


Phosphate and ammonia concentrations in waters from a meadow complex located on peat soils in various range of groundwater level

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Abstract: The aim of the study was to assess the P-PO₄ and N-NH₄ pollution of water in grasslands located on peat soils and to identify the impact of groundwater level on this pollution formation. The research was conducted in 2000–2010 on grounds of ITP-PIB in Biebrza village (Poland). Within lowland fen a total of 18 monitoring points of groundwater and watercourses were established in 6 separate test stands. The subject of the research was water collected from drainage ditches/channels and groundwater, which was taken from wells installed in organic-soil layer and wells whose bottom was 15–20 cm below this layer. Water samples were collected several times a year, and in the case of groundwater, its level was also measured. It was found that: 1) due to concentration level of P-PO₄ and N-NH₄, about 46 and 39% of water samples from organic-soil layer and more than 40 and 37% of water samples from mineral-organic-soil layer respectively, were characterized by poor chemical status; 2) due to the exceeding of the limit values of P-PO₄ and N-NH₄ concentration, water samples from watercourses in over 30 and 27% respectively were not within 1st and 2nd class of surface water quality; 3) P-PO₄ and N-NH₄ concentrations in each water type were statistically significant and positively correlated with each other; 4) in organic-soil layer the groundwater level changing every 10 cm was a statistically significant factor differentiating the average P-PO₄ concentration in groundwater associated with mineral-organic layer of peat soil and average N-NH₄ concentration in each type of water.

Keywords: grassland, groundwater level, peat soils, inorganic nitrogen and phosphorus concentration, soil phosphorus cycle

INTRODUCTION

Contrary to mineral soils, phosphate-phosphorus (P-PO₄) leaching from organic soils is high and generally exceeds 1 kg P·ha⁻¹·y⁻¹ [KOLENBRANDER 1972; RIDDLE *et al.* 2018], particularly from lowland fen peat soils [RUPP *et al.* 2004; STEENVOORDEN 1976]. Drainage and intensive agricultural use of these soils result in oxidation of peat material, thinning the organic horizon and decrease of water-table depth. In order to restore degraded peatlands and reduce their negative environmental effects, various of remedial measures and actions are being undertaken. Proposed restoration measures relate mostly to the elevation of groundwater level in dewatered peat soils. However, increased depth to the water-table promotes mobilisation of P-PO₄ and its leaching

into the groundwater [LITAOR *et al.* 2003; MARTIN *et al.* 1997; MEISSNER *et al.* 2003; RENGER *et al.* 2002; ROBINSON *et al.* 1998]. Therefore, rewetting and restoration of Histosols may result in significant phosphorus losses to adjoining aquatic ecosystems, and as a consequence, accelerated eutrophication and deterioration of water quality [LUCASSEN *et al.* 2005; RUPP *et al.* 2004; VENTERINK *et al.* 2002; ZAK *et al.* 2004].

In order to strengthen the scientific foundation in the field of sustainable management of peat soils, the PROWATER project – Program for the prevention of diffuse pollution from degraded and rewetted peat soils [MEISSNER, LEINWEBER 2004] was initiated. As a part of it, Institute of Technology and Life Sciences – National Research Institute (ITP-PIB) in Falenty undertook wide-ranging studies on water pollution by phos-

phorus (P) and nitrogen (N) in the area of agricultural peat soils. The studies were situated on drained peatland of Kuwasy, which is a part of vast wetlands area in the central Biebrza River basin (northeast Poland). As a result of artificially draining for agricultural purposes about 6,000 ha of peatlands in the 1930s and 1960s, peat-moorsh soils were formed [JASZCZYŃSKI 2015]. Such soils, apart from containing large amount of organic P and N, are also characterized by their laminar structure resulting in variable sorption properties of peat deposits of different origin and strength of P binding [SAPEK 2012]. Considering different factors including soil moisture conditions or precipitation, organic P accumulated in soil could be released to different extent and transformed into forms which undergo leaching [SAPEK 2010; 2014]. Similarly, the moisture conditions of peat soils affect the organic N transformation and can lead to increasing the concentration of dissolved organic nitrogen (DON) and ammonium nitrogen (N-NH₄) in soil water [LAINE *et al.* 2013]. Previous research on N and P behaviour in peat-muck soils, especially in terms of migration to waters, is rather scarce and does not exhaust cognitive scope of this subject.

The aim of the study was to assess the P-PO₄ and N-NH₄ pollution of water in grasslands located on peat soils and to identify the impact of groundwater level depth on this pollution formation.

MATERIALS AND METHODS

The research was conducted between 2000 and 2010 on Kuwasy peat bog (53°39' N, 22°34'–22°37' E) located in the Biebrza River basin on grounds of Experimental Station of ITP-PIB in the Biebrza village (northeast Poland). The study site was situated on organic soils formed from sedge (*Cariceti*) and alder peat (*Alneti*) with 80–200 cm depth of peat layer. Mineralization process involves soil layers to about 25 cm of depth. The investigations started within the PROWATER project from May 2000 to December 2003 and continued to September 2010 as an Institute's statutory activity. The study area was ditch and channel drained in the 1930s and 1960s and currently is used as an agricultural area (grassland) with groundwater irrigation system, whereby the groundwater level is maintained at 40–60 cm during the vegetation season.

Six separate control and measurement stations were established within study area with a total of 18 monitoring points for ground and surface water (Tab. 1, Fig. 1), which were distant from each other from 0.6 to 5.9 km in a straight line. Distance of these points from surface water sampling points ranged from 60 to 200 m. The groundwater monitoring points were two types of wells with bottom made of PVC pipes (∅ 50 mm). The first type – “S” wells were used to take water samples from organic layer of soil and the second type of wells, with symbol “P”, were used to take water samples from mineral-organic soil layer. These wells were perforated along the entire section located in organic soil layer and along the 15–20 cm long section located in mineral soil layer (approx. 20 cm below the organic formation), respectively [JASZCZYŃSKI 2010]. The surface water monitoring points “C” were located in drainage ditches and channels near groundwater monitoring points. Water samples for laboratory analyses were collected once a month, except for the winter period. In some years, there were cases of collecting

unusual number of samples per year (from 5 to 16), mainly due to commencement and completion dates of research work and additional analytical needs. “S” and “P” wells were purged by a bailer and a pump to remove accumulated stagnant well water before sample collection. At the same time the groundwater level was measured. In collected water samples the concentration of N-NH₄ and P-PO₄ was determined in the laboratory using automated colorimetric Skalar analyser.

Table 1. Location of monitoring points (MP)

Test stand code	Form of land use	Soil type	Depth of peat layer (cm)	Monitoring point code	Location of MP ¹⁾
K2	mown meadow	MtII developed from alder peat	0–210	K2S	53°39'40.7" N 22°37'14.0" E
				K2P	
				K2C	53°39'44.2" N 22°37'14.6" E
K4	hay meadow	MtII developed from alder peat	0–210	K4S	53°39'17.8" N 22°34'25.3" E
				K4P	
				K4C	53°39'22.7" N 22°34'32.6" E
K5	permanent pasture	MtII developed from sedge peat	0–78	K5S	53°38'33.1" N 22°34'22.9" E
				K5P	
				K5C	53°38'33.4" N 22°34'17.2" E
K7	permanent pasture	MtII developed from sedge peat	0–145	K7S	53°38'1.2" N 22°35'4.8" E
				K7P	
				K7C	53°38'4.3" N 22°35'9.57" E
K8	temporary meadow	MtII developed from sedge peat	0–150	K8S	53°37'46.8" N 22°35'31.9" E
				K8P	
				K8C	53°37'48.4" N 22°35'21.8" E
K9	alternate mown-grazed grassland	MtIII developed from sedge peat	0–135	K9S	53°36'54.3" N 22°34'38.7" E
				K9P	
				K9C	53°36'53.6" N 22°34'41.8" E

¹⁾ After: JASZCZYŃSKI [2010].

Explanations: MtII = second mucking degree of peat-muck soil; MtIII = third mucking degree of peat-muck soil.

Source: own elaboration.

Soil samples were taken from the 5–30 cm layer and then submitted to the laboratory for analysis. Soil pH was measured potentiometrically in 1 M KCl solution. Determination of soil organic matter (SOM) content was made using “loss-on-ignition” method (soil samples burning at 550°C), while total P, calcium (Ca), iron (Fe) content was measured after mineralization of soil samples in a mixture of HNO₃ and HClO₄ according to the method of chemical analyses of organic soils [SAPEK, SAPEK 1997]. N content in soils was determined by the modified Kjeldahl method.

In addition, as a part of research work, meteorological data was also collected. Precipitation sum and air temperature data

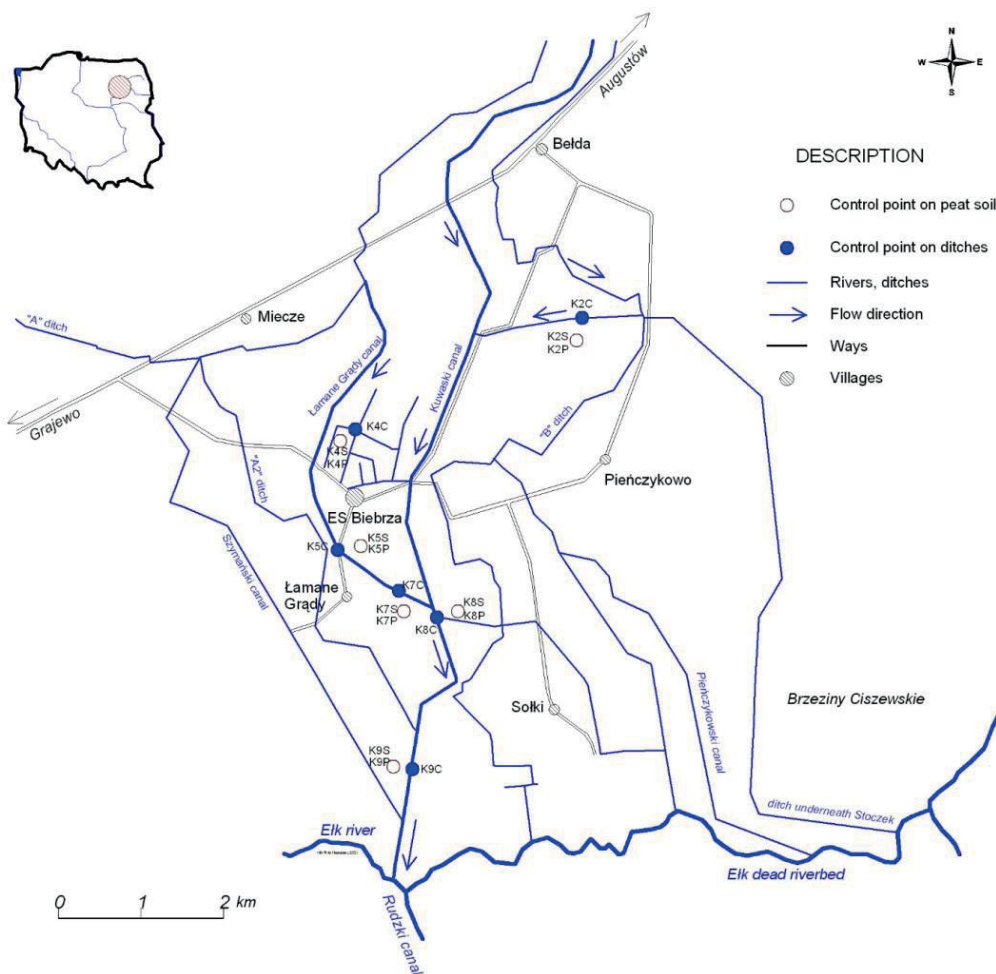


Fig. 1. Study site on bog Kuwasy; source: own elaboration

was measured by Biebrza meteorological station (53°39' N, 20°34' E) located near the research area.

For a better understanding of processes taking place in the analysed soil-water systems, the results obtained of ground- and surface water quality were analysed statistically using the Statistica 6 Program. In this regard: a) descriptive statistical analysis of water test results were performed, calculating arithmetic means, medians, standard deviations and minimum and maximum values, b) on the basis of Pearson's and Spearman's correlation coefficients relationships between various analysed factors were assessed, c) statistically significant difference between P-PO₄ and N-NH₄ mean concentration in water and selected intervals of water levels in organic soil layer was determined using the Kruskal–Wallis test ($p < 0.05$ values were considered as statistically significant).

RESULTS AND DISCUSSION

In the study area peat soils were relatively poor in ash, but richer in P and Ca. There was no significant difference between subsequent monitoring points of soil (Tab. 2). Annual precipitation and mean annual air temperature between 2000 and 2010 ranged between 477 and 793 mm per year and 6.5–8.3°C, respectively (Fig. 2). The highest average rainfall and air temperature for this period occurred in July and August (Fig. 3).

Table 2. Chemical composition of soil samples from 5–30 cm soil layer

Test stand code	pH	Ignition losses (%)	P	N	Ca	Fe
			g·kg ⁻¹			
K2	5.2	85	1.32	3.54	6.7	2.0
K4	5.5	78	2.65	3.11	21.0	22.7
K5	4.6	76	1.70	3.24	13.6	83.2
K7	5.1	81	1.87	3.42	14.6	45.8
K8	5.2	82	1.61	3.37	17.5	44.4
K9	4.7	85	1.21	3.45	16.3	30.2
Mean	5.1	81	1.55	3.34	14.7	30.6

Source: own study.

During the entire period between 2000 and 2010 monthly average of groundwater level in organic soil and mineral-organic soil layer ranged from 37.4 to 57.5 cm and from 33.8 to 58.1 cm, respectively (Fig. 4). These measured water-table levels were closely correlated (Pearson's $r = 0.834$; $a = 0.05$; $n = 508$). The average P-PO₄ concentration in water oscillated between 0.76 and 2.01 mg P-PO₄·dm⁻³ in case of water collected from organic soil

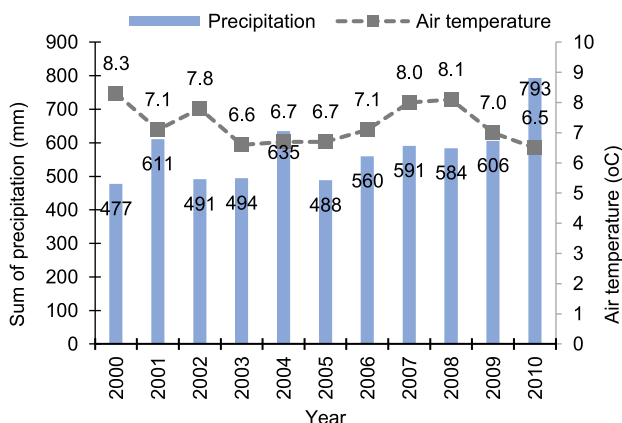


Fig. 2. Annual sums of precipitation and mean annual air temperature for the Biebrza meteorological station; source: own study

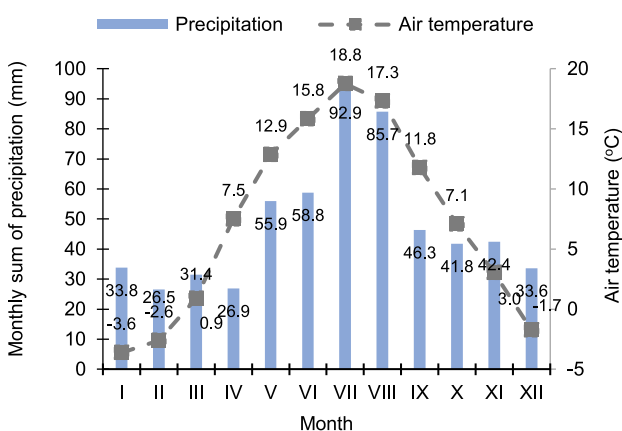


Fig. 3. Average monthly sums of precipitation and air temperature for the Biebrza meteorological station in years 2000–2010; source: own study

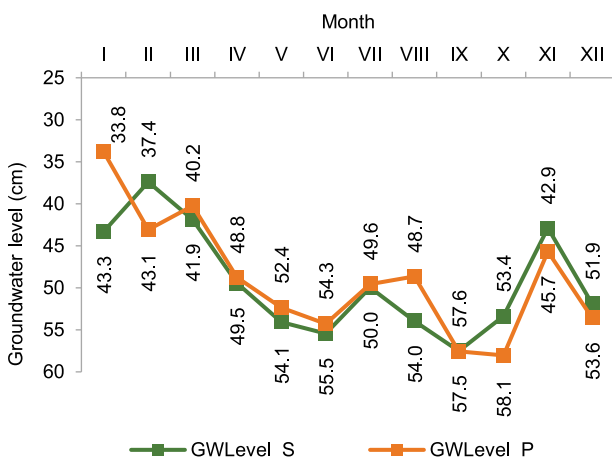


Fig. 4. Average monthly levels of groundwater in „S” and „P” wells; source: own study

layer and between 0.37–4.37 mg P-PO₄·dm⁻³ in case of water from mineral-organic soil layer (Tab. 3) while average N-NH₄ concentration in water from these layers reached values from 4.28 to 12.17 mg N-NH₄·dm⁻³ and from 1.69 to 21.68 mg N-NH₄·dm⁻³, respectively. Large amounts of rainfall in July and August did not have a relatively strong influence on the rise of water-table level because air temperatures in those months were the highest and therefore intense evapotranspiration took place.

The concentrations of N-NH₄ and P-PO₄ were often unusually high as compared with the literature data. Mean concentration of P-PO₄ was 1.23 mg P-PO₄·dm⁻³ in 669 samples of groundwater from organic soil layer and 1.83 mg P-PO₄·dm⁻³ in 508 samples from mineral-organic soil layer (Tab. 3).

Table 3. Ammonium nitrogen (N-NH₄) and phosphate-phosphorus (P-PO₄) concentrations in groundwater and surface water

Descriptive statistics	Groundwater from organic soil layer		Groundwater from mineral-organic soil layer		Surface water	
	P-PO ₄	N-NH ₄	P-PO ₄	N-NH ₄	P-PO ₄	N-NH ₄
	mg·dm ⁻³					
n	669		508		671	
Mean	1.23	7.98	1.83	9.69	0.13	0.47
Median	0.26	0.97	0.17	0.74	0.06	0.23
Standard deviation	2.26	20.89	4.62	28.01	0.26	1.28
Max.	21.50	159.90	40.04	220.21	2.78	25.35
Min.	0.00	0.01	0.00	0.01	0.00	0.01

Explanations: n = total of data. Source: own study.

Mean content of N-NH₄ in groundwater samples from organic and mineral-organic soil layer were 7.98 and 9.69 mg N-NH₄·dm⁻³, respectively. These concentrations were about 17 and 21 times higher than N-NH₄ concentration in surface water from drained ditches and channels. Concentrations of both compounds varied greatly. Furthermore variability coefficient usually exceeded 180% for both kinds of groundwater samples from each control point. Maximum values of P-PO₄ concentration reached 21.50 and 40.04 mg P-PO₄·dm⁻³ in groundwater samples from organic and mineral-organic soil layer, respectively and 2.78 mg P-PO₄·dm⁻³ in surface water samples. Maximum values of N-NH₄ concentrations were over 5.5 times higher – they reached 159.90, 220.21 and 25.35 mg N-NH₄·dm⁻³, respectively. Therefore, during the entire study period high levels of P-PO₄ and N-NH₄ concentration were maintained in tested groundwater considering groundwater quality standards (Tab. 4).

Table 4. Ground water quality classification with limit values for ammonium nitrogen (N-NH₄) and phosphate-phosphorus (P-PO₄)

Ground-water quality index	Unit	Limit values in I–V classes				
		I	II	III	IV	V
N-NH ₄	mg NH ₄ ·dm ⁻³	0.5	1.0	1.5	3.0	>3.0
	mg N-NH ₄ ·dm ⁻³	0.389	0.777	1.166	2.331	>2.331
P-PO ₄	mg PO ₄ ·dm ⁻³	0.5 ¹⁾	0.5 ¹⁾	1.0	5.0	>5.0
	mg P-PO ₄ ·dm ⁻³	0.163	0.163	0.326	1.630	>1.630

¹⁾ There is no sufficient ground for differentiating the limit values in some quality classes; for assessment the class of the highest quality is assumed within the classes having the same limit value. Source: Rozporządzenie ... [2019].

In 21.8% and 23.6% groundwater samples from organic and mineral-organic soil layer, respectively, P-PO₄ concentration exceeded the limit value of 1.630 mg P-PO₄·dm⁻³ for fifth class of groundwater quality, including poor quality waters (Fig. 5). One-third of groundwater samples belonged to the same fifth class of groundwater quality due to N-NH₄ concentration limit reached as well.

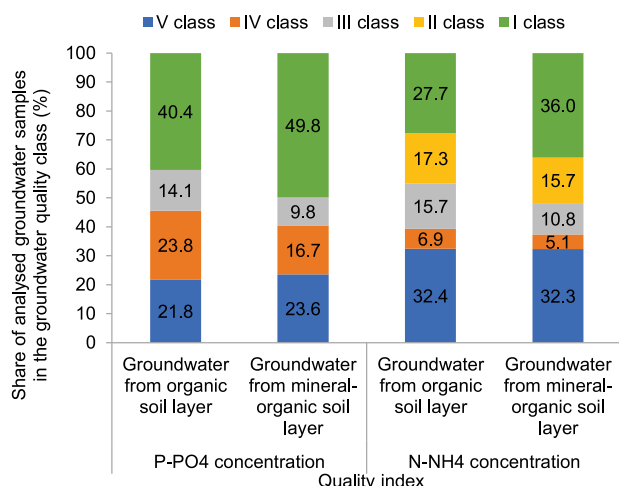


Fig. 5. Percentage distribution of groundwater quality in terms of phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄) concentrations; source: own study

Furthermore, surface water pollution by ammonia and phosphate was similar. In more than 30% and 27% of water samples, the concentration of P-PO₄ and N-NH₄, respectively, exceeded limit values specified for first and second surface water quality class (Tab. 5). For all of three types of analysed waters there was a clear relationship between these nutrients ions. P-PO₄ and N-NH₄ data was not normally distributed due to random extreme values, so Spearman's rank correlation coefficients were calculated (Tab. 6). The strong correlation with a statistical significance between P-PO₄ and N-NH₄ concentration in groundwater can be explained by their common origin related to the mineralization process of peat soil organic matter which depends mainly on changes of soil water regime.

Table 5. Percentage distribution of surface water quality with limit values for phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄); surface water quality classification for stream or water jet in a valley with large share of peatlands

Quality index	Surface water quality class	Limit values (mg · dm ⁻³)	Amount/percentage of samples	
			n	%
N-NH ₄	I	≤0.07	385	57.4
	II	(0.07–0.09>	83	12.4
	non-classified waters ¹⁾	>0.09	203	30.3
P-PO ₄	I	≤0.14	229	34.1
	II	(0.14–0.42>	258	38.5
	non-classified waters ¹⁾	>0.42	184	27.4

¹⁾ No limit values.

Source: own study based on Rozporządzenie ... [2021].

Table 6. Coefficients of Spearman's rank correlation (significant at α = 0.05) between phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄) content in: groundwater from organic soil layer „S”, groundwater from mineral-organic soil layer „P” and surface water „C” between 2000 and 2010

Variable	S: N-NH ₄	P: N-NH ₄	C: N-NH ₄
S: P-PO ₄	0.774		
P: P-PO ₄		0.778	
C: P-PO ₄			0.464

Source: own study.

Mean concentrations of P-PO₄ and N-NH₄ at individual water monitoring points varied depending on nutrient ion and water type (Tab. 7). The Kruskal–Wallis test confirmed that differences between them were statistically significant (Tab. 8), which may indicate that water pollution was influenced by local factors. The flow and water storage in soil profile, and thus the flow and storage of nutrients, depends largely on the physical properties of peat soil [REZANEZHAD *et al.* 2016]. Obtained results have been associated with this phenomenon. Moreover, state of the groundwater contamination may have been influenced by the distance of its monitoring points from the surface water. It results indirectly from the research of KOERSELMAN *et al.* [1993], who found that river water is a factor stimulating the release of P from peat. Furthermore, mean P-PO₄ and N-NH₄ concentrations in groundwater samples collected from organic soil layer decreased with the depth of this layer (Fig. 6). However, this relationship was statistically significant only in case of P-PO₄ concentration (Spearman's rho = -0.8117; p-value < 0.05). The existence of this correlation can be explained to a certain extent by a laminar structure of peat soils in research area which results in varying sorption properties. Due to the different sorption capacity and strength of P binding in organic formation, the mitigation of inorganic and organic P into the soil profile and the possibility of its release into groundwater had differed [SAPEK 2012]. Moreover, at varied organic levels of soil formations at individual monitoring points there were different storage and water flow conditions which shaped especially the state of decomposition and reduction in the volume (compaction or consolidation process) of deeper parts of soil organic matter [MORRIS *et al.* 2015; REZANEZHAD *et al.* 2016; WORONKO 2008].

The groundwater level in organic soil layer was the factor differentiating the mean P-PO₄ and N-NH₄ concentration in all of three types of water. In most of them, an increasing nutrients concentration trend with a successive decreasing the groundwater level in organic soil layer by 10 cm was found (Fig. 7). In relation to N-NH₄ concentration in groundwater in peat-muck soils, this pattern was also noticed by SZYM CZYK *et al.* [2010]. Based on Kruskal–Wallis test analysis it was shown that there are statistically significant differences in mean P-PO₄ concentrations in groundwater from mineral-organic soil layer and mean N-NH₄ concentrations in all types of studied water in intervals of 10 cm of groundwater level in the organic soil layer (Tab. 9). Therefore, changes in groundwater level in organic soil layer cause changes

Table 7. Descriptive statistics of phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄) concentrations in groundwater and surface water for individual test stands

Type of water	Descriptive statistics	Unit	Test stand code					
			K2	K4	K5	K7	K8	K9
P-PO₄								
Groundwater from organic soil layer	<i>n</i>		120	119	110	110	109	101
	mean	mg P-PO ₄ ·dm ⁻³	0.97	0.76	1.60	2.01	1.01	1.08
	median		0.40	0.14	0.31	0.82	0.11	0.19
	SD		1.81	1.62	2.72	2.48	2.59	1.94
	max.		15.40	12.70	21.50	10.28	20.07	8.67
	min.		0.01	0.00	0.01	0.03	0.01	0.01
Groundwater from mineral-organic soil layer	<i>n</i>		115	85	77	78	78	75
	mean	mg P-PO ₄ ·dm ⁻³	1.26	0.37	0.49	4.37	1.13	3.81
	median		0.17	0.12	0.10	1.84	0.07	0.57
	SD		2.13	0.86	1.08	6.97	2.29	8.08
	max.		9.48	6.02	7.08	35.00	12.75	40.04
	min.		0.01	0.00	0.00	0.01	0.01	0.01
Surface water	<i>n</i>		116	112	124	122	84	113
	mean	mg P-PO ₄ ·dm ⁻³	0.11	0.13	0.08	0.08	0.28	0.13
	median		0.06	0.07	0.05	0.06	0.08	0.05
	SD		0.28	0.22	0.13	0.10	0.45	0.27
	max.		2.78	1.86	1.30	0.94	2.50	2.15
	min.		0.00	0.00	0.00	0.00	0.00	0.01
N-NH₄								
Groundwater from organic soil layer	<i>n</i>		120	119	110	110	109	101
	mean	mg N-NH ₄ ·dm ⁻³	4.28	4.29	11.72	12.17	9.18	6.77
	median		1.26	0.64	1.11	2.55	0.55	0.73
	SD		12.38	12.94	27.69	23.63	26.39	16.34
	max.		85.44	84.43	159.90	140.80	156.20	99.98
	min.		0.04	0.05	0.04	0.05	0.04	0.01
Groundwater from mineral-organic soil layer	<i>n</i>		115	85	77	78	78	75
	mean	mg N-NH ₄ ·dm ⁻³	5.77	1.69	2.10	21.68	10.74	19.01
	median		0.95	0.42	0.46	4.04	0.39	1.06
	SD		21.66	4.22	5.62	33.17	32.47	44.26
	max.		188.40	30.76	38.95	126.00	216.50	220.21
	min.		0.04	0.01	0.01	0.01	0.02	0.01
Surface water	<i>n</i>		116	112	124	122	84	113
	mean	mg N-NH ₄ ·dm ⁻³	0.45	0.43	0.31	0.32	0.84	0.60
	median		0.19	0.25	0.20	0.19	0.30	0.30
	SD		1.41	0.51	0.34	0.34	2.85	1.04
	max.		14.65	3.71	2.01	1.97	25.35	5.78
	min.		0.01	0.03	0.01	0.01	0.01	0.02

Explanations: SD = standard deviation, *n* = total of data.
Source: own study.

Table 8. Kruskal–Wallis analysis for phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄) indicators related to water sampling place

Indicator		Independent (grouping) variable: mean P-PO ₄ and N-NH ₄ concentration in water samples at each monitoring points (mg×dm ⁻³)						H	p-value
		K2	K4	K5	K7	K8	K9		
P-PO ₄ _S	n	115	113	104	103	104	93	52.48	0.0000
	R	39,787	29,025	35,390	41,692	27,120	27,016		
P-PO ₄ _P	n	110	82	71	71	75	68	49.72	0.0000
	R	26,733	16,124	14,466	21,960	14,654	20,067		
P-PO ₄ _C	n	108	102	103	101	75	90	19.41	0.0016
	R	28,007	32,272	28,049	29,007	26,448	24,128		
N-NH ₄ _S	n	115	113	104	103	104	93	33.55	0.0000
	R	38,775	29,719	34,423	40,169	29,088	27,857		
N-NH ₄ _P	n	110	82	71	71	75	68	44.40	0.0000
	R	26,824	15,768	14,449	21,882	15,554	19,527		
N-NH ₄ _C	n	108	102	103	101	75	90	18.66	0.0022
	R	27,943	31,068	27,345	26,937	24,716	29,902		

Explanations: *n* = total of data, *R* = rank sum, *H* = Kruskal–Wallis test value, *p*-value – significance level; P-PO₄_S/N-NH₄_S = concentration of nutrient ions in groundwater from organic soil layer; P-PO₄_P/N-NH₄_P = concentration of nutrient ions in groundwater from mineral-organic soil layer; P-PO₄_C/N-NH₄_C = concentration of nutrient ions in surface water; in bold – statistically significant.
Source: own study.

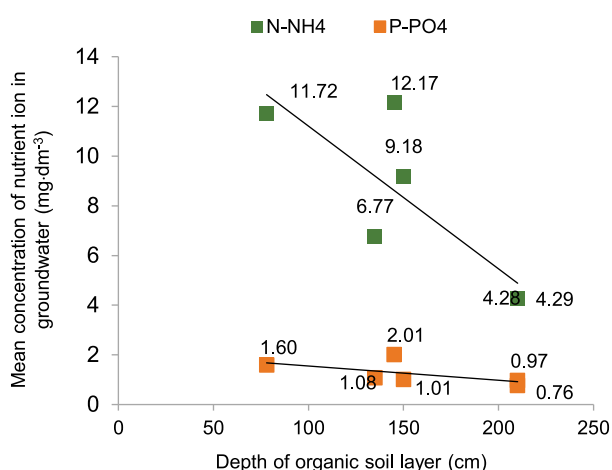


Fig. 6. The relationship between the depth of organic soil layer and the phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄) concentration in groundwater from this layer at individual test stands; source: own study

in the concentration of one or two analysed ions in each type of water. It can be concluded that there were vertical and horizontal flow processes, and more precisely – groundwater-groundwater and groundwater-surface water connectivity. Presence of these

interactions facilitated migration and exchange of P-PO₄ and N-NH₄ between different types of water. Levels of nutrient ions concentrations in groundwater in organic soil layer, as well as the dynamics of their changes, were related to a set of various environmental and economic factors (such as: rainfall, local soil specificity, irrigation, doses of P and N fertilizers, organic fertilizers application) and soil P and N cycle. Undoubtedly, cycle of P and N in peat soil from research area largely shaped the process of SOM mineralization which leads to the release of N and P mineral forms and affects the ground and surface water quality. And furthermore, the groundwater level has a significant impact on the rate of nutrient release in peat soils too [KOERSELMAN *et al.* 1993]. With the lowering of the groundwater table, the rate of peat soil mineralization accelerates [METTROP *et al.* 2014; TUUKKANEN *et al.* 2017] and the concentration of soluble P and N forms in it increases [SAPEK 2010]. With this in view, it should be stressed that the groundwater level in peat soils and the amount of mineralized N and P can be influenced by controlling the water level in drainage ditches. Skillful use of such type of control is important, among others, in terms of reducing surface water pollution by nutrients. Within this scope, VAN BEEK *et al.*'s [2007] studies conducted in the Netherlands have shown, that increasing groundwater level by 20 cm in drainage crossing grassland led to 30% decrease in N load introduced into it.

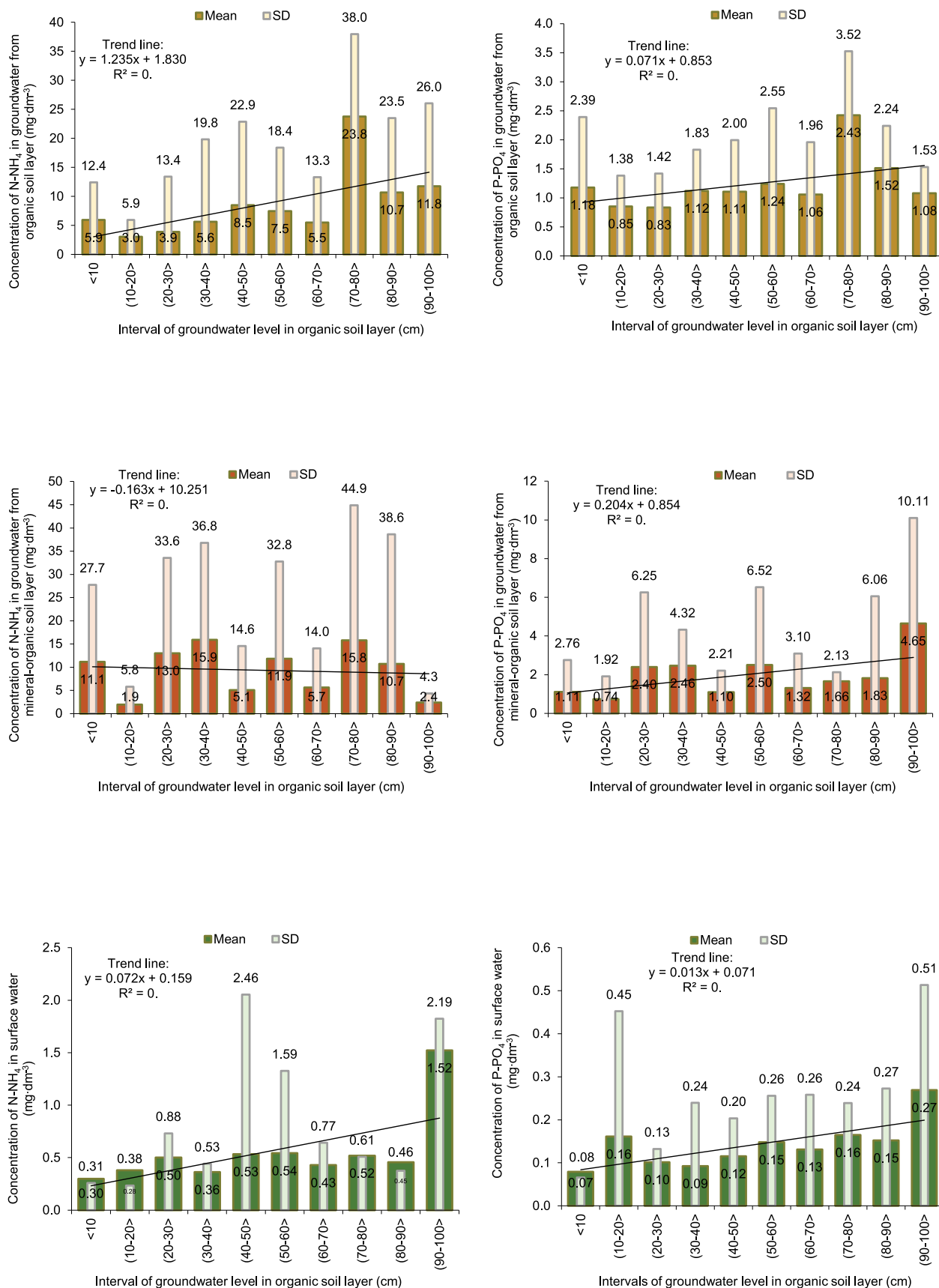


Fig. 7. Mean concentration of ammonium nitrogen (N-NH₄) and phosphate-phosphorus (P-PO₄) in each type of studied water in separated 10 cm intervals of groundwater level in organic soil layer; source: own study

Table 9. Kruskal–Wallis test analysis for phosphate-phosphorus (P-PO₄) and ammonium nitrogen (N-NH₄) P-PO₄ and N-NH₄ indicators related to groups distinguished by the groundwater level in organic soil layer

Indicator		Independent (grouping) variable: groundwater table in „S” well used for water sampling from organic soil layer (cm)										H	p-value
		<10	(10–20>	(20–30>	(30–40>	(40–50>	(50–60>	(60–70>	(70–80>	(80–90>	(90–100>		
P-PO ₄ _S	n	28	31	56	83	114	110	113	62	23	12	15.83	0.071
	R	8,754	9,884	16,209	26,052	34,359	35,612	34,900	24,552	6,499	3,211		
P-PO ₄ _P	n	20	24	47	69	88	91	83	35	15	5	20.54	0.015
	R	3,924	4,372	12,107	18,960	18,820	22,463	19,947	9,698	2,687	1,027		
P-PO ₄ _C	n	27	30	52	79	106	102	100	55	22	6	8.60	0.476
	R	7,735	7,392	14,701	20,857	30,631	30,512	29,778	18,381	6,356	1,569		
N-NH ₄ _S	n	28	31	56	83	114	110	113	62	23	12	18.79	0.027
	R	8,351	9,978	16,736	25,703	33,726	35,141	34,651	25,290	6,669	3,787		
N-NH ₄ _P	n	20	24	47	69	88	91	83	35	15	5	19.75	0.020
	R	4,101	4,401	12,471	19,284	18,943	22,039	19,557	9,393	2,738	1,079		
N-NH ₄ _C	n	27	30	52	79	106	102	100	55	22	6	17.22	0.046
	R	7,394	9,797	15,738	22,067	28,106	27,743	28,388	18,258	7,821	2,601		

Explanations as in Tab. 8.
 Source: own study.

CONCLUSIONS

The results of eleven-year-long studies of P-PO₄ and N-NH₄ concentrations in groundwater from a meadow complex located on peat soils showed mostly high content of both nutrient ions. In the water from organic soil layer the highest concentrations of P-PO₄ and N-NH₄ reached the level of 22 and 160 mg·dm⁻³ while in water from mineral-organic soil layer they exceeded values of 22 and 160 mg·dm⁻³, respectively. In surface water the highest recorded nutrient ions concentrations were much lower – close to 2.8 mg P-PO₄·dm⁻³ and 25 mg N-NH₄·dm⁻³. Due to P-PO₄ and N-NH₄ concentrations, about 46 and 39% of water samples from organic soil layer and more than 40 and 37% of water samples from mineral-organic soil layer, respectively, were characterized by poor chemical status which includes IV–V groundwater quality classes. At the same time, due to the exceeding of the limit values of P-PO₄ and N-NH₄ concentrations, water samples from watercourses in over 30 and 27%, respectively, were not within 1st and 2nd class of surface water quality.

The concentrations of P-PO₄ and N-NH₄ were significantly positively correlated with each other which can be associated with the release of accumulated amounts of P and N into soil solution and groundwater as a result of decomposition of peat organic matter. In the spatial arrangement, a set of results of P-PO₄ and N-NH₄ concentration in ground- and surface water was characterized by a considerable diversity. This suggests that the contamination of water bodies with P-PO₄ and N-NH₄ was influenced by site-specific factors, especially the physical properties of peat. Moreover, the thickness of organic soil layer had

a significant influence on P-PO₄ formation and concentration in groundwater from this layer.

The groundwater level depths in organic soil layer considered in separated 10 cm intervals was a factor determining the changes of analysed ions in all selected water types. In this regard, it was found that the average groundwater level in organic soil layer had a statistically significant impact on the mean P-PO₄ concentration in groundwater associated with mineral-organic soil layer and on the mean N-NH₄ concentration in each type of water. It was also reported that the trend of P-PO₄ concentration values in all types of water was increasing with the groundwater table in organic soil layer decreasing every 10 cm. A course of changes in N-NH₄ concentration values was similar in relation to groundwater in organic soil layer and surface water.

In conclusion, obtained research results show that in the studied area of grasslands located on peat-muck soils:

- relatively high levels of P-PO₄ and N-NH₄ were permanently sustained in ground and surface water;
- P-PO₄ and N-NH₄ concentrations in groundwater were correlated with each other, which indicates that the peat mineralization process is common cause for their origin;
- concentrations of P-PO₄ and N-NH₄ in analysed waters were spatially diversified, which suggests that they were formed under locally different conditions;
- in general, the concentrations of P-PO₄ and N-NH₄ in ground and surface water increased along with a decreasing level of groundwater deposition.

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