

Effects of long-term drainage on vegetation, surface topography, hydrology and water chemistry of north-eastern part of Great Vasyugan Mire (Western Siberia)

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Abstract. In this study, we determine the influence of a long-term drainage on the vegetation, surface topography, hydrology, and water chemistry of the north-eastern drained part of the Great Vasyugan Mire. Many studies have shown an increase in the projective coverage of *V. Uliginosum*, *A. polifolia*, *P. schreberi*, *P. Strictum* and *D. polysetum*, *Cladonia stellaris* and *Cladonia rangiferina* and a decrease in the projective coverage of *C. calyculata*, and *L. palustre*, *S. angustifolium* *S. magellanicum*. In the peat core, in comparison with archival data (1985), an increase in the degree of peat decomposition by 5-10% in the top 10-100 cm layer is noted, which may be due to the partial degradation of the peat deposit as a result of dehumidification. The microrelief is characterized by a decrease in the proportion of heights at the middle surface from 44 to 37% and the presence of steep slopes between the positive and negative forms of the microrelief. A decrease in the water table levels of bog waters and an increase in the amplitude of the oscillation are noted. In the chemical composition of the drained bog, we note an increase in the concentrations of the main ions by 6-38%, as well as DOC by 13%, Pb by 9%, Cu by 46%, and Zn by 215%. In the river waters there is an increase in NO_3^- by 11%, NH_4^+ by 26%, SO_4^{2-} by 36%, Fe_{total} by 89%, and DOC by 17%; no increase in the concentrations of Pb, Cu, Zn is observed.

1. Introduction

Drainage and peat extraction fundamentally change the mires, their water regime, vegetation, and properties of the peat deposit. Depending on the initial state of the mire and the degree of anthropogenic load, modern accumulation of peat or degradation of peat deposits is noted. Many authors draw attention to a number of negative consequences associated with the danger of peat fires, changes in the biogeochemical cycles, pollution of water, and an increase in the emission of carbon dioxide [1-2].

As a result of the organization of drainage channels in the bog, the water table level of the mire is reduced and the amplitude of it is increased [3]. A decrease in the water level leads to the degradation of the peat deposit, loss of carbon [4], and an increase in the removal of micronutrients [5-6]. As a



result of drainage, a change in the species composition of the vegetation is noted, but it is possible to restore the natural vegetation cover to increase the water level and reduce the runoff through drainage channels [7].

In the 1970-80 in the territory of Tomsk region of Russia, drainage of mires was carried out, whose main purpose was to regulate the surface runoff and reduce the water level with the prospect of peat extraction, agricultural use, and forestry. Currently these mires are not used; the consequences of their drainage are not unambiguous and require a comprehensive study.

The aim of this study is to determine the long-term drainage effect on the vegetation, surface topography, hydrology, and water chemistry of the north-eastern part of the Great Vasyugan Mire (with the Gavrilovka River basin as an example).

2. Study Area

The West Siberian plain, which is an alluvial plain, is located within the vast inland lowland formed after the retreat of the sea and as a result of widespread and prolonged wandering of large rivers [8]. The study area is located within the first-order morphostructure of the Vasyugan inclined plain with absolute heights from 40 to 250 m above sea level (Figure 1). In the second half of the Quaternary period the Vasyugan plain underwent waterlogging, haying, and partial erosion dismemberment. The surface of the plain is composed of troughs of ancient bed, a hilly relief, and all kinds of depressions almost completely buried under peat. The quaternary deposits are represented by carbonate loams and clays, which cover almost all river interfluvies. The thickness of the quaternary deposits on the interfluvium of the Bakchar River and the Iksa River reaches 40-60 m [9].

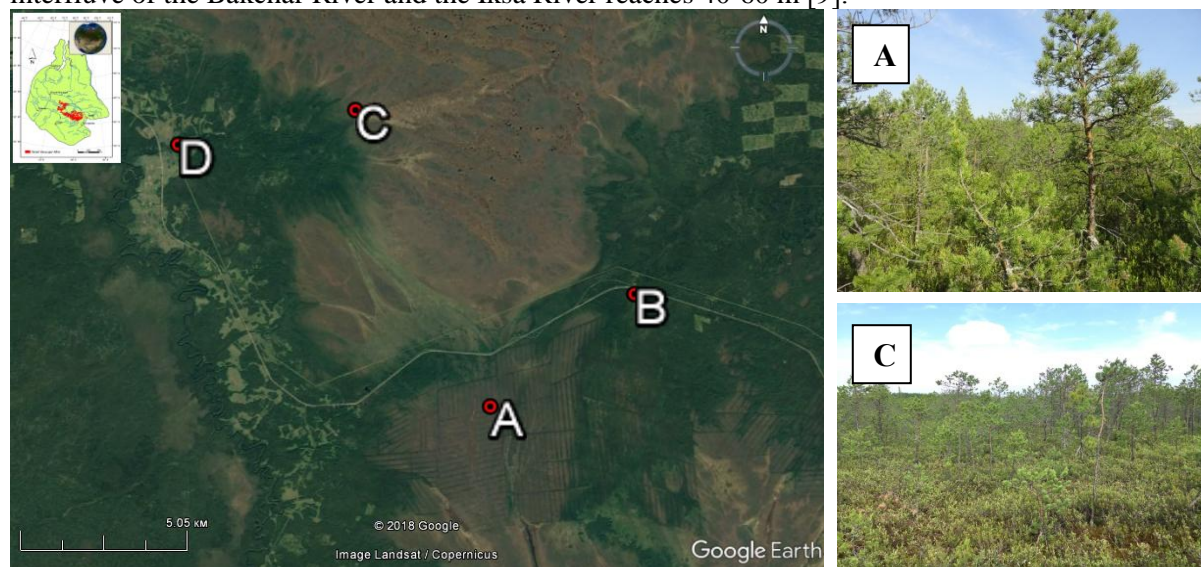


Figure 1. Investigation area

(A- drained bog, B – Gavrilovka River, C – pristine bog, D – Klyuch River).

The climate of the territory is characterized as continental with a short warm summer and a long harsh and snowy winter. The average annual temperature of the territory is $+0.4^{\circ}\text{C}$. The lowest temperature is observed in January and reaches -48.3°C , and the highest temperature in July is $+35.0^{\circ}\text{C}$. The duration of the period with an average temperature above 0°C is seven months, and the period without frosts is two months. The average annual precipitation is 467 mm. The greatest amount of precipitation is observed in the summer months with a maximum value in July - 76 mm. Over the summer period the annual rainfall is 42%. The minimum amount of precipitation is observed in February (15 mm). The vegetation period lasts from May to early October with an average duration of 155 days. In some years, the duration of the growing season can vary from 138 to 173 days. The snow cover is set at the end of October and beginning of November, and the maximum value is in March (up

to 109 cm), the average thickness of the snow cover is 65.8 cm. There is a clear predominance of precipitation over evaporation [10]. The territory belongs to the southern taiga zone, and the total mire area is 56%.

The study was performed in the north-eastern drained part of the Great Vasyugan Mire within Bakchar district in Tomsk region of Russia, 200 km to the northwest from Tomsk (Figure 1). The territory represents the (drained for forestry) area of pine-shrub-sphagnum raised bog (N56°53'25,8" E82°40'50,9") in the basin of the Gavrilovka River, a left tributary of the Iksa River (the Middle Ob River watershed). Absolute surface heights range from 115 to 117 m with a general slope to the north and north-west. The mineral bottom of the bog is composed mainly of silty clays and heavy loam. The average thickness of the peat deposit is 1.7 m, and the moss peat type prevails. In 1980, the raised bog was drained for forestry. The distance between the drainage channels is 150-160 m, the planned width is 1-2 m, and the depth is up to 1 m. At present there is a decrease in the culvert capacity of the channels due to their overgrowing and hoarding. In 2016, a fire occurred in a territory of more than 7 km². To assess the effect of drainage on the vegetation, surface microrelief and hydrology, chemical composition, a comparison was made in a similar pristine part of the Great Vasyugan Mire- pine-shrub-sphagnum raised bog in the Klyuch River basin (N56°58'24.3"E82°36'41.2"). The Klyuch River is a right-bank tributary of the Bakchar River, whose detailed description is presented in [11].

3. Material and Methods

3.1. Field study

The field studies included a geobotanical description of the vegetation, peat sampling, determination of the peat deposit thickness, a study of the species composition and the degree of decomposition, and a survey of the profile of the vertical section of the horizon of the formation of the microrelief in a model section with a pitch of 50 cm using a tachymeter Sokkia CX-105 (Japan). Peat cores were collected manually using a Russian peat core with a 50 cm sample chamber. The sample cores were sliced at irregular interval (by peat class) down to the core base. The peat materials were classified using the scale of decomposition and the guidance for peat class determination by visual observation [12-14]. Visual examination of the peat was made by squeezing the undisturbed peat sample in hand. Visual observation of the peat decomposition was based on the determination of the plastic property, the plant remains content, and the quantity and color of the squeeze water.

3.2. Hydrometeorology measurements

The observations of the water level were carried out using an autonomous differential pressure sensor (CAM, IMCES SB RAS). The atmospheric precipitation was measured using a Davis Rain Collector II 7852M sensor, and the temperature of the peat deposit and air was measured by a DS18B20 sensor. The measurements were carried out at intervals of 4 hours in the year-round mode.

3.3. Water sampling

Samples of water taken from depths of 30-50 cm were transferred into a specially prepared glass and plastic bottles. Previously wells 1 m deep were drilled in the peat deposit. Before sampling pumping of water (about 5 liters) from the water wells was carried out to avoid dilution due to atmospheric precipitation. Ph and Eh (PH200, ORP200 HM Digital, South Korea), the water temperature and O₂ (WTW, Oxi 3205, Germany), and CO₂ were determined immediately after sampling. After the selection the samples were preserved. Preservation of the samples for the determination of NO₃⁻ and NH₄⁺ ions was carried out by the addition of CHCl₃. To determine the Fe_{total}, the samples were preserved with HCl to a pH of less than 2. To determine Pb, Cu, and Zn, the samples were HNO₃ assayed. Before the analysis the samples were stored at a temperature of +4 ... + 6 °C and filtered through a filter with a pore diameter of 1-2.5 µm. Chemical analysis of the samples was carried out in the accredited analytical laboratory of SibRIAP (Accreditation Certificate No. POCC RU.0001.10ΠΦ01).

3.4. Analytical methods

The concentrations of Ca^{2+} , Mg^{2+} , CO_2 , HCO_3^- , and Cl^- in the water were determined using the titrimetric method; F_{etotal} , NH_4^+ , NO_3^- , SO_4^{2-} , and DOC were determined using the spectrophotometry method (Specol-1300, Analytik Jena, Germany); and the chemical oxygen demand (COD), humic and fulvic acids were estimated with potassium dichromate. The determination of the concentrations of K^+ and Na^+ ions was carried out using the method of flame photometry (PFA-378, Russia); Pb, Cu, and Zn concentrations were determined using the method of inversion voltammetry (STA, Russia).

3.5. Statistical and data analysis

The statistical analysis of the data included the calculation of the average ordinate of the profile of the horizon of the formation of the microrelief, the determination of the mean square deviation and the skewness, and the distribution profile of the heights relative to the mean surface. The statistical analysis of the chemical composition was carried out using the principal component analysis (PCA).

The geoinformation landscape modeling included the construction of a peat bog model using the data on the thickness and types of peat presented in [15], the compilation of a landscape map using time-varying space images of Landsat 2012 and 2017. Based on the results of the field descriptions, a comparison was made with the available archival data for the site [15], as well as with data on a similar pristine part of the Great Vasyugan Mire – the pine-shrub-sphagnum raised bog in the Klyuch River basin [11].

4. Results and discussion

4.1. Vegetation

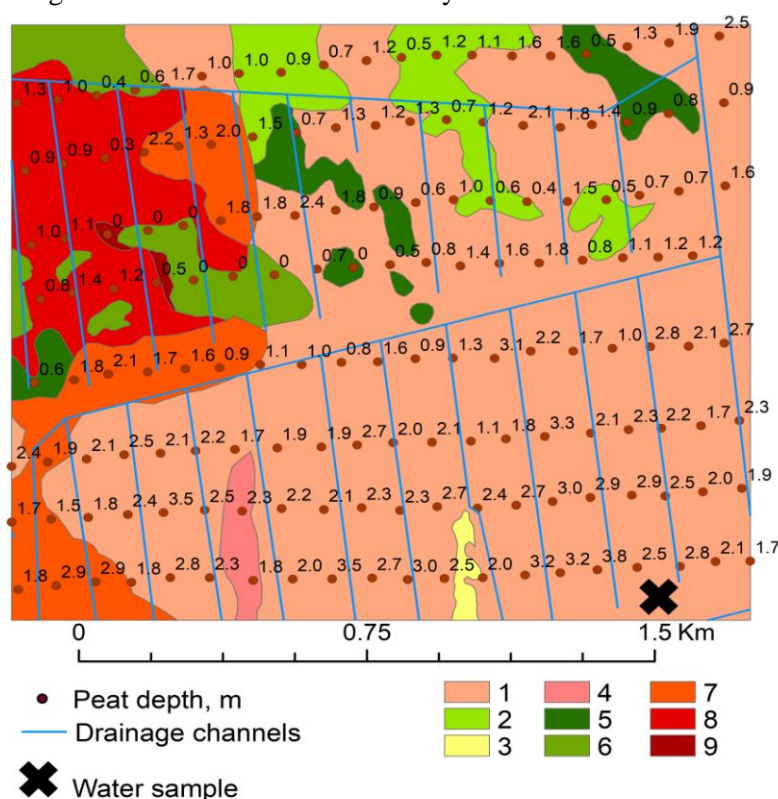
The field studies of the vegetation have shown that the tree layer is represented by *Pinus sylvestris* with a height of up to 4 m and a crown closure of 0.6, *Pinus sibirica* with a height of up to 3 m. The projective cover of the grass-shrub layer with a height of 30–40 cm is 70%. Dominant in this tier are *Chamaedaphne calyculata* (projective cover 20%) and *Vaccinium uliginosum* (30%). There are also shrubs such as *Ledum palustre* (10%), *Andromeda polifolia* (10%), and *Oxycoccus microcarpus* (less than 10%). The herbs are represented by *Eriophorum vaginatum*, *Rubus chamaemorus* (less than 10%), and *Drosera rotundifolia* (singly). The basis of the moss-lichen layer is *Sphagnum fuscum* (projective cover: 70%), with an admixture of *Sphagnum magellanicum* and *Sphagnum angustifolium*. In the depressions there are *Polytrichum strictum* (less than 10%), *Pleurozium schreberi* (10%), and *Dicranum polysetum* (10%). The lichens are represented by the genera *Usnea* and *Cladonia* (the projective cover is 10%). In comparison with the results of previous studies [11], the difference between the vegetation and undisturbed areas is a change in the projective cover of shrubs and the occurrence of moss species. The projective cover of *V. uliginosum* is increased 8 times and that of *A. polifolia*, 2 times. The projective cover of *C. calyculata* decreases (3.6 times) and of *L. palustre* (6 times). In the moss layer, the occurrence of *S. angustifolium* decreases (3.4 times) and of *S. magellanicum* (9 times). The occurrence of green mosses is increasing: *P. schreberi* (2 times), *P. Strictum* (5 times), and *D. polysetum* (18 times). The occurrence of the lichen *Cladonia stellaris* and *Cladonia rangiferina* grows 5 times.

4.2. Peat structure

According to the sounding and field description of the peat deposit, its thickness is 2.4 m and it belongs to the fibric type. The upper horizons up to a depth of 1.3 m are composed of sphagnum peat whose degree of decomposition increases with a depth of 10 to 20%. Next are layers of grass-moss and wood-grass-moss peat with a degree of decomposition of 30–35%. In comparison with the data presented in [15], it should be noted that the degree of decomposition of the peat is increased by 5–10% in the 10–100 cm layer, which is likely to be due to the partial degradation of the peat deposit as a result of the drying process (Figure 2).

4.3. Mire surface topography

The microrelief of the site is large-ham, formed by moss cushions and extensive leveled depressions (Figure 2). The heights amplitude and the average value of the microrelief vertical subdivision are 40.5 cm and 22.4 cm/m², respectively, which does not differ from the characteristics of pristine pine-shrub-sphagnum bogs. The mean-square deviation reflecting the degree of heterogeneity of the surface of the bog is somewhat higher than the value characteristic of pristine bogs (8.61 and 9.72, respectively). To a greater extent, the differences between the drained and pristine bogs in question are expressed in the regularities of the distribution of heights relative to the average surface of the bog, expressed in terms such as the skewness and the height fraction of the average surface in the interval from -5 to 5 cm. Previous studies have shown that pristine bogs are characterized by a normal law of distribution of heights relative to the mean surface with values of the asymmetry coefficient near zero and a fraction of the height of the average surface of about 50 % [16]. The deviation of the values within the considered drained area from pristine bogs reflects the degree of transformation of the bog surface as a result of lowering of the level of the bog waters. The positive value of the asymmetry coefficient, equal to 0.78, indicates the predominance of negative forms of the microrelief, which occupy 65% of the surface within the model area and have a depth of no more than 15 cm below the middle surface. The positive forms occupy smaller areas, and in comparison with depressions their height reaches 25-30 cm relative to the middle surface. The decrease in the proportion of heights at the average surface from 44 to 37% in comparison with pristine areas reflects the presence of steep slopes between the positive and negative forms of the microrelief (Figure 2). The noted features of the surface microrelief can be explained by an increase in the productivity of the vegetation on the elevations and some lowering of the surface as a result of the peat subsidence in depressions during the period after drainage. A comparison of the obtained data with the results of previous studies [11] showed the average degree of transformation of the study area surface.



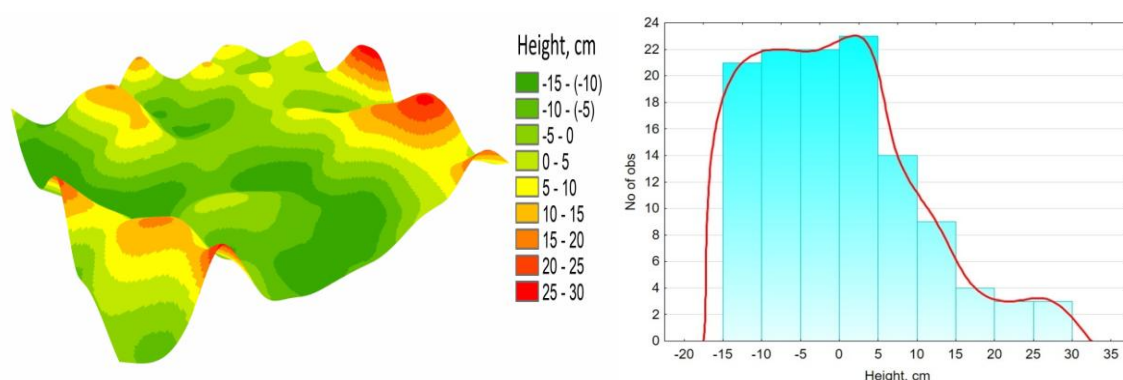


Figure 2. Peat depth and mire surface topography

(1 – pine-shrub-sphagnum raised bog; 2 - pine-shrub grass-sphagnum raised bog with high pine; 3 - grass-sphagnum raised bog; 4 –hummock-hollow raised bog; 5 - pine swampy forest; 6 - aspen-birch forest; 7 - crown fire area of pine-shrub-sphagnum raised bog; 8 - crown fire area of pine-shrub-grass-sphagnum raised bog; 9 - crown fire area of aspen-birch forest.

4.4. Hydrology

In comparison with the pristine parts of the Great Vasyugan Mire (N56°58'24.3"E82° 36'41.2"), the lower water table levels were noted (by 5-12 cm), but the differences are not statistically reliable. According to the data for April-September of 2016, the water table level was noted at -24 cm below the surface, and the oscillation amplitude was 38 cm. The seasonal dynamics is characterized by the synchronism of fluctuations in the level of waves leading to the pristine part; however, in some periods this trend was disrupted, and a more intensive reaction of the water levels to the falling atmospheric precipitation is significant (up to 22 cm) (Figure 3).

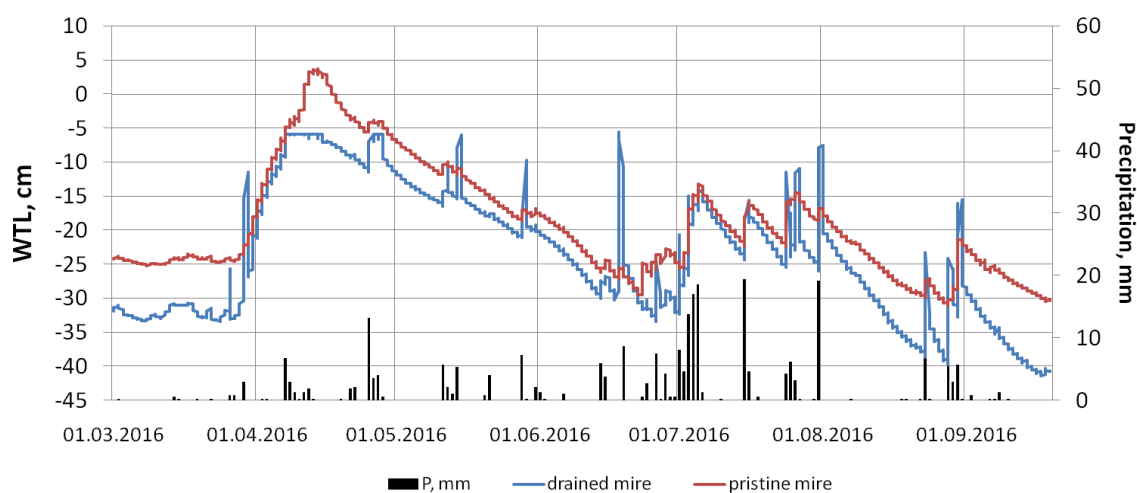


Figure 3. Seasonal dynamics of water level and precipitation.

4.5. Water chemistry

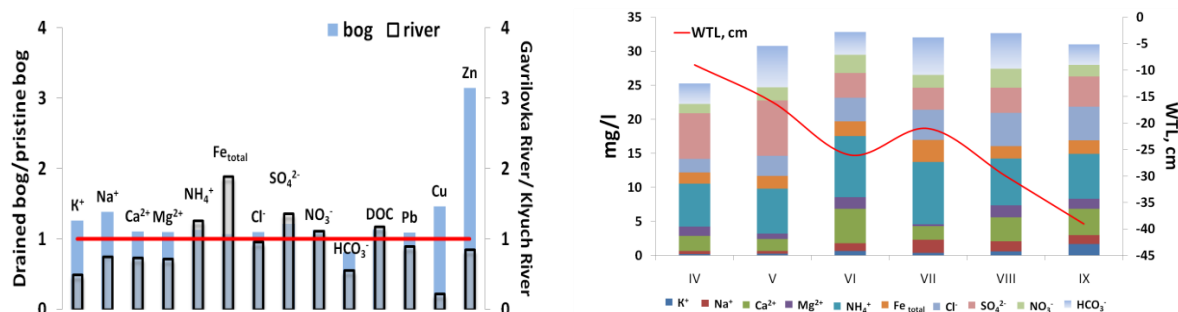
According to the chemical composition, the bog waters are characterized by the predominance of Ca^{2+} and HCO_3^- ions, which agrees with the previously obtained data [17]. According to the data for 2016, in comparison with the pristine site the concentration of the main ions is 6-38% higher (% (K^+ -26 %, Na^+ - 38 %, Ca^{2+} - 11 %, Mg^{2+} - 10 %, NH_4^+ - 13 %, Fe_{total} - 6 %, Cl^- - 10 %, SO_4^{2-} - 21 %, NO_3^- - 13 %), and that of DOC, by 13%. It should be noted that the concentration of HCO_3^- decreases in the waters

of the drained area relative to the pristine bog, which is associated with a low pH (3.8-5.3) under the conditions of high concentrations of organic substances (Figure 4, Table 1).

In the waters of the Gavrilovka River to the catchment area, which belongs to the investigated drained area of the Great Vasyugan Mire, in comparison with the pristine site there is an increase in the concentrations of NO_3^- by 11%, NH_4^+ by 26%, SO_4^{2-} by 36%, Fe_{total} by 89%, and DOC by 17%. In the waters of the drained bog, in comparison with pristine areas there are increased concentrations of Pb by 9%, Cu by 46%, and Zn by 215%. In general, the extreme concentrations of Zn in waters of the drained bog are explained by its aerosol transport from a burnt out site. However, in the waters of the Gavrilovka River, in comparison with the waters of the Klyuch River no increase in the concentrations of Pb, Cu, and Zn was observed, despite their higher concentrations in the waters of the drained bog.

In the seasonal dynamics, variation in the chemical composition of the bog waters is observed under the influence of the air temperature fluctuations and peat deposits, the amount of atmospheric precipitation, and the water level dynamics. In May, there is an increase in the concentrations of HCO_3^- ions, which is due to their entry into the bog with the snowmelt waters. In the same period, an increase in the SO_4^{2-} concentrations is observed; they enter the water during the decomposition of organic substances in the winter period and actively migrate during the periods of high levels. In June, the concentrations of Ca^{2+} ions increase, which is determined by a decrease in the water levels and an increase in the sums of the active air temperatures and, as a result, activation of the decomposition of plant residues. In July, the Na^+ concentrations increase due to their arrival with the atmospheric precipitation, an increase in the content of the NH_4^+ waters entering the water due to the decomposition of plant residues in the aerobic layer of the peat deposit with a decrease in the level, as well as the Fe_{total} accumulated as a result of the change in the value of Eh. In August-September, the concentrations of K^+ , Mg^{2+} basic plant nutrients and NO_3^- which is the final product of mineralization of the plant residues observed in the waters, and the DOC itself indicate a significant role of the processes of decomposition of plant residues in the composition of the bog waters; an increase in the Cl^- concentration is associated with the arrival of an ion with the atmospheric precipitation, as well as with its active migration in the conditions of increasing levels in the event of precipitation.

The studies have shown that drainage contributes to a change in the thermal regime of the peat deposit, an increase in the range of temperature fluctuations, and a decrease in the heat capacity due to a reduction in the water levels of the bog. Data on the water temperature in the drained area for 2016 showed that in the first half of the vegetation period (April-July) the water temperature on the sampling dates varied from 2 °C to 16 °C, which is 0.90-7.2 °C higher than in the pristine part of the Great Vasyugan mire. In August-September, the water temperature of the drained area decreased to 12.7 °C in August and 7.1 °C in September, respectively, which is 0.7 °C and 2.0 °C lower than in the pristine area. As a result, its more intense heating and, correspondingly, more intensive processes of decomposition of the plant residues is observed and, in the seasonal dynamics, an earlier increase in the concentration of the components entering the water during the decomposition process of organic substances (Ca^{2+} , Na^+ , NH_4^+ , FA). Thus, within the drained bog the concentrations of Ca^{2+} , Na^+ , NH_4^+ , and FA are the greatest in the season in June-July, whereas in the pristine bog the concentration maxima of these components are shifted in August-September, and the seasonal variations of the content of the remaining components have a similar tendency.



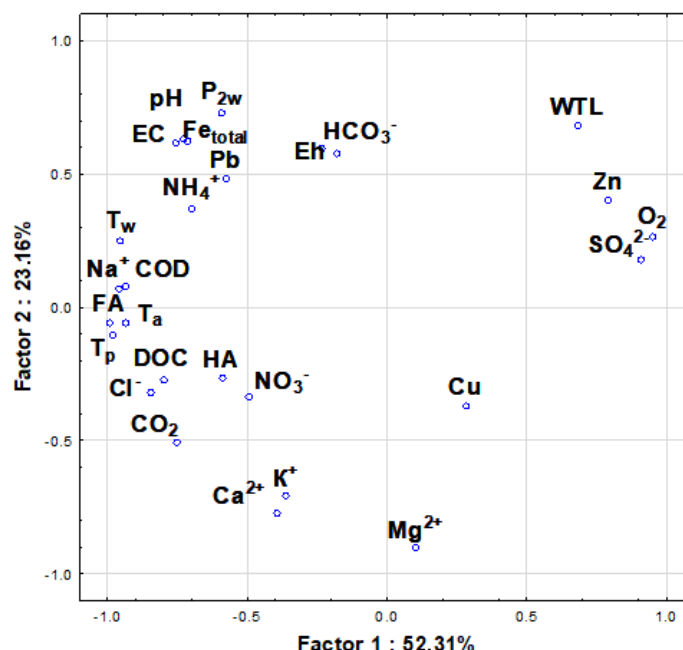


Figure 4. Comparison of the water chemical composition of drained and pristine bogs, seasonal dynamics and PCA (T_a - air temperature, T_p - peat temperature, T_w - water temperature, P_{2w} - 2 week sum of precipitation, WTL - water table level).

The PCA allowed us to distinguish three main factors, which by 89% describe the variability of the initial data (Figure 4). For the drained area, the first component determines 52% of the variability in the system: high factor loads have the peat deposit temperature (-0.98), the air temperature (-0.94), and the water temperature (-0.95) that are in direct correlation with pH, Na^+ , NH_4^+ , Fe_{total} , Cl^- , COD, FA, CO_2 , DOC, and EC and in feedback with the content of SO_4^{2-} , O_2 , Zn in the bog waters. The second component determines 23% of the total variance, and the high factor load has the total amount of precipitation in the previous 2 weeks (0.73) and the water table level (0.68) which are in inverse correlation with the content of Ca^{2+} , K^+ , and Mg^{2+} in the water. The second component determines the processes of diluting the waters and reducing the concentration due to the precipitation. The third component determines 14% of the total variability, and the high factor loads have Eh (-0.68), HCO_3^- , NO_3^- , Pb, Cu, and HA. The third component characterizes the processes of mineralization of organic substances, which is the result of an increase in the concentrations of HCO_3^- , NO_3^- , Pb and a decrease in Cu, HA under the conditions of an increase in Eh.

Table 1. Water chemistry composition and temperature.

Date	pH	K^+ , mg/l	Na^+ , mg/l	Ca^{2+} , mg/l	Mg^{2+} , mg/l	NH_4^+ , mg/l	Fe_{total} , mg/l	Cl^- , mg/l	SO_4^{2-} , mg/l	NO_3^- , mg/l	HCO_3^- , mg/l	DOC, mg/l	T , °C
Drained bog													
28.04.2016	3.80	0.20	0.50	2.20	1.34	6.32	1.64	2.02	6.65	1.37	3.05	35.52	2.5
20.05.2016	3.80	0.30	0.40	1.76	0.78	6.58	1.90	2.93	8.10	1.95	6.10	58.0	7.6
23.06.2016	4.21	0.70	1.10	5.09	1.70	8.94	2.18	3.48	3.64	2.62	3.36	58.67	10.8
22.07.2016	5.03	0.40	1.90	2.04	0.27	9.14	3.25	4.40	3.25	1.86	5.49	67.54	18.8
18.08.2016	4.18	0.60	1.50	3.49	1.80	6.87	1.79	4.92	3.65	2.82	5.19	76.93	13.1
18.09.2016	3.70	1.70	1.30	3.89	1.46	6.56	2.03	4.92	4.44	1.67	3.05	71.89	11
Gavrilovka River													
27.04.2016	6.04	0.30	3.10	10.98	4.50	4.93	1.92	2.83	10.63	2.14	21.36	53.27	5.3
20.05.2016	5.89	0.20	1.75	11.42	4.64	5.66	2.05	5.13	8.77	2.64	35.09	62.8	13.5
23.06.2016	6.93	0.50	2.55	18.04	7.53	8.43	5.48	4.13	5.10	1.57	76.28	61.73	18.5
20.07.2016	6.54	0.10	2.00	11.5	5.81	6.01	5.51	3.19	2.81	2.41	40.27	80.13	18.9

18.08.2016	6.71	0.40	4.20	24.65	3.09	3.83	6.39	4.54	4.16	2.08	66.21	75.18	13.5
22.09.2016	6.17	0.30	5.70	18.84	7.78	3.08	6.55	4.99	2.81	2.34	83.29	79.12	11.3
Pristine bog													
26.04.2016	4.09	0.20	0.45	2.36	1.05	4.54	1.25	1.34	3.00	0.46	7.02	29.87	1.2
19.05.2016	4.18	0.20	0.40	1.96	0.53	4.12	1.51	2.26	7.39	2.24	3.05	38.4	4.9
22.06.2016	4.21	0.70	1.00	3.41	1.70	4.67	1.69	3.30	4.48	0.49	9.15	57.87	10.8
21.07.2016	4.36	0.30	0.60	2.12	0.66	8.67	2.73	3.33	2.61	2.53	3.05	63.03	14.6
16.08.2016	4.06	1.00	1.40	2.28	1.41	10.24	2.68	5.38	3.65	2.67	3.05	72.79	13.4
19.09.2016	3.79	0.70	1.00	4.57	1.34	7.02	2.16	5.01	3.41	2.49	7.02	63.31	9.10
Klyuch River													
27.04.2016	6.07	0.40	3.75	10.38	3.74	3.74	1.46	2.47	9	0.46	43.02	33.5	3.40
19.05.2016	5.87	0.40	2.15	9.06	3.55	4.03	1.51	4.37	7.21	2.54	35.39	36.8	8.60
21.06.2016	7.75	0.90	3.20	20.36	7.97	2.97	2.39	3.75	3.13	1.83	104.04	58.43	19.8
21.07.2016	6.86	0.30	2.60	18.24	5.42	6.58	4.03	4.38	1.86	2.91	50.65	85.53	18.4
16.08.2016	7.06	0.75	4.15	27.25	8.75	6.12	3.56	6.38	3.13	2.68	103.73	85.61	14.1
20.09.2016	6.66	0.90	9.85	44.09	17.05	1.96	1.79	4.62	0.87	1.45	240.42	51.03	8.0

5. Conclusions

Many studies have shown that within the drained area, in comparison with the pristine part, of the Great Vasyugan Mire, the projective cover of *V. uliginosum* increased 8 times, in *A. polifolia* by a factor of 2, the projective coverage of *C. calyculata* decreased 3.6 times, and *L. palustre*, 6 times. In the moss layer there is a decrease in the incidence of *S. angustifolium* (3.4 times) and *S. magellanicum* (9 times). The occurrence of green mosses increased in *P. schreberi* (2 times), *P. Strictum* (5 times) and *D. polysetum* (18 times) and lichen *Cladonia stellaris* and *Cladonia rangiferina* (5 times).

In comparison with archival data (1985), an increase in the degree of peat decomposition by 5-10% in the top 10-100 cm layer was noted, which may be due to the partial degradation of the peat deposit as a result of dehumidification.

The microrelief of the drained area is characterized by an increase in the negative forms of the microrelief and a decrease in the proportion of heights at the middle surface from 44 to 37% compared to the pristine areas, reflecting the presence of steep slopes between the positive and negative forms of the microrelief.

In comparison with the pristine areas of the Great Vasyugan Mire, lower water table levels (by 5-12 cm) and a more intensive response to atmospheric precipitation was noted.

The concentrations of the main ions in the drained bog water increased by 6-38%, as well as DOC by 13%, Pb by 9%, Cu by 46%, and Zn by 215% in comparison with the pristine area. The drainage contributes to the increase in the river water concentrations of NO_3^- by 11%, NH_4^+ by 26%, SO_4^{2-} by 36%, Fe_{total} by 89%, and DOC by 17%, and the concentrations of Pb, Cu, and Zn are not changed.

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