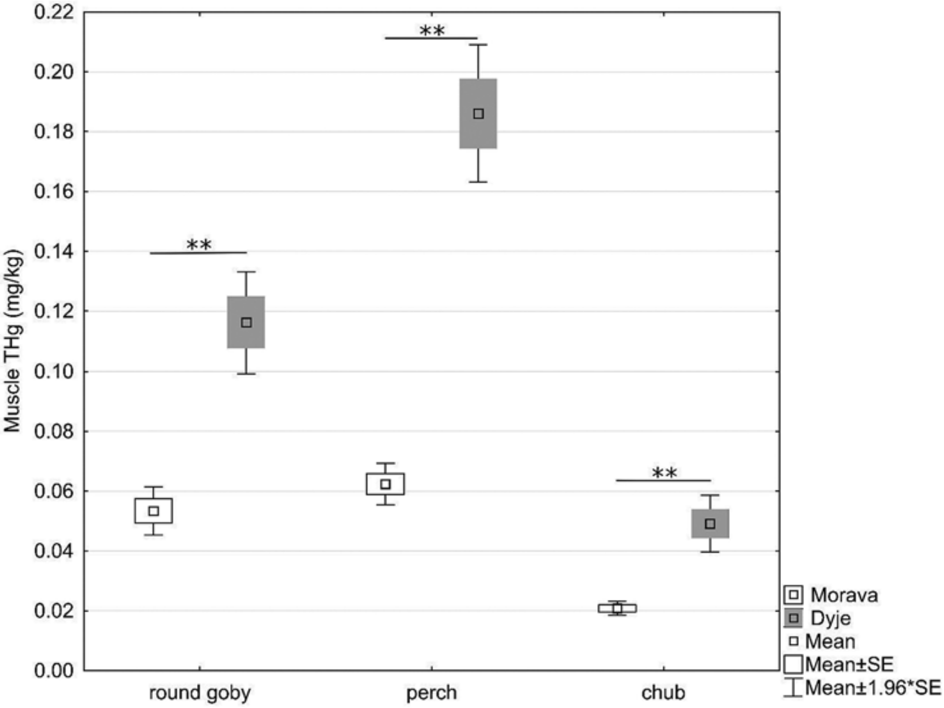

Fig. 2. Comparison of total mercury (THg) content (mg/kg) in the muscle tissue of round goby, perch and chub in both studied rivers

Environmental conditions

According to the data from the Czech Hydrometeorological Institute and Povodí Moravy s.p., the chemical oxygen demand (COD_{Cr}) as well as concentrations of Cl^-, SO_4^{2-}, $P\text{-}PO_4^-$, and total P differed significantly ($P < 0.01$) between the rivers Dyje and Morava, being higher in the Dyje during the monitored period of 2021–2023. While average oxygen concentrations were similar at both localities, fluctuations in oxygen contents were observed in the Dyje during the growing season, ranging from 2.9 to 14.0 mg/l. Furthermore, a significantly higher Hg content was found in alluvial sediments in the Dyje compared to the Morava ($P < 0.05$). The results of environmental indicators are shown in Table 1.

Discussion

Comparison of monitored rivers

The THg content in the muscle tissue of fish from the rivers Morava and Dyje did not exceed the maximum limits (0.5 mg/kg) for Hg content in fish intended for human consumption set by Commission Regulation (EU) 2023/915. Based on our results, it can be concluded that fish from the Dyje exhibit higher contamination levels compared to those from the Morava.

Furthermore, several water quality indicators (COD_{Cr}, Cl^-, SO_4^{2-}, $P\text{-}PO_4^-$ and total P) and THg concentrations in alluvial sediments were significantly higher (Table 1) compared to the Morava. This indicates that the distinct environmental conditions in the Dyje may support methylation and subsequent bioaccumulation within living organisms. Yu et al. (2018) report that higher organic pollution creates more favourable conditions for Hg methylation, with this process being more intense in anaerobic, organically rich sediments containing sulphate-reducing bacteria. The COD_{Cr} value shows how much oxygen is used for the decomposition of chemically degradable organic substances (Pitter 2015), i.e. in the case of the Dyje, more oxygen is used for the decomposition of organic substances. The higher proportion of organic matter on the Dyje is probably related to the flooding of the landscape and the felling of floodplain forests, which was needed during the construction of three reservoirs in the Nové Mlýny system in 1974–1989. It is therefore obvious that there are more organic substances in the Dyje, so it can be assumed that the conversion of inorganic Hg to organic Hg will take place in the bottom sediments and thus there will be a higher accumulation of Hg in the food chain.

Our results show a significantly higher content of THg in both muscle and liver of fish from the Dyje compared to fish from the Morava. Although Chakraborty et al. (2016) focused on Hg accumulation in sediments, their results suggest that higher organic carbon contents under suboxic conditions promote Hg retention in sediments, which may represent an important environmental source influencing Hg exposure in fish. Yediler and Jacobs (1995) found Hg accumulation to be higher at low O_2 in water, which explains the higher THg in fish from the Dyje. Zhao et al. (2024) state that higher COD_{Cr} indicates a higher amount of degradable organic matter, resulting in greater oxygen consumption, causing a hypoxic to anoxic environment, thereby stimulating anaerobic microorganisms and increasing Hg methylation. These conclusions are supported by the results of Pelcová et al. (2010) who found a positive correlation between the content of carbon, nitrogen, and sulphur in the sediment and Hg adsorption. Recent evidence suggests that sediment- and riparian-derived methylmercury represents an important source for riverine food webs, potentially contributing to elevated Hg exposure in fish (Krause et al. 2024). In newly flooded localities, it can lead to changes in conditions in the aquatic environment, as in the case of the river Želivka (Kružíková et al. 2011), and to an increase in the Hg content in fish. In the following periods, the Hg content in fish gradually decreased and subsequently stabilized. This is probably also occurring in the Dyje, and further monitoring of the Hg content in the aquatic environment is advisable.

Comparable Hg content results for chub and perch were also obtained for Czech rivers and reservoirs by Kružíková et al. (2011) and Novotna Kruzikova et al. (2022). A historically contaminated location in the Czech Republic is the Skalka Reservoir, where THg values in predatory fish remain around 3.5 mg/kg (Maršálek et al. 2005). In comparison with these sites, it can be concluded that the lower reaches of the rivers Morava and Dyje do not affect fish health or welfare in terms of Hg contamination. A positive correlation between muscle THg content and length in predators, and also between muscle and liver THg was previously reported, for example, by Łuczyńska et al. (2016).

Non-native species – round goby

The THg in the muscle tissue of round goby was significantly higher in the Dyje compared to the Morava (*P* = 0.0006). This indicates that Hg contamination is lower in the Morava, and therefore aquatic organisms are exposed to lower concentrations. Mercury content in muscle tissue of round goby of similar weight from the Dyje was monitored by Jurajda et al. (2020), who reported an average content of 0.069 ± 0.005 mg/kg compared to our finding of 0.089 ± 0.047 mg/kg. Jurajda et al. (2020) measured THg in fry homogenate, which may explain the lower THg values. Furthermore, in the river Elbe, Jurajda et al. (2020) reported an average muscle THg content of 0.100 ± 0.014 mg/kg, which appears higher compared to our results from the Dyje and approximately twice as high as the average Hg content in goby muscle from the Morava. The invasive round goby does not differ in average Hg content from fish species at the same trophic level (gudgeon and perch), and at similar body weights it reaches comparable concentrations in muscle tissue. For further assessment of potential new bioaccumulation pathways, we recommend future monitoring of THg in round goby and fish at the same trophic level.

Based on the measured THg values, data were expanded for perch, chub, roach, Prussian carp, gudgeon, and white-finned gudgeon, including the round goby, which is a non-native species in Czech rivers, from the lower reaches of the rivers Morava and Dyje. The level of Hg accumulation in goby muscle corresponds to species at the same trophic level, such as gudgeon. Although no industrial sources of Hg are known along these rivers, significantly higher Hg concentrations were found in the monitored fish (chub, perch, and round goby) from the Dyje compared to those from the Morava. This difference is attributed to varying environmental conditions, specifically COD_{Cr}, Cl^-, SO_4^{2-}, P-PO_4^-, total P and oxygen deficits. The results of this study demonstrate the influence of environmental conditions on Hg accumulation in both sediments and fish tissues. The Hg concentrations in fish tissues did not exceed the maximum limits set for fish intended for human consumption.

Acknowledgement

This work was supported by the Internal Creative Agency Project of the University of Veterinary Sciences Brno No. 2024ITA26.

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Plate XV
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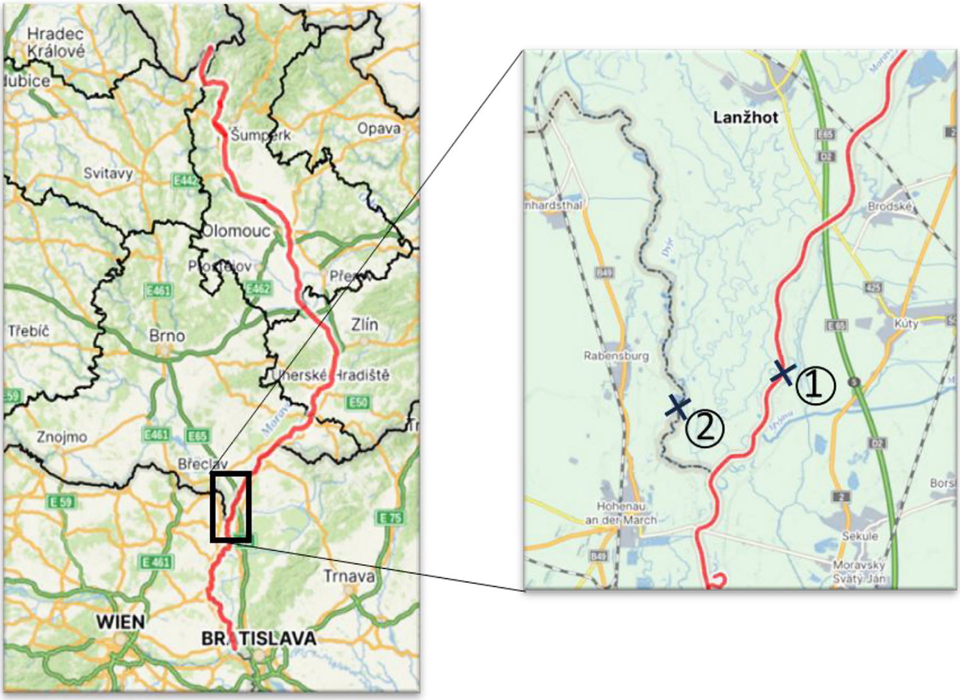

Fig. 1. Map of the sampling sites on lower reaches of the rivers Morava and Dyje
1 = Sampling site on the river Morava; 2 = sampling site on the river Dyje