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Monitoring of basic physicochemical parameters in the flow and their possible influence on the quality of the small water source

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Abstract

The ground source of drinking water for the village of Skalice nad Svitavou is located 35 km North of Brno (Czech Republic). An evaluation of developments in selected indicators of water quality in this groundwater source in the period 2013–2017 was the essence of this work. The data was provided by Vodárenská akciová společnost, a.s., i.e. the operator. At the same time, annual monitoring of water quality in the Úmoří stream, which flows through the catchment area and can affect the quality of groundwater, was carried out. Water samples were collected in 2017–2018 from 6 profiles on the Úmoří stream and its two tributaries. Raw water from the groundwater source does not meet the requirements for drinking water in some indicators and needs to be treated. Monitoring of surface water shows that the most problematic indicator is total phosphorus, the concentration of which exceeded limit values on all sampling profiles. The highest values were found in the tributaries, where total phosphorus concentrations exceeded 10 mg·dm^{-3}. There are 12 municipalities in the area of interest, only two of which have their own sewage treatment plant. It is clear from the results that wastewater in some municipalities is discharged directly into the recipient and is the cause of above-limit concentrations of both phosphorus and nitrogen. Intensively used agricultural land is another major source of pollution. Based on an analysis of sources of pollution, corrective measures have been proposed to improve the quality of surface and groundwater in the area.

Key words: *Czech Republic, nitrates, phosphorus, sampling profiles, waste water, water protection*

INTRODUCTION

It is known that groundwater is an indispensable element without which we cannot think of life on our planet. It is also known that around 50% of the world's population uses drinking water sources to meet the existential needs. Increment of population, industrial development and environmental pollution in our globe, directly or indirectly, has not only impacted groundwater pollution, but has also contributed in reducing the amount of water needed to meet elementary needs of man and other living beings [KELMENDI *et al.* 2018].

Agricultural management primarily ensures the production of raw materials for food production, but at the same time affects the shaping of the landscape, its functionality and aesthetic value. Agricultural landscape management also involves water quality and water production and has a direct link to soil quality. Intensive agriculture, however, can negatively affect water sources and the quality of the environment [FUČÍK *et al.* 2016].

Groundwater is an important source of drinking water. Groundwater sources are preferred to secure the supply of drinking water. However, due to their location and yield, they often cannot adequately secure the supply of drinking water for the entire population. More and more, they are being replaced by surface sources and, for this reason, catchment areas are being built. There is a similar trend in the Czech Republic. A large number of small villages are supplied from local groundwater sources.

In recent years, public interest in the quality of drinking water has increased considerably. This is especially true for residues of various chemical substances used in agriculture, which may potentially impair the quality of ground and surface water. People are concerned that the chemicals from agriculture contained in drinking water can endanger their health [CRUTCHFIELD *et al.* 2016].

Water source protection zones (PZ) are areas designed to protect the quantity, quality or safety of sources of surface and groundwater used or usable for the supply of drinking water. PZ in the Czech Republic are divided into 1st degree PZ and 2nd degree PZ [Zakon č. 254/2001 Sb]. Under the previous Water Act, so-called Hygienic protection zones were established (HPZ) divided in 1st degree HPZ, 2nd degree HPZ and 3rd degree HPZ – for surface water sources only.

Waste water is one of the most significant sources of pollution of surface and groundwater; of the area sources this is mainly agriculture. Point sources represent a crucial category for the P_{total} flow load. This category includes all municipal sources (irrespective of the manner of discharge, i.e. from septic tillage, etc.) and industrial sources [KONEČNÁ *et al.* 2018]. In addressing point sources of pollution, it is very important to deal with the operation of the whole site for precipitation-flow events [POTUŽÁK *et al.* 2013].

Nutrients, heavy metals and agrochemicals (pesticides and their residues, industrial fertilizers), drug residues and sediments are the main pollutants in agriculture that pollute surface and groundwater. Phosphorus is the most limiting factor in the growth of phytoplankton in fresh water and is associated with the eutrophication of flowing and standing surface waters [PITTER 2009]. Surface water is highly susceptible to phosphorus inputs from agricultural sources because critical concentrations of total phosphorus from the perspective of eutrophication (10–20 $\mu g \cdot dm^{-3}$) tend to be lower than the soil phosphorus content required for successful plant growth (200–300 $\mu g \cdot dm^{-3}$) [KVÍTEK *et al.* 2017]. Although there is no single European regulation or directive focused on phosphorus, some European Member States are dealing with phosphorus losses from agricultural sources through national or regional legislation. The approach of countries or regions varies greatly: e.g. the width of the protection zone along watercourses (0.5–500 m) and the reduction of fertilization – from no phosphorus regulation to a strict maximum phosphorus dose [AMERY, SCHOUMANS 2014].

There are many problems with nitrate pollution and pesticides from agricultural sources in European drinking water catchments, and various management options are currently being sought in these areas. Organic farming is one of the ways to reconcile agricultural activities and water protection [BARATAUD *et al.* 2014].

About 400 pesticides are used in the Czech Republic and their number is still increasing. The negative aspect of their use is that they can be washed into surface and groundwater and cause serious ecotoxicological problems in both terrestrial and aquatic biota and deteriorate the quality of the water.

The method of determining protection zones for drinking water sources and the scope of protection measures is different in individual EU countries, but the objective of protecting water sources is very similar. In most cases this involves 3–4 degrees of protection [SIAUVE, AMORSI 2015]. The norms regarding the protection of water resources and water management refer to the observance of procedures concerning the issuing of permissions for irrigation and the maintenance of buffer zones along watercourses [KOPACZ *et al.* 2018].

NOVÁK and FUČÍK [2017] recommend an open dialogue between all stakeholders in the catchment area, which is the only way to reach agreement on the restrictions on agricultural activities in the catchments of water reservoirs and to consequently ensure the required water quality for future generations. Experience from abroad also shows that good cooperation between farmers and water suppliers can only be achieved with the active participation of farmers in the definition of water protection programs and agricultural contracts [WEZEL *et al.* 2016].

The need to reduce the negative impact of agriculture on water quality also follows from Council Directive 91/676/EEC (the Nitrate Directive) concerning the protection of waters against pollution by nitrates from agricultural sources. Methodology according to KLÍR and KOZLOVSKÁ [2016] includes the principles of good agricultural practice for the protection of water against pollution by nitrates from agricultural sources. Nitrogen leaching depends on several factors, especially at the level of fertilization, the type and timing of fertilizer application, form of fertilizer, manner of application to the soil, type of crops and their requirements for fertilization, etc. The key factor determining the intake of nutrients by plants is also the availability of microelements and macroelements in soil, in particular the weight ratio between elements [LAWNICZAK *et al.* 2016].

However, agriculture is only one of many sources contributing to eutrophication and algal growth. Major sources of phosphorus include phosphates in detergents, fertilizer and feedlot runoff, as well as municipal wastewater discharges. Municipial wastewaters may contain 10 to 20 $mg \cdot dm^{-3}$ of phosphorus as P, much of which comes from phosphate builders in detergents [SPELLMANN 2009]. Ucontaminated waters contain 0.01 to 0.03 $mg \cdot dm^{-3}$ of total phosphorus [NEMEROW *et al.* 2009]. It is often difficult to distinguish the direct link between agriculture and ecological impacts on watercourses that receive nutrient inputs from multiple sources and where problems with eutrophication occur. For example, in the UK, in most water catchment areas, N and P feeds are complemented by direct and almost continuous discharges of domestic and industrial wastewater from a large number of wastewater treatment plants (WWTPs) [WITHERS *et al.* 2014]. The situation is also problematic in many catchment areas in the Czech Republic, where numerous small municipalities lack WWTPs.

Eco-friendly and technical measures need to be implemented in the agricultural land fund leading to a significant improvement in the quality of discharged water flowing over the surface of agricultural land and through drainage systems during increased rainfall [KVÍTEK *et al.* 2017].

This paper presents a risk analysis of the quality of drinking water in the groundwater source Skalice nad Svitavou and simultaneously analyses the risk of surface water in the catchment area of this water source. The main aim of the research is to propose corrective measures to improve the quality of surface water, while at the same time improving the protection of the ground source of drinking water and improving its quality.

MATERIAL AND STUDY METHODS

Study area. The ground source of drinking water Skalice nad Svitavou is located in the southern part of the cadastral area of Voděrady, about 35 km North of Brno (Czech Republic) – Figure 1. In view of the fact the study also involves monitoring water quality in the Úmoří stream, flowing in the immediate vicinity of the water source, the area of interest is delineated by the 4th level hydrologic unit in order to include the whole watercourse in question (Fig. 1). The area of interest is 30.6 km^2. The north-western, predominantly forested section is far from the water source, which is located in the eastern part of the area of interest. Therefore, the characteristics of the area of interest focus more on the area around the water source, predominantly consisting of agricultural land.

There are several cadastral areas in the area of interest, namely Hluboká u Kunštátu (60 population equivalent – PE), Touboř (25 PE), Kunice (1500 PE), Zbraslavec (214 PE), Lhota u Lysic (140 PE), Drnovice (1200 PE), Voděrady (530 PE), Lysice (2000 PE), Krhov (158 PE), Jabloňany (397 PE), Obora (324 PE) and Skalice nad Svitavou (618 PE).

In terms of the protection of water supply interests, local geological conditions afford significant natural protection of ground sources. Minimally permeable to virtually impermeable cohesive soils prevail, both in the subsoil and overburden. The subsoil contains almost exclusively highly plastic tertiary clays. The overburden of the flood plain consists of flood clay soil to clay to a depth of about 5 m. The surrounding area has a continuous eolithic cover of loess soil, predominantly in the nature of medium-plastic clay to a depth of over 10 m [ČIHÁK 2003].

There are several soil types in the area in question, mostly cambisol, brown earth and luvisol. According to QUITT [1971], the area of interest is a moderate climate area.

The area of interest is considerably elongated (Fig. 1), with coniferous and mixed forests in the western section, together with variously utilized agricultural areas (e.g. pastures). In contrast, the landscape matrix in the eastern section is formed by arable land. There is 66.2% of agricultural land in the area of interest, the arable land represents 44.4%. There are 12 municipalities in the area of interest, distributed over the whole territory and form independent, but significant segments of the landscape in terms of their impact. Agricultural land is farmed in the standard intensive manner, both in crop and livestock production. Crop production primarily focuses on growing cereals for food, seed production, feed grain, rapeseed, sugar beet and fodder crops. Part of crop production also specialises in growing fruit. Livestock production is mainly focused on cattle and pig breeding. There are two biogas stations in the area of interest, whose digestate is used for fertilizing. Vulnerable areas only include the cadastral area of Lysice and the cadastral area of Lhota u Lysic in the southern part of the area of interest. Only two municipalities are connected to mechanical-biological WWTPs – Drnovice and Lysice (Tab. 1).

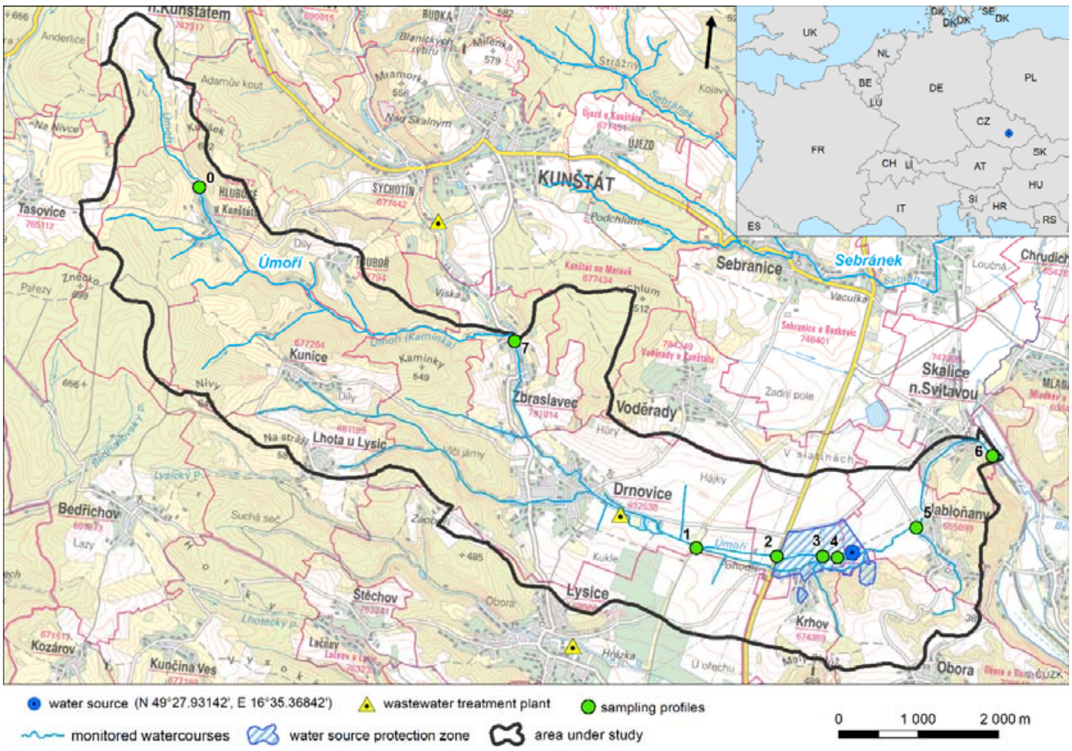

Fig. 1. Area of interest and sampling profiles identification; source: © VÚV TGM, modified

Table 1. Wastewater treatment plants (WWTPs) characteristics

Municipality name	Built in	Population equivalent	WWTP capacity $m^3 \cdot year^{-1}$	Wastewater sources	Amount of wastewater discharged ($m^3 \cdot year^{-1}$)	Nitrogen average annual concentration in the outflow ($mg \cdot dm^{-3}$)	Phosphorus average annual concentration in the outflow ($mg \cdot dm^{-3}$)
Drnovice	2006	1 200	140 000	sewage	117 401	22.3	0.73
Lysice	1996	2 000	146 000	sewage, rainwater	106 263	28.8	3.90

Source: own elaboration.

WATER SOURCE SKALICE NAD SVITAVOU

The catchment area of Skalice is located on the left bank of the Úmoří stream, about 400 m northeast of the town of Krhov (Fig. 1). The source of drinking water is quaternary water bound to the fluvial sediments of the flood basin of the Úmorí watercourse with total mineralization from 500 to 1,000 $mg \cdot dm^{-3}$. The water source consists of two bored reinforced concrete wells (ST1, ST2) 12 m deep. The authorized take-off is 8.0 $dm^3 \cdot s^{-1}$. Raw water is treated and subsequently pumped into a natural water reservoir, from where it is distributed to the network of Skalice nad Svitavou, Jabloňany, Krhov and Mladkov [ČIHÁK 2003].

The groundwater level in the area of the Úmoří watercourse is about 1.8–3.3 m below ground level. Water in this quaternary subsoil mainly accumulates in the more permeable sections of the fluvial deposits (fluvial clay layer – clayey gravel). The groundwater level has a slightly tense surface. The aquifer is subsidised by accumulated rainwater [ČIHÁK 2003].

The water source has established hygiene protection zones (HPZ) from 1983 according to the previous Water Act. The 1st degree HPZ is common to both wells, it is grassed, fenced and there is prohibited entry by unauthorized persons. The 2nd degree HPZ is delineated around the 1st degree HPZ and it is divided into an inner and outer zone. It should be marked by warning signs in the field. The total area of the HPZ is approximately 54 ha. The 2nd degree HPZ is intensively used in agriculture, and there is no organic farmer. The main crops are: wheat, barley, oats, rye, canola, peas, sugar beet, alfalfa.

In the summer of 2017, a field study was conducted in the HPZ of the water source. A maintained access road leads to the 1st degree HPZ. The entrance is secured by a lockable gate. The entire 1st degree HPZ is fenced, but the fencing is completely destroyed in one place and so does not fulfil its function. There are warning signs prohibiting entry along the fence. Most of the area of the 1st degree HPZ is grassed and regularly mowed. There is a water treatment plant here, two collecting wells and electricity poles. 2nd degree HPZ warning signs were not found even at intersections with major roads.

WATER COURSE ÚMOŘÍ

The Umoří watercourse originates North of the town of Hluboká u Kunštátu at an altitude of 638 m above sea level. It is a right-hand tributary of the Svitava, into which it flows in the town of Skalice nad Svitavou. The length of the watercourse is 16.03 km, the fan-shaped catchment area has an area of 30.6 km^2; the average annual rainfall is 620 mm. The long term average flow is 0.215 $m^3 \cdot s^{-1}$ and Q_{355} is 0.026 $m^3 \cdot s^{-1}$ (average daily flow that is reached or exceeded on average 355 days per year). An important left-hand tributary is Petrůvka, which flows into Úmoří in the town of Zbraslavec. The watercourse manager is Povodí Moravy, s.p. (PMO). The average gradient of the catchment area is 13.5%. Two technical modifications of the bed and banks were made to the watercourse in 1977 and 1987. These modifications were made in built-up areas of the towns of Hluboká u Kunštátu and Zbraslavec, where water spilled the banks and flooded the surrounding land during heavy rain, causing considerable damage to municipal and private property. In 1977, transverse structures were built to catch stream loads, unsuitable bridges were replaced by culverts with adequate capacity and bank ripping was repaired. Thanks to these modifications, the flow through of the bed increased and the risk of flooding has been reduced to a minimum.

After the floods in 1987, when the bed of the watercourse was damaged, the flow profile was modified (double in some places, irregular in others) and the banks were fortified. A new supporting wall was built near the Lysice–Kunštát district road, which was damaged during the flood [JUREČKOVÁ 2015].

GROUND WATER QUALITY MONITORING

The evaluation of raw water quality from the groundwater source Skalice nad Svitavou was conducted on the basis of data provided by Vodárenská akciová společnost (VAS, a.s.) for the period 2013–2017. 19 physical, chemical and microbiological indicators were evaluated. The values of the selected indicators were processed into graphs (charts) and compared with Decree No. 252/2004 Coll., which lays down hygiene requirements for drinking water and hot water and the frequency and scope of drinking water checks, as amended.

SURFACE WATER QUALITY MONITORING

During the field study in the summer of 2017, six sampling points (SP) were designated in the catchment area (SP 0, SP 2, SP 3, SP 4, SP 6) and two sampling profiles on tributaries of the Úmoří. These were SP 5 (right-handed nameless tributary) and SP 7 (left-hand tributary, Petrůvka) – Figure 1. Sampling and laboratory analyses took place regularly (monthly) between 2017 and 2018. Selected indicators (pH, conductivity, oxygen and temperature) were measured directly in the field, and other indicators (chemical oxygen demand, total phosphorus, total nitrogen and nitrate nitrogen) were determined in the Laboratory of the Department of Applied and Landscape Ecology, Faculty of Agronomy, Mendel University in Brno.

The measured values were used to calculate annual averages, which were evaluated according to the limits stipulated by Government Regulation No. 401/2015 Coll., as amended [Nařízení vlády č. 401/2015 Sb.] (Tab. 2) and the results were processed into graphs (charts). Regular monthly measurements were also compared with limits according to Czech state standard ČSN 75 7221 (Tab. 3) which classifies surface water into five classes of quality. In the end, individual SPs were classified in the appropriate class. The standard deviations were calculated for each sampling profile – measure of the dispersion of the average.

Table 2. Chosen indicators and permissible pollution according to Nařízení vlády č. 401/2015 Sb.

Quality indicator	Symbol	Unit	Permissible pollution	
			annual average	maximum
Water temperature	t	°C	–	29
Water reaction	pH	–	5–9	–
Oxygen saturation	O_2	mg·dm^{-3}	>9	–
Chemical oxygen demand	COD_{Cr}	mg·dm^{-3}	26	–
Phosphorus total	P_{total}	mg·dm^{-3}	0.15	–
Nitrogen total	N_{total}	mg·dm^{-3}	6	–
Nitrate nitrogen	N-NO_3^-	mg·dm^{-3}	5.4	–
Nitrite nitrogen	N-NH_4^+	mg·dm^{-3}	0.23	–

Source: GR No. 401/2015 Coll., as amended.

Table 3. Chosen indicators and classes of quality according to ČSN 75 7221

Quality indicator	Class				
	I	II	III	IV	V
Conductivity (mS·m^{-1})	[0;40)	[40;70)	[70;110)	[110;160)	[160;∞)
Dissolved O_2 (mg·dm^{-3})	(7.5;∞)	(6.5;7.5]	(5;6.5]	(3;5]	(0;3]
COD (mg·dm^{-3})	[0;15)	[15;25)	[15;45)	[45;60)	[60;∞)
N-NO_3 (mg·dm^{-3})	[0;3)	[3;6)	[6;10)	[10;13)	[13;∞)
P_{total} (mg·dm^{-3})	[0; 0.05)	[0.05;0.15)	[0.15;0.4)	[0.4;1)	[1;∞)

Source: Czech state standard ČSN 75 7221.

SAMPLING PROFILE (SP) CHARACTERISTICS

SP 0 was chosen above the town of Hluboká u Kunštátu, which is the source area of the Úmoří stream.

SP 1–3 lie close to each other, above the water source. Several weirs have been artificially created in this section of the watercourse to help oxygenate the water in the stream. After the first analyses, it was found that the water quality in these SP varied very little, so the average was then always calculated from these values, which subsequently appears in the results.

SP 4 is located near the ground source of drinking water (approx. 50 m).

SP 5 is the right-hand nameless tributary of the Úmoří stream in the town of Jabloňany. The water in this tributary was turbid, and sewage was often smelt in the water.

SP 6 is located in Skalice nad Svitavou, under the railway crossing, above the confluence of the Úmoří and Svitava.

SP 7 is located on the Petrůvka stream, which is a left-hand tributary of the Úmoří in the town of Zbraslavec.

ANALYSIS OF WATER QUALITY

Water samples were taken from the banks of the watercourse into pre-prepared, labelled, plastic sampling containers, which were rinsed with water from the appropriate sampling point before sampling. Samples were stored in a refrigerator until the next day, when they were processed in the laboratory. Water temperature, conductivity, dissolved oxygen, and pH were measured in the field using a HQ30D portable digital multimeter with exchangeable probes by HACH. Laboratory processing of collected samples was always performed in accordance with safety regulations. Water analyses were always performed within 24 hours of sampling. HACH official methodologies were followed for the determination of selected parameters; samples were analysed in a HACH DR/4000V spectrometer and HACH Digital Reactor Block 200 (DRB200) mineralizer (thermoreactor).

RESULTS

WATER QUALITY IN GROUND SOURCES – CAPTATION WELL ST1 AND CAPTATION WELL ST2

A clear table for sources ST1 and ST2 was prepared from individual reports on raw water quality provided by VAS, a.s. (Tab. 4), in which the limit for drinking water is also indicated. The results show that the collected raw water did not exceed limits for drinking water in any of the monitored physical and chemical indicators. Microbiological indicators are adjusted through hygienic safety measures at the water treatment plant. The limit value of E-coli, coliform bacteria, *Clostridium perfringens* and intestinal enterococci in drinking water is 0 CFU·100 cm^{-3}.

The high nitrate concentrations at both sources in 2016 should be pointed out in the results (42.9 and 36.2 mg·dm^{-3}). Due to the decline in nitrates in the following year, this fluctuation can be explained by the one-time pollution of the water source with nitrates. According to the analysed data, developments in water quality due to nitrate pollution are favourable for both collecting points because they remain below the limit of 50 mg·dm^{-3} stipulated by the Decree on Drinking Water.

The operating company also provided reports on the quality of treated drinking water produced by mixing water from both sources, which was collected from the faucet. Hygienic safety measures at the water treatment plant eliminate the concentration of microbiological indicators (E-coli and coliform bacteria) to 0 CFU·100 cm^{-3}. Somewhat startling are the concentrations of iron in drinking water, which were around the limit value of 0.2 mg·dm^{-3}, although the concentrations in raw water often ranged below the limit for determination, i.e. 0.05 mg·dm^{-3}. This clearly indicates that the increase in iron concentrations in treated drinking water occurred after passing through the water pipeline.

Table 4. Raw water quality in the ground sources – caption wells ST1 and ST2

Parameter	Unit	Raw water quality in the ground source ST1 in terms of sampling					Drinking water limit
		03.09.2013	19.08.2014	21.04.2015	01.08.2016	24.07.2017	
Ground source ST1							
Escherichia coli	CFU·100 cm^{-3}	0	1	0	0	7	**0**
Coliform bacteria	CFU·100 cm^{-3}	0	36	0	>100	75	**0**
Enterococcus	CFU·100 cm^{-3}	8	9	0	18	13	**0**
Living organisms	individuals· cm^{-3}	0	0	0	0	0	**0**
Abioseston	%	<1	<1	1	<1	1	**10**
Conductivity	mS·m^{-1}	86.0	80.1	90.8	91.2	89.8	**125.0**
pH		7.5	7.2	6.9	7.1	7.0	**6.5–9.5**
Colour	mg·dm^{-3} Pt	<2	<2	<2	<3	5	**20**
Haze	ZFt	0.4	0.3	<0.3	<0.3	<0.3	**5**
Nitrites	mg·dm^{-3}	<0.004	0.010	<0.004	<0.05	<0.004	**0.5**
Ammonium ions	mg·dm^{-3}	0.06	0.080	0.080	<0.02	<0.060	**0.5**
Nitrates	mg·dm^{-3}	10.5	10.5	10.9	42.9	10.8	**50.0**
COD	mg·dm^{-3}	1.7	1.5	1.5	1.5	1.1	**3.0**
Iron	mg·dm^{-3}	<0.05	<0.05	<0.05	0.056	<0.05	**0.2**
Manganese	mg·dm^{-3}	<0.03	<0.03	<0.03	0.001	<0.03	**0.05**
Aluminium	mg·dm^{-3}	<0.045	<0.045	<0.045	0.001	<0.045	**0.2**
Calcium	mg·dm^{-3}	120	124	146	122	136	**30**
Magnesium	mg·dm^{-3}	26.4	15.6	22.2	22.8	15.4	**10.0**
Chlorides	mg·dm^{-3}	47.3	49.0	48.9	42.3	61.2	**100**
Ground source ST2							
Escherichia coli	CFU·100 cm^{-3}	0	2	0	15	0.0	**0**
Coliform bacteria.	CFU·100 cm^{-3}	32	29	0	>100	20.0	**0**
Enterococcus	CFU·100 cm^{-3}	9	14	0	>100	5.0	**0**
Living organisms	individuals· cm^{-3}	0	0	0	0	0.0	**0**
Abioseston	%	<1	<1	2	<1	<1	**10**
Conductivity	mS·m^{-1}	105.0	71.8	95.7	104.8	75.7	**125.0**
pH		7.5	7.2	7.1	7.3	7.2	**6.5–9.5**
Colour	mg·dm^{-3} Pt	<2	<2	<2	<3	5.0	**20**
Haze	ZFt	<0.3	0.3	<0.3	<0.3	0.3	**5**
Nitrites	mg·dm^{-3}	<0.004	<0.004	<0.004	<0.05	<0.004	**0.5**
Ammonium ions	mg·dm^{-3}	0.06	0.060	0.080	<0.02	<0.060	**0.5**
Nitrates	mg·dm^{-3}	19.0	19.9	20.0	36.2	7.1	**50.0**
COD	mg·dm^{-3}	1.8	1.6	1.6	1.7	1.2	**3.0**
Iron	mg·dm^{-3}	<0.05	<0.05	<0.05	0.009	<0.05	**0.2**
Manganese	mg·dm^{-3}	<0.03	<0.03	<0.03	<0.001	<0.03	**0.05**
Aluminium	mg·dm^{-3}	<0.045	<0.045	<0.045	0.002	<0.045	**0.2**
Calcium	mg·dm^{-3}	140	114	171	140	110	**30**
Magnesium	mg·dm^{-3}	30.0	20.6	20.0	28.3	19.2	**10.0**
Chlorides	mg·dm^{-3}	59.8	41.8	61.2	58.3	44.6	**100**

Source: own study based on datas of VAS, a.s.

EVALUATION OF WATER QUALITY IN THE ÚMOŘÍ WATERCOURSE

Evaluation of water quality according to Czech state standard ČSN 75 7221

Classification according to ČSN 75 7221 classifies surface water into classes according to its quality using a set of limit values. The resulting class is determined according to the least favourable classification for individual selected indicators at a single sampling point. Based on the above results (Tab. 5), it can be stated that water quality in the Úmoří gradually deteriorates downstream. The worst indicator is always total phosphorus. SP 0 is classified in class I–III of water quality, the other SP on the Úmoří stream fall in class IV of water quality (heavily polluted water). Both tributaries (SP 5 and SP 7) are always rated in class V (very heavily polluted water). Standard deviation values demonstrate that the most fluctuating values out of all monthly measurements in the course of a year were on tributaries SP 5 and SP 7. Conductivity demonstrates the highest dispersion, while values of pH were the least dispersed (Tab. 5).

Evaluation of water quality according to Government Regulation [Nařízení vlády č. 401/2015 Sb.]

Average pH values at all sampling points meet the limits in accordance with Government Regulation. On average, the lowest pH (7.2) was recorded at the source (SP 0) and the highest (7.9) at the tributary from Jabloňany (SP 5). The pH of water is one of the few indicators in which the tributaries did not show significantly different values from the values measured on the Úmoří stream.

The value of 9 mg·dm^{-3} of dissolved oxygen in water specified in specified above Government Regulation is the limit below which the annual average should not fall. The results show that all SPs met this limit with the exception of SP 5, where the average annual value was 6.4 mg·dm^{-3} of dissolved oxygen in water. Water was most saturated with oxygen at SP 4 (average 11.6 mg·dm^{-3}).

Table 5. Evaluation of water quality in Úmoří watercourse according to ČSN 75 7221

Sampling profile	$N\text{-}NO_3$		P_{total}		COD		Conductivity		Dissolved O_2		pH		N_{total}	
	A	*SD*	A	*SD*	A	*SD*	A	*SD*	A	*SD*	A	*SD*	A	*SD*
	$mg \cdot dm^{-3}$						$mS \cdot m^{-1}$				$mg \cdot dm^{-3}$		$mg \cdot dm^{-3}$	
SP 0	2.40	0.951	0.18	0.099	10.85	1.042	24.125	0.4969	11.275	1.5911	7.2	0.559	3.70	2.112
SP 1–3	2.79	0.839	0.23	0.189	6.80	0.843	61.225	3.836	11.380	2.236	7.4	0.569	3.80	1.912
SP 4	2.50	0.653	0.43	0.216	5.65	0.320	62.850	3.7427	11.578	3.3744	7.3	0.641	3.60	1.298
SP 5	2.83	2.343	4.72	4.756	43.90	15.890	156.68	65.098	6.3875	1.756	7.9	0.225	22.80	6.449
SP 6	4.25	3.041	0.77	0.487	15.80	5.934	69.625	7.0624	10.668	2.8508	7.3	0.574	6.00	1.588
SP 7	4.60	1.458	9.00	3.549	32.80	9.860	73.1	35.489	11.450	1.985	7.4	0.589	6.80	4.572

Explanations: A = annual average – calculated from regular monthly monitoring = 12 measurements, *SD* = standard deviation.
Source: own study.

Nitrate nitrogen is one of the indicators that has no problems according to this Government Regulation. The average annual value of 5.4 $mg \cdot dm^{-3}$ was not exceeded at any of the SPs. The highest annual average concentration of 4.6 $mg \cdot dm^{-3}$ was found at SP 7, the lowest 2.4 $mg \cdot dm^{-3}$ at SP 0.

COD indicates the presence of organic substances in the water. The results show that a higher amount of organic substances is found on both tributaries (SP5, SP7), where the average annual COD concentration was 43 and 32 $mg \cdot dm^{-3}$. The average annual COD values were below the limit on all SPs on the Úmoří.

Average annual concentrations of total N for SP 0 – SP 4 were below the limit according to Government Regulation [Nařízení vlády č. 401/2015 Sb.]. High concentrations of total N (annual average 23 $mg \cdot dm^{-3}$) were regularly found on the tributary from Jablořany SP 5. This polluted tributary also significantly affected water quality in the Úmoří and the average annual value reached limit values at SP 6. Above-limit values were also recorded at SP 7, although they did not reach concentrations as high as SP 5 (Fig. 2)

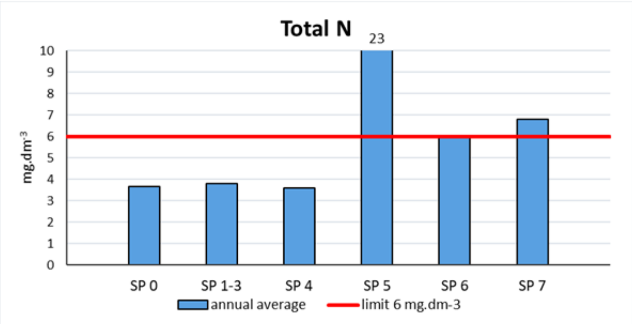

Fig. 2. Annual average concentration (from monthly measurements from three replicates) of total nitrogen – acc. to Government Regulation [Nařízení vlády č. 401/2015 Sb.]; *SD* < 1%; source: own study

As mentioned above, the most problematic indicator is total P. The limit value for the annual average of 0.15 $mg \cdot dm^{-3}$ was exceeded at all SPs. The average at SP 0 was 0.18 $mg \cdot dm^{-3}$ and concentrations increased downstream with increasing pollution. Both tributaries contributed to this significantly, where the average values of total phosphorus are several times higher than the average values in the Úmoří (Fig. 3).

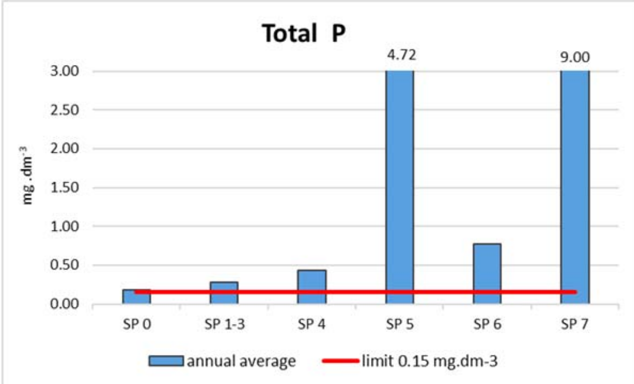

Fig. 3. Annual average concentration (from monthly measurements from three replicates) of total phosphorus – acc. to Government Regulation [Nařízení vlády č. 401/2015 Sb.]; *SD* < 1%; source: own study

DISCUSSION

Monitoring at some SPs on the Úmoří has taken place in the past, so it is possible to compare the current data with the results from previous years by different authors. Annual monitoring of profiles SP 0, SP 1, and SP 6 ran from 2013/2014 [JUREČKOVÁ 2015]. The watercourse manager, Povodí Moravy, s.p. (PMO) monitored SP 4 in 2011 and 2015. Monitoring of other small watercourses (the left-hand tributary Sebránek and the right-hand tributary Semíč), which flow into the Svitava at Svitávka (Fig. 1), took place between 2014/2015 (Sebránek) and 2013/2014 (Semíč) [MATALOVÁ 2015; OPPELTOVÁ et al. 2015]. There are similar economic and natural conditions in the catchment areas of these watercourses as in the catchment area of the Úmoří.

At SP 4, the average conductivity value was 59.2 $mS \cdot m^{-1}$ in 2011 and 2015 (Povodí Moravy, s.p.). Currently, an average annual concentration of 62.9 $mS \cdot m^{-1}$ was measured at the same location. Similarly, lower conductivity values than at present were reported at the same sampling points (SP 0, SP 1 and SP 6) in the work of JUREČKOVÁ [2015]. MATALOVÁ [2015] states that average annual conductivity increased in the Sebránka catchment area from the source to the estuary and ranged from 30.3 to 70.1 $mS \cdot m^{-1}$. Average annual conductivity in the Semíč catchment area was around 76 $mS \cdot m^{-1}$ at all SPs with the exception of the source [OPPELTOVÁ *et al.* 2015].

According to current results, the average annual dissolved oxygen concentration at SP 4 was 11.6 $mg \cdot dm^{-3}$.

When compared to PMO results, the average concentration measured at SP 4 in 2011 was 11.4 mg·dm^{-3} and 11.3 mg·dm^{-3} in 2015. In 2013/2014, lower values (9.8–10.3 mg·dm^{-3}) were found at SP 0, SP 1 and SP 6. However, the average annual values on all SPs were always above the limit of 9 mg·dm^{-3} prescribed by Government Regulation [JUREČKOVÁ 2015; Nařízení vlády č. 401/2015 Sb.]. The average annual oxygen saturation value in the Semíč catchment area was below the limit of 9 mg·dm^{-3} at most SPs [OPPELTOVÁ *et al*. 2015]. MATALOVÁ [2015] also states that the average annual concentration of dissolved oxygen was below the limit of 9 mg·dm^{-3} at some SPs on the Sebránek stream. All of the results show that water in the Úmoří is sufficiently oxygenated. This is undoubtedly aided by the series of gradients, weirs and sluices built along the entire length of the stream.

Highly fluctuating COD values were found in 2015 when, for example, autumn values were around 50 mg·dm^{-3}, which significantly increased the annual average, which was 21.9 mg·dm^{-3} [JUREČKOVÁ 2015]. These fluctuations were not observed during current monitoring, and current results show that the annual average at SP 0, SP 1 and SP 6 ranged around 13.7 mg·dm^{-3}. Lower average values were also found at SP 4 (5.4 mg·dm^{-3}) than in 2015 and 2011 (10.5, 11.1 mg·dm^{-3}). The average annual COD value in the Semíč catchment area ranged around the limit of 26 mg·dm^{-3} at most SPs, while this value was exceeded at some SPs [OPPELTOVÁ *et al*. 2015]. According to MATALOVÁ [2015], the COD values on Sebránek stream were highly variable over time and at individual profiles, and the average annual concentration at individual SPs ranged from 11.11 to 39.27 mg·dm^{-3}.

A comparison of pH values at SP 4 with results from PMO, s.p. is not relevant as PMO determined the pH in laboratory conditions, not in the field. On comparison of the results with the work of JUREČKOVÁ [2015], the pH is quite different. Jurečková states that the lowest pH (on average 4.23) was recorded during summer, the highest in winter (average 6.3). Current measurements show the lowest pH (average 6.7) during spring and the highest pH (average 7.8) during summer and autumn. The average value at SP 0, SP 1 and SP 6 in 2013/2014 was lower (5.4) than today (7.3) according to JUREČKOVÁ [2015]. The average annual value at individual SPs in the Semíč catchment area ranged from 8.2 to 8.9, with the exception of the value at the source, where it was around 7.2 [OPPELTOVÁ *et al*. 2015]. MATALOVÁ [2015] states that annual average pH values for the Sebránek watercourse varied from 6.5 to 8.2 in 2014/2015.

The concentrations of nitrate nitrogen at SP 4 were lower compared to previous measurements the long-term trend shows a slight decrease (Fig. 4). The average annual concentration was 2.5 mg·dm^{-3}; according to the values provided by PMO, s.p., the average concentration was 4.9 mg·dm^{-3} in 2011 and 4.3 mg·dm^{-3} in 2015. SP 4 is located about 50 m from ground sources of drinking water. The obtained results are positive for groundwater quality, as the low nitrate nitrogen values in the Úmoří show that the groundwater source is not adversely affected by surface water from the stream. The results reported by JUREČKOVÁ [2015] also show that the average annual nitrate nitrogen concentration at SP 0, SP 1 and SP 6 has decreased to the current 3.2 mg·dm^{-3} compared to the results in 2013/2014. The average annual value at individual SPs in the Semíč catchment area ranged from 3.1 to 5.5 mg·dm^{-3} [OPPELTOVÁ *et al*. 2015]. Nitrate nitrogen concentrations fluctuated highly on the Sebránek stream in 2014/2015 and ranged from 2.5 to 7.6 mg·dm^{-3} [MATALOVÁ 2015].

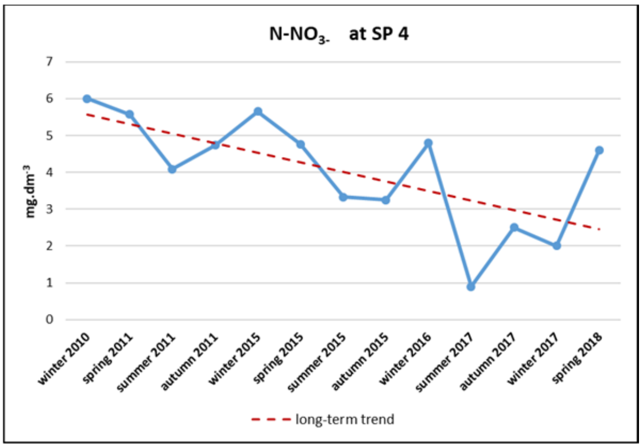

Fig. 4. Long-term trend of N-NO^{3-} concentration at SP 4; source of data: Povodí Moravy, s.p. and own study

One way to reconcile agricultural activities and water protection is to change the conventional way of farming to organic. This management regime has proved to be functional in a number of European catchment areas [Barataud *et al*. 2014; Garnier *et al*. 2014; Dumbrovský *et al*. 2015].

The results show that the concentration of total nitrogen in the Úmoří are strongly affected by its tributaries (SP 5 and SP 7). These flow into the Úmoří downstream from sources of drinking water, therefore the quality of drinking water is not affected by these tributaries. During monitoring, concentrations of ammoniacal nitrogen were also measured irregularly. Because of this irregularity, they were not graphically processed, but the analysis shows that a large amount of ammoniacal nitrogen flows into the watercourse from tributaries SP 5 and SP 7, which mainly comes from sewage. Compared to the results reported by JUREČKOVÁ [2015], the average annual total N concentrations decreased slightly at SP 0, SP 1 and SP 6 and average annual concentrations did not exceed the limit value at SP 0–4 (Fig. 2). Average annual total N concentrations at most SPs on the Semíč stream in 2013/2014 exceeded the limit value according to Government Regulation [Nařízení vlády č. 401/2015 Sb.]. The average concentration of total N was about 1 mg·dm^{-3} in the area near the source on the Sebránek stream, to about 6.9 mg·dm^{-3} further downstream.

As has already been mentioned in the results, the Úmoří watercourse is heavily contaminated with nutrients – especially phosphorus. Therefore, the problem of phosphorus is given more space than other indicators.

Total phosphorus content at all SPs exceeded the limits according to specified above Government Regulation. Limit values are already exceeded at SP 0. Similar results showing significant pollution in source areas were also reported by MARKOVÁ and PELIKÁN [2016]. It is important to mention a slight increase of P_{total} between SP 0 and SP 1 which lies below Drnovice municipality after a wastewater treatment plant. Average yearly concentration of P_{total} at SP 1 is above the limit value of 0.15 mg·dm^{-3}, but compared to profiles characterizing tributaries from municipalities without WWTP (SP 5) or with WWTP without phosphorus removal (SP 7), the influence of WWTP Drnovice on the quality of water in the watercourse is positive.

Phosphorus average annual concentration in the outflow of WWTP is 0.73 mg·dm^{-3} (Tab. 1).

SP 4 is the most significant when looking at the quality of water, since it is located in the immediate proximity of the water source. That is why more attention was paid to this SP. A part of the catchment area between SP 1 and SP 4 is an agricultural land and the results of the monitoring show that there is no significant rise in the concentration of total nitrogen, nitrates or total phosphorus between profiles of SP 1 and SP 3. This shows that the agricultural land in this part of the catchment area does not have a significant influence on the quality of the surface water. The difference in P_{total} concentrations between SP 3 and SP 4 points to the influence of the waste water which enters the watercourse below Krhov municipality which is not equipped with a WWTP.

By comparing results for SP 4 with monitoring data from PMO, s.p., it can be stated that the annual average (0.43 mg·dm^{-3}) was higher than in 2011 (0.29 mg·dm^{-3}) and 2015 (0.22 mg·dm^{-3}) – Figure 4. This phenomenon can be explained by the increasing number of inhabitants, and hence increasing phosphorus production.

OPPELTOVÁ *et al*. [2015] state that average annual concentrations significantly exceeding Government Regulation [Nařízení vlády č. 401/2015 Sb.] were also found at all SPs when monitoring the Semíč watercourse (the lowest average annual value was 0.2 mg·dm^{-3}, most SPs were around 0.5 mg·dm^{-3}, with the highest average concentration being 1.1 mg·dm^{-3}). Limit values at some SPs on the Sebránek watercourse were even exceeded up to tenfold [MATALOVÁ 2015].

Pollution of surface water with phosphorus is a long-term problem addressed by a number of catchment areas not only in the Czech Republic.

However, agriculture is only one of many sources contributing to water pollution. It is often difficult to distinguish the direct link between agriculture and ecological impacts on watercourses that receive nutrient inputs from multiple sources and where problems with eutrophication occur. For example, in the UK, in most water catchment areas, N and P feeds are complemented by direct and almost continuous discharges of domestic and industrial wastewater from a large number of WWTPs. While agriculture is undoubtedly the main source of N, wastewater is the main source of P (the main limiting nutrient for the destruction of algal growth). According to British findings, the contribution of agriculture to the eutrophication of rivers also depends on whether P is released from sewage sediments during periods of low flow, which are the times of greatest ecological sensitivity [WITHERS *et al*. 2014].

Based on a long-term study, HEJZLAR *et al*. [1996] state that annual export rates of total P from the Vltava River basin (Czech Republic) to the Elbe River ranged between 38 and 68 kg·km^{-2}·y^{-1}. Point sources (municipal wastewaters) were most important and their share varied from approximately 60% in wet years to more than 90% in dry years. Export from diffuse sources (dominated by output from farmland) was highly dependent on discharge and fluctuated between 5 and 40 kg·km^{-2}·y^{-1} in dry and wet years, respectively.

However, the existence of WWTPs is not always a guarantee that clean water flows out of them. There is no phosphorus precipitation at many WWTPs, and the concentration of total P at the outflow is alarming. In their study, ROSENDORF *et al*. [2017] stated that even a high rate of connection to the public sewage system by inhabitants that ends at wastewater treatment plants may not lead to an improvement in the condition of water bodies. Even in catchment areas, where the percentage of connection exceeds 90%, the condition of water bodies according to total phosphorus concentration is assessed as unsatisfactory. The cause is the concentration of wastewater and its discharge into the river network, mostly without the effective removal of phosphorus. Similar results are reported by NEAL et al. [2005] from a UK study, where the significance of the contribution of different types of pollution to water eutrophication has been heatedly discussed in recent years, and point sources of pollution are slowly becoming the focus of interest.

There is also a high level of total P in the Svratka catchment area. The annual quantity of phosphorus between Vír dam and Brno dam is nearly 17.5 t [GRMELA *et al*. 2013].

Protecting water bodies from eutrophication, ensuring long-term food security and shifting to a circular economy are compelling objectives in phosphorus management strategies. However, research results from Austria indicate that erosion still accounts for about 42% of total Austrian emissions. The results show that there is plenty of room for controlling the flow of phosphorus, not only in Austria. Part of the results is an analysis of individual materials that could serve as sources of P instead of non-renewable resources: meat and bone meal, sewage sludge, compost, digestate, biomass ash, manure recycling [ZOBOLI *et al*. 2016].

Also WITHERS *et al*. [2015] recently reviewed a number of management strategies to address P-related challenges in Europe and they have put forward a framework of 5R stewardship (re-align P inputs, reduce P losses, recycle P in bio-resources, recover P in wastes, and redefine P in food systems).

The absence of sewers and wastewater treatment plants (WWTPs) in small municipalities is not only a problem in the Czech Republic, but also in other countries. HÚSKA *et al*. [2013] state that it is not possible to build WWTPs in small municipalities in Slovakia for financial reasons and due to unsuitable natural conditions, so Slovakia will not achieve good water conditions by the set deadline under the Framework Directive. According to HÚSKA *et al*. [2013], the production of wastewater, as well as the use of the landscape, has a significant impact on the quality of water in the watercourse.

CONCLUSIONS

There are 12 municipalities in the area of interest in the Úmoří catchment area, only two of which have their own WWTPs (Drnovice and Lysice). It is clear from the results of monitoring water quality on the Úmoří stream that wastewater from some of these municipalities ends up directly in this recipient. These are the cause of above-limit phosphorus concentrations over the entire measured section of the watercourse and above-limit nitrogen, although this is higher in the section beyond the water sources. Area sources of pollution of the landscape depend on how the land is used. The area surrounding water sources in the Úmoří catchment area is predominantly arable land, the main factor here is therefore agriculture. The area is intensively used in the conventional method of farming. Part of the land (about 50 ha) is located in the 2nd degree water source protection zone. Based on the evaluation of water quality in water sources, the concentration of nitrates is below the limit set by the Decree on Drinking Water. At the same time, there is a long-term downward trend in the concentration of nitrates at SP 4 (Fig. 4). Looking at the nitrogen fertilization, it is possible to state that agriculture has no significant influence on the quality of surface or groundwater in the proximity of the water source in the catchment area of the Úmoří watercourse. However, this does not mean that agricultural activity could not affect water sources in the future. Crops (e.g. rapeseed) which are treated with pesticides are regularly grown on the arable land in the catchment area. Because of that it is recommended to regularly monitor the concentration of pesticides and their metabolites in a water source. These conclusions may be applied to other catchment areas with similar land and physiogeographical attributes where the concentrations of nutrients may not negatively influence surface and groundwater sources granted that agricultural entities abide by the principles of correct agricultural practice.

To improve the quality of water in the area of interest, the following corrective measures have been proposed.

The construction of new WWTPs with effective phosphorus removal – in terms of the effectiveness of wastewater treatment, modern biomechanical WWTPs are clearly the most effective (for example WWTP Drnovice). However, their construction is often financially demanding for small municipalities, which is the most frequent reason why their further construction is not planned. Therefore, joining several municipalities into a voluntary union of municipalities, which can more easily obtain provided subsidies or co-finance a joint WWTP could be a solution here.

One option for the collection of municipal wastewater – in small municipalities where it would not be cost-effective to build treatment plants, is the possibility to support the collection of wastewater from self-contained wastewater holding tanks to the nearest WWTP with high cleaning efficiency. It is important to prevent the direct discharge of wastewater into the recipient. Naturally, it is also vital to ensure that holding tanks are watertight in order to prevent wastewater from escaping into the surrounding area.

If wastewater is disposed of at wastewater treatment plants (whether through sewers or transported from septic and holding tanks), high cleaning efficiency is required.

A review of water source protection zones – protection zones are a preventive tool and serve to protect the quality and yield of water sources. HPZ sources ST1 and ST2 were established in 1983. Concepts and legislation on water protection and water use have changed significantly since then. Therefore, a review of these PZ is required. During the field study, it was found that 1st degree PZ fencing has been destroyed in some places and thus fails to fulfil its function. The absence of warning signs was also found in 2nd degree PZ. The first step is therefore to secure 1st degree PZ against the entry of unauthorized persons. When proposing a farm management regime in 2nd degree PZ it is advisable to work with the economic operators concerned. Currently, there are no analyses being done on the pesticides in the water source. That is why in pursuance of revision of protection zones we recommend the implementation of a regular monitoring of presence of pesticides in a water source or prohibition of the usage of pesticides in the 2nd degree protection zone.

According to valid legislation, there is the possibility of compensation for proven restrictions on the use of land and buildings in protection zones. So, operators on these plots could apply for financial compensation for potentially stricter measures to be introduced in the context of the review of PZ. On the other hand, if compensation is paid, it is very likely that the cost of drinking water will rise and water rates will increase.

Vulnerable areas – most of the area of interest is not a nitrate vulnerable zone that serves to protect water sources from nitrate pollution. According to current results on the quality of raw water, nitrate concentrations are not increasing in water sources. However, if necessary, the inclusion of the cadastral areas of Voděrady and Jabloňany in vulnerable areas, where farmers would have to operate according to the principles of good agricultural practice, is one of the possibilities for increasing the protection of water sources. This would mean, for example, that the amount of applied nitrogen may not exceed 170 kg per hectare per year within one enterprise, the prohibited application of fertilizers in the protection zone (width 3 m along the watercourse), the prohibited use of nitrogen fertilizers during the specified period, etc. Protective measures within vulnerable areas must be respected by all local farmers. However, there is no compensation for any damages.

The above measures are only suggestions on how to improve the quality of water in water sources and the Úmoří watercourse, which flows nearby. Water quality in ground sources is relatively good so far and shows no signs of excessive pollution. However, surface water pollution in the Úmoří stream is alarming. Although the watercourse does not significantly affect the quality of groundwater in ST1 and ST2, the connection of at least some municipalities to WWTPs would help to improve water quality in the Úmoří. Whatever measures are taken, it is always important to monitor compliance therewith, since it is only in this way that water sources can be effectively protected.

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