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Peculiarities of acid-base properties of peat formed in various agroclimatic zones of the Altai mountainous region

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Abstract. The results of the study of acid-base indicators of peat in the Altai mountainous region are presented. The natural factors that in the aggregate determine the peculiarities of the physico-chemical properties of mountain peat of different agro-climatic zones of the Altai Mountains have been revealed. The variation in the acid values, total absorbed bases, adsorption capacity and the degree of saturation of raised-bog, transitional, fen peat, the number of exchangeable ions Ca^{2+} and Mg^{2+} has been estimated. The interrelation among these indicators has been presented. For the first time, regression equations of the relationship between exchangeable acidity pH_{KCl} and the degree of peat base saturation V, between total absorbed bases S and the degree of peat base saturation V have been obtained using nonlinear regression analysis. The adequacy and stability of the developed models have been verified. The calculated mean errors of approximation of regression models characterise the high accuracy of the forecast and are indicative of a good selection of models for the initial data.

1. Introduction
In the Altai mountainous region, various soil types with their geographical distribution obey the law of vertical zonality [1]. The basic climatic parameters, species diversity of the vegetation, hydrogeological conditions, and vital activity of microflora change along with the terrain elevation, which as a whole influences the formation of peat in local peatlands of the Altai Mountains. According to the agroclimatological zoning on the territory of the Russian Altai (Altai Mountains), the Northern, Central and South-Eastern agroclimatic zones can be distinguished [2-3]. Peat as one of the basic components of ecosystems is a raw, slowly renewable organic resource [4-6]. To assess the quality of peat as a raw material source, a complex of general technical, chemical, physico-chemical indicators is used [7]. Complex chemical processing of peat to obtain supplementary humic feeds [8], veterinary preparations

[9], as well as individual ingredients for biologically active supplements [10], balneology and medicine [11] is promising for the Altai Republic. The establishment of indicators of acid-base properties of mountain peat will allow identifying the peculiarities of the genesis of mountain peat formation in various agroclimatic zones. The results of the research are essential for the development of the nature management strategy in the mountainous territory of the republic in the conditions of an intensively developing recreational industry, as well as for the elaboration of measures for environmental monitoring and nature protection activities. The aim of the work is to determine the specified number of physico-chemical indicators of peat within three different agroclimatic zones of the Altai Mountains, which differ in a number of natural factors; to identify differences in the ranges of key indicators for oligotrophic, mesotrophic and eutrophic types of peat; to determine the major factors regulating the acid-base properties of mountain peat.

2. Methods and materials

The object of the study is peat deposits of peatlands of various agroclimatic zones of the Altai mountainous region (figure 1).

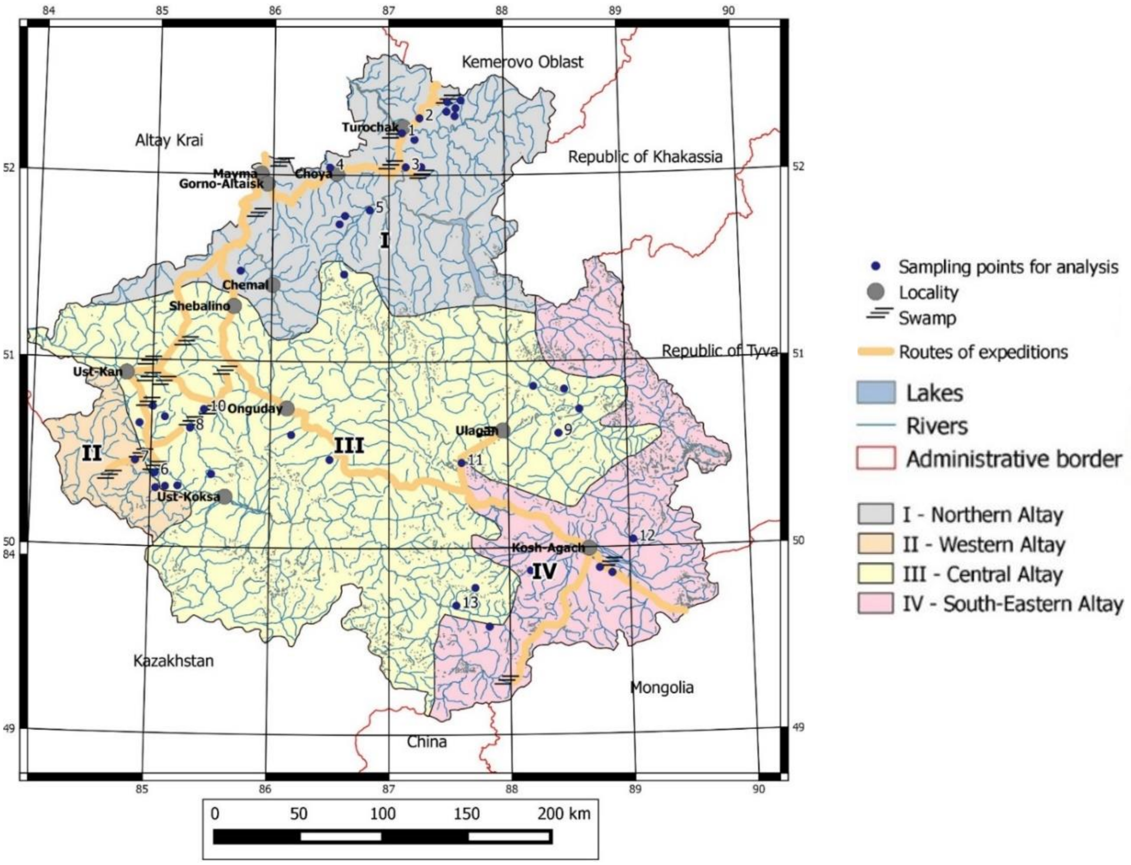

Figure 1. The schematic location map of the studied peatlands in the Mountain Altay Region: 1 – Turochak (52°13'30"N, 87°06'45"E); 2 – Kutyush (52°18'20"N, 87°15'58"E); 3 – Balanak (52°02'35"N, 87°08'41"E); 4 – Choya (52°02'25"N, 86°29'19"E); 5 – Ynyrga (51°48'44"N, 86°50'03"E); 6 – Abay (50°23'36"N, 85°02'13"E); 7 – Souzar (50°27'34"N, 84°52'04"E); 8 Tyuguryuk (50°38'13"N, 85°19'27"E); 9 – Onulu (50°36'46"N, 88°25'37"E); 10 – Kara-Kobek (50°44'18"N, 85°26'17"E); 11 – Aigulak (50°27'28"N, 87°36'32"E); 12 – Sas (50°02'13"N, 89°01'54"E); 13 – Yuzhno-Chuiskiy (49°41'35"N, 87°33'24"E)

The objects of the research were the peat samples that differ in the botanical composition, the degree of decomposition and ash content, taken from oligotrophic, mesotrophic and eutrophic types of peatlands in the Altai Mountains. Peat samples were selected in July-August of 2008-2012 (figure 1). Peat samples were selected every 25 cm in the places of the greatest depth of the peat deposit using the peat drill ‘TBG-1’. The average sample of peat was picked by quartering and it was dried in the ventilated room. The dried peat was ground and sifted through the sieve with holes 2 mm in diameter.

The peatlands in the Altai Mountains occupy a small percentage of the area of the mountainous region and are widely represented in the low-mountain and high-mountain zones.

The *Kutyush peatland* is located in the North-Eastern Altai; it has a mixed atmospheric-groundwater feed and is characterised as transitional. It belongs to the valley type and is located between the Siya and Maly Kutyush rivers. The underlayer is re-deposited fine-grained deluvial deposits of the heavy (loamy) granulometric composition. It is dominated by *Sphagnum magelanicum*, *Andromeda polifolia*, *Menyanthes trifoliata*, *Carex caespitosa, Carex vesicaria*, *C. acuta*, *C. leporina*, *Drosera rotundifolia*. There are *Vaccinium vitis-idaea*, *Equisetum palustre*, *Orchis militaris*, *Platanthera bifolia*. *Corronaria flos-cuculi* can be rarely met. There is *Galium uligimosum* and cranberries *Vaccinium myrtillus* on hummocks and along the edge of declivities.

Various geomorphological locations (basins, extended river valleys, flat mountain plateaus, altiplanation terrace, kar bottoms, concave slopes, slope and valley-slope) and a significant phytocenotic diversity are typical of the mountain bogs [12]. The peatlands, located in the river valleys and in extended basins, have a shallow depth of the peat profile, from 10-20 to 50-60 cm (Chuiskiy, Abay basins). This depends on a set of factors that determine the processes of peatlands formation in mountainous conditions: peculiarities of the relief and microclimate, groundwater level, underlying rocks, presence of permafrost soils, acting as a waterproof stratum. In the aggregate, the above-mentioned is reflected in a significant variation of the depth and stratigraphic structure of peat profiles of high-altitude bogs.

The *Abay peatland* is located in the similarly named basin in the floodplain of the Abay and Urmalyk rivers. The Abay basin is confined to the zone of the recent sublatitudinal Yuzhno-Terektin fault and is located between the spurs of the Terektin, Korgon and Kholzun mountain ranges. The underlayer (inorganic soil) is carbon-bearing loams with a significant content of stony inclusions – quaternary deposits of fluvioglacial, lacustrine and alluvial origin. Outflows of cryogenic artesian springs of suprapermafrost water are typical of the areas of the Abay basin in the most severe winters. The vegetation of the short-grass rhizomatous-sedge fen is represented by *Carex vulpine* L., *C. bicolor*, *C. rostrana*, *Triglochin palustre*, *Calamagrostis neglecta*, *Eriophorum brachyantherum*, *Deschampsia cespitosa* [13].

The *Aigulak peatland* is located in the Sorulukul basin, having a typical glacial relief of the Upper Pleistocene glaciation. The peat profile is located in the valley of a chain of lakes between lake Cheibekkel and lakes Taldukel and Sorulukel that have formed during the directed degradation of valley glaciers of the Aigulak range [14]. The underlayer is the Upper Holocene glacial-lake sediments. In single quantities, representatives of the *Betulaceae* genus can be observed: dwarf birch. (*Climacium dendroides*, *Bryum pseudotriquetrum, Aulacomnium palustre, Tomentypnum nitens*, *Polytrichum juniperinum)* and *Sphagnum nemoreum*, *Carex cf. altaica, C. Rostrata, C. diandra,* grow there.

The *high-altitude Sas peatland (Aru)* is located in the Chuiskiy basin (South-Eastern Altai), which is located in the basin of upper Chui and it has inherited the shape and direction of the ancient Chuiskiy downwarp in its development. On all sides, the basin is confined with mountain ranges. The high-altitude Aru peatland belongs to a type of Central Asian mountain sedge peatlands. The proved area of the peatland is located in the northeast of the Kokorya village in a depressed sag, elongated in the latitudinal direction from the northwest to the southeast. The *Sas peatland* is fed mainly by groundwater. Eutrophic type of peat is representative. The underlayer is a weakly permeable soil in the form of loams and sandy loam, under which there is a thick mass of loose sediments of various genesis. Its occurrence at a shallow depth of 30 cm from the daylight surface contributes to the formation of suprapermafrost groundwater level in the *Sas peatland*. Such peatlands can be characterized by intensive humidification, large turfness of 60-70%, sparse hillocks. The depth of peat is 0-20(30) cm. *Carex altaica, C. dichroa, C. Orbicular* is predominate. *Calamagrostis macilenta*, *Leymus paboanus, Hordeum brevisubulatum*, *Agrostis trinii*, *Puccinellia tenuiflora* can also be found. The Sas peatland is fed by groundwater with a minimum amount of precipitations falling in the Chuiskiy Depression (table 1).

Table 1. Physical-chemical properties of peat in the Altai mountainous region.

*A, %	pH_{KCl}	Ca^{2+}	Mg^{2+}	H_H	S	E	V, %
Oligotrophic and mesotrophic peat							
North-Eastern Altai, n=3							
3.9 / 2.8-5.7	3.5 / 3.1-4.1	24.3 / 17.6-30.0	–	84 / 72-96	24.8 / 17.8-31.3	80.1 / 119.2	23.0 / 15.6-30.3
Central Altai, n=5							
10.1 / 2.9-17.3	5.1 / 2.6-6.3	50.7 / 13.8-81.1	61.8 / 3.5-121.9	46.6 / 2.6-165.9	107.2 / 55.6-179.2	153.7 / 58.2-239.7	76.3 / 30.8-98.0
South-Eastern Altai, n=6							
13.0 / 2.0-34.4	4.4 / 4.3-4.5	10.0 / 7.5-12.5	–	49.6 / 5.7-106.2	12.4 / 1.8-33.6	62.0 / 21.0-117.7	31.1 / 4.5-82.8
Altai Mountains, oligotrophic and mesotrophic peat n=14							
10.0 / 2.0-34.4	4.3 / 2.6-6.0	30.6 / 7.5-81.1	23.3 / 0-121.9	55.9 / 2.6-165.9	48.9 / 1.8-179.2	98.6 / 17.8-239.7	45.5 / 6.6-98.0
Eutrophic peat							
North-Eastern Altai, n=12							
33.7 / 18.2-53.6	5.5 / 4.4-7.3	27.3 / 17.5-50.0	31.1 / 14.0-77.5	67.5 / 36-102	63.4 / 31.5-97.5	130.9 / 81.0-199.5	45.7 / 0.4-70.0
Central Altai, n=18							
29.5 / 7.8-68.0	6.2 / 5.2-7.5	143.4 / 82.5-195	19.6 / 5.0-45.0	10.5 / 0-24.0	286.1 / 17.1-864.5	296.6 / 22.2-864.5	92.5 / 76.5-100
South-Eastern Altai, n=4							
44.7 / 33.4-63.2	5.8 / 4.3-7.2	–	–	19.1 / 1.7-37.2	81.5 / 38.4-203.0	100.6 / 44.8-204.7	74.0 / 54.0-99.2
Altai Mountains, eutrophic peat, n=34							
36.0 / 7.8-68.0	5.8 / 4.3-7.5	85.4 / 17.5-195	25.4 / 5.0-77.5	32.4 / 0-102.0	143.7 / 17.1-864.5	176.0 / 22.2-864.5	70.7 / 0.4-100

*Note: the numerator contains the mean value, the denominator – content (variation) range; '–' – indicators are not identified; A – peat ash-content; pH_{KCl} – reverse acidity, Ca^{2+}, Mg^{2+} – content of exchangeable Ca^{2+}, Mg^{2+} (mmol(eq.)/100 g); H_H and S – hydrolytic acidity and total absorbed bases (mmol(eq.)/100 g); E – peat adsorptive capacity, mmol(eq.)/100 g; V – degree of peat base saturation.

Groundwater is slightly alkaline and hydrocarbonate-chloride of the magnesium-sodium composition with a relatively high mineralization of up to 1000 mg/l and an increased concentration of microelements [15].

The *Yuzhno-Chuiskiy peatland* is located on the southern macroslope of the Yuzhno-Chuiskiy range. In the mentioned area, in the range of heights from 1900 m above the sea level and up to the foot (the valley of the Dzhazator River), there are many small-scale mountain-valley bogginesses and bogs in kar degradations, in secondary depressions, in the valleys of mountain streams, brooks, in erosion hollows. The *Yuzhno-Chuiskiy peatland* is fed by glacial streams (mountain peak – Iiktu, glacier – Bolshoy Taldura) and those of snowfields in the Yuzhno-Chuiskiy range, by waters of the Uzungur and Tyun rivers, as well as by fairly significant atmospheric precipitations. The mineral layer of the peat profile has been formed by a loamy-arenaceous-rubbly substrate. The thickness of the studied peat deposit is 1.8 m. Sedges and true mosses predominate in the vegetation cover. Sedges (*Carex rostrata*), hillockgenerating *Carex juncella* dominate in the composition of the herbaceous layer. *Carex dioica* and *Carex canescens* are spread to a lesser degree. The botanical species of alpine and subalpine meadows grow in the immediate vicinity as accompanying species.

The hydrolytic acidity (H_H) of peat was determined according to [16]. The essence of the method consists in the extraction of exchangeable hydrogen ions from peat with a solution of sodium acetate and subsequent titration of acetic acid with a solution of sodium hydroxide. Total absorbed bases in peat samples (S) was determined by the Cappen-Gilkovitz method [8]. The analysis is based on the treatment of a peat sample weighing 2 g 0.1 mol/l with a solution of hydrochloric acid at a ratio of 1:100 for 24 hours. In this case, part of the acid is aimed at reduction and neutralisation of the absorbed bases. The acid residue in the filtrate was titrated with 0.1 mol/l of the NaOH solution in the presence of a phenolphthalein indicator.

The peat absorption capacity (E) was determined by the Cappen method [17] as the sum of H_H and S. The degree of peat base saturation (V, %) was calculated as the ratio of total absorbed bases S to the peat absorption capacity. The content of exchangeable Ca^{2+} and exchangeable Mg^{2+} in peat was determined according to [16] by the complexometry method after pre-treatment of a peat sample of 0.2 mol/l with a solution of HCl acid.

The statistical analysis was performed using the Microsoft Excel 2016 office and the Statistics packages StatSoft Statistica 12.5, IBM SPSS Statistics 23. The comparison of nonlinear regression models and the selection of the best one in both studies were carried out using the Williams-Kluth criterion [18] with a confidence probability of 0.99.

3. Results and discussion

The acid-base properties of peat are characterised by reverse acidity, hydrolytic acidity, total exchangeable bases, absorption capacity, degree of peat base saturation. The exchangeable and hydrolytic acidities are related to the solid phase and reflect the quantity of titrated substances possessing acidic properties. The peat potential acidity is determined by soluble low-molecular organic acids and specific humic acids, formed as a result of complex biochemical transformations of organic residues [7]. It is known that the physico-chemical indicators of peat differ within the limits of type and species membership. Biochemical processes, proceeding at different depths of a peat deposit, also influence the peat chemical composition. In this connection, the mentioned indicators H_H, S, E, V, the quantitative content of Ca^{2+} and Mg^{2+} of peat differ significantly. Regional peculiarities contribute to the chemical composition of peat-forming plants and to the process of peat genesis in the peculiar conditions of the mountainous area. The agroclimatic zones of the Altai mountainous region, taking into account different high-altitude levels, are characterised by their meso- and microclimates, peculiarities of the mountainous relief and they differ by hydrogeochemical types of surface and groundwater.

The values of the target parameters for the mountain peat under study are shown in table 1. The ranges of variation in exchangeable acidity pH_{KCl} of oligotrophic and mesotrophic mountain peat and the peat of the European part of Russia (EPR) are almost the same [19]: pH_{KCl} – 2.6-6.0 and 2.6-5.8; 2.8-5.9. They differ from those of the West Siberian peat by shifting the range of variation in pH_{KCl} to a more acid domain. The eutrophic peat of Western Siberia and those of the mountainous zones have similar ranges of variation in the exchangeable acidity pH_{KCl}: 4.3-7.2 and 5.0-7,3, respectively, and are less acidic relatively the eutrophic peat of the European part of Russia, which has a wider range, shifted to the acidic area up to H_{KCl} 2.8 [20].

The landscape-climatic specifity is typical of the Altai mountainous region under study. The complexity and mosaic character of the climate are conditioned by the peculiarities of the relief structure. Orographic and climatic factors determine the ratio of heat and moisture, which is reflected in the formation of various types of mountain-valley and intermountain-hollow landscapes, among which meadow-bog and peatlands take place in the considered mountainous region [21].

Locally positioned peatlands are characterised by a variety of the hydrothermal mode, botanical composition of peat-forming plants, types of water-mineral nutrition, composition of bedrocks and mineral deposits. The above-mentioned factors are reflected in the variability of the composition and physico-chemical indicators of mountain peat (table 1).

The hydrolytic acidity (H_H) of mountain eutrophic peat varies from zero to 102 mmol(eq)/100 g with a mean value of 32.4 mmol (eq)/100 g, which is almost 2 times less than the hydrolytic acidity of fen peat in EPR – 57.6 mmol(eq)/100 g [17]. Virtually zero hydrolytic acidity of high-ash Abay and Souzar peat with their significant ash content of 41.6% and 44.0%, respectively, should be noted. This fact is associated with the saturation of the Abay and Souzar peat with alkali-earth bases (Ca^{2+} and Mg^{2+}), which is 99-100%. The mean value of hydrolytic acidity of oligotrophic and mesotrophic peat of 55.9 mmol(eq)/100 g is also quite low: 2-2.5 times less than similar indicators for EPR peat. This indicates a sufficient base saturation of mountain oligotrophic and mesotrophic peat, for which the degree of saturation is 45.5%, for the representatives of the EPR it is 17.2% and 42.5%, respectively.

The eutrophic peat in high-mountain area of the Central and South-Eastern Altai is characterised by a significant degree of peat base saturation: 93% and 74% compared to peat in low-mountain area – 45.7%. Respectively, for peat samples from high-mountain area, the inverse relation is manifested – reduced values of hydrolytic acidity – 10.5 mmol(eq)/100 g and 19.1 mmol(eq)/100 g. Peat from low-mountain has an increased hydrolytic acidity – 67.5 mmol(eq)/100 g.

The mean values of total absorbed bases of oligotrophic and mesotrophic peat and similar peat of the EPR are comparable to each other: S=48.9 mmol (eq)/100 g and S=51 mmol(eq)/100 g. But along with this, peat in Altai mountain is characterised by a greater variability of S values: from 2 to 180 mmol(eq)/100 g. In this way, the minimum number of absorbed bases (S) for the mesotrophic peat of the high-altitude Yuzhno-Chuyskiy area, equal to 12.4 mmol(eq)/100 g, is determined by the water-mineral content of the Yuzhno-Chuyskiy peatlands, which is fed with outwash, as well as groundwater of the high-altitude zone of the South-Eastern Altai, which are characterised by low mineralization [6].

Studies have revealed that the peat exchangeable acidity has a statistically significant relationship with the calcium content: when the saturation of peat with calcium and magnesium increases, its acidity decreases [22]. The content of Ca^{2+} ions is 50-70% of the total ion content in peat; calcium is a regulator of acidity, of biochemical processes of plant decay and it is a sign of the type belonging of peat. According to the content of calcium cations, peat is divided into five groups: extremely saturated (more than 185), highly saturated (130-185), medium satturated (100-130), cation-saturated (70-100) and low cation-saturated (less than 70 mg-eq/100 g) [23].

According to the mentioned classification, the oligotrophic and mesotrophic peat in the mountain area is on average low cation-saturated in terms of calcium – 30.64 mmol(eq)/100 g. At the same time, cation-saturated eutrophic peat is also formed in the Central Altai. For example, there are the surface layers of the Aygulak and Saratan profiles (0-15 cm), for which the degree of base saturation (Ca^{2+} and Mg^{2+}) is 91-98% at low hydrolytic acidity values of 17.2 and 2.9 mmol(eq)/100 g. The mentioned peat is classified as slightly acidic: their exchangeable acidity pH_{KCl} is equal to 5.3 and 6.3, respectively. According to the above-mentioned classification, the eutrophic peat of the Altai mountainous region is cation-saturated relatively Ca^{2+} with a mean value of 85.35 mmol(eq)/100 g. The mean values of total exchangeable bases (S) of eutrophic peat of mountain and plain areas are similar: 144 mmol(eq)/100 g and 154 mmol(eq)/100 g; the same is true for the variability intervals of absorption capacity: 22-865 and 100-800 mmol(eq)/100 g [24,25].

Anomalously high amounts of total absorbed bases (S) are typical for Souzar peat (mid-mountain zone, Central Altai): 437-865 mmol(eq)/100 g with virtually zero hydrolytic acidity (H_H): 0-4 mmol (eq)/100 g. The degree of its base saturation is 99-100%. The mentioned peat belongs to neutral – its exchangeable acidity (pH_{KCl}) is equal to 7.4-7.5. The Souzar peatland is located in a depressive extended valley of the Souzar River; the of peat depth is 0-25 cm. The high saturation of this peat with alkali-earth bases (Ca and Md) is explained by supply with ground hydrocarbonate-calcium waters of increased mineralization. The above-mentioned circumstance is confirmed by the increased mineralization of waters of Souzar – 441.6 mg/l and an alkaline medium of pH=7.7 [26]. Probably, as a result of the decelerated intensity of water exchange with the host karst limestones, the groundwater of the Souzar peatland have an increased mineralization of about 278-307 mg/l and a slightly alkaline medium according to [15].

In this way, water-mineral supply, namely, different mineralization of ground waters makes a significant contribution to the differentiation of a number of acid-base indicators of mountain peat. For the Altai-Sayan mountainous region, the regularity in increasing mineralization of underground waters has been established as far as the absolute height and intensity of water exchange with the host rocks decrease [15]. This regularity manifests itself within individual mountain systems and is of regional character. In this way, in the high-altitude zone of the Chuiskiy Ridge, ground waters of low mineralization (about 100 mg/l) and slightly acidic nature are formed, supplying local peatlands at the foot of the Yuzhno-Chuiskiy Ridge. Therefore, the Yuzhno-Chuiskiy oligotrophic and mesotrophic peat have a small amount of total absorbed bases: from 2 to 34 mmol(eq)/100 g, increased hydrolytic acidity – up to 106 mmol(eq)/100 g and they are acidic [24,25]. As a result of the nonlinear regression analysis, the relationships between the pH value of the salt extract and the degree of base saturation (1), total absorbed bases and the degree of base saturation (1) have been established, which are illustrated by point scattering diagrams around the regression line according to the type of hyperbolic tangent (1) and the logistic curve (2) (figure 2a, figure 3a).

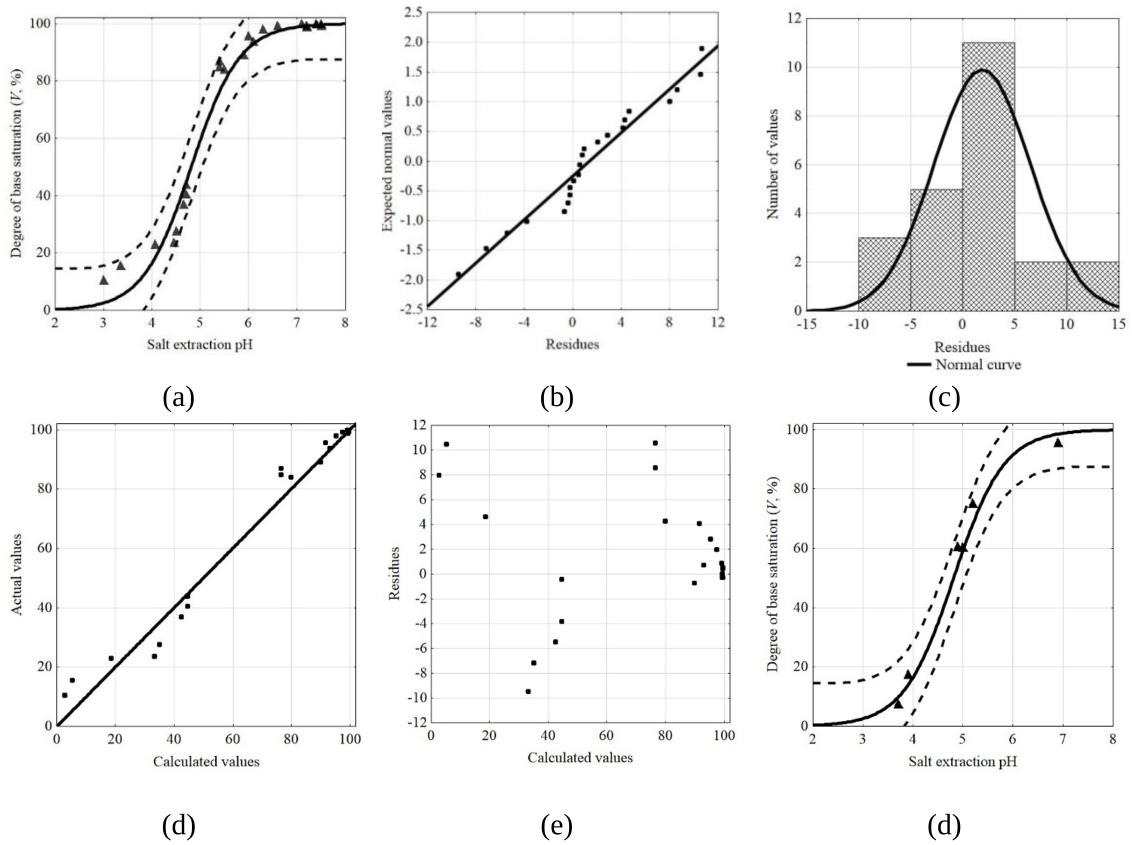

Figure 2. Nonlinear regression model of the relationship between the pH value of salt extract and the degree of base saturation (a); a regression residual plot on the normal probability paper (b); a residue distribution histogram with a superimposed normal curve (c); the dependence of the actual values of the degree of base saturation on the calculated values (d); the dependence of the residues on the calculated values of the degree of base saturation (e); regression model verification according to the forecast of the degree of base saturation: ▬ – predicted values; ─ ─ ─ – a confidence band with a confidence level of 0.99; ▲ – empirical data (f).

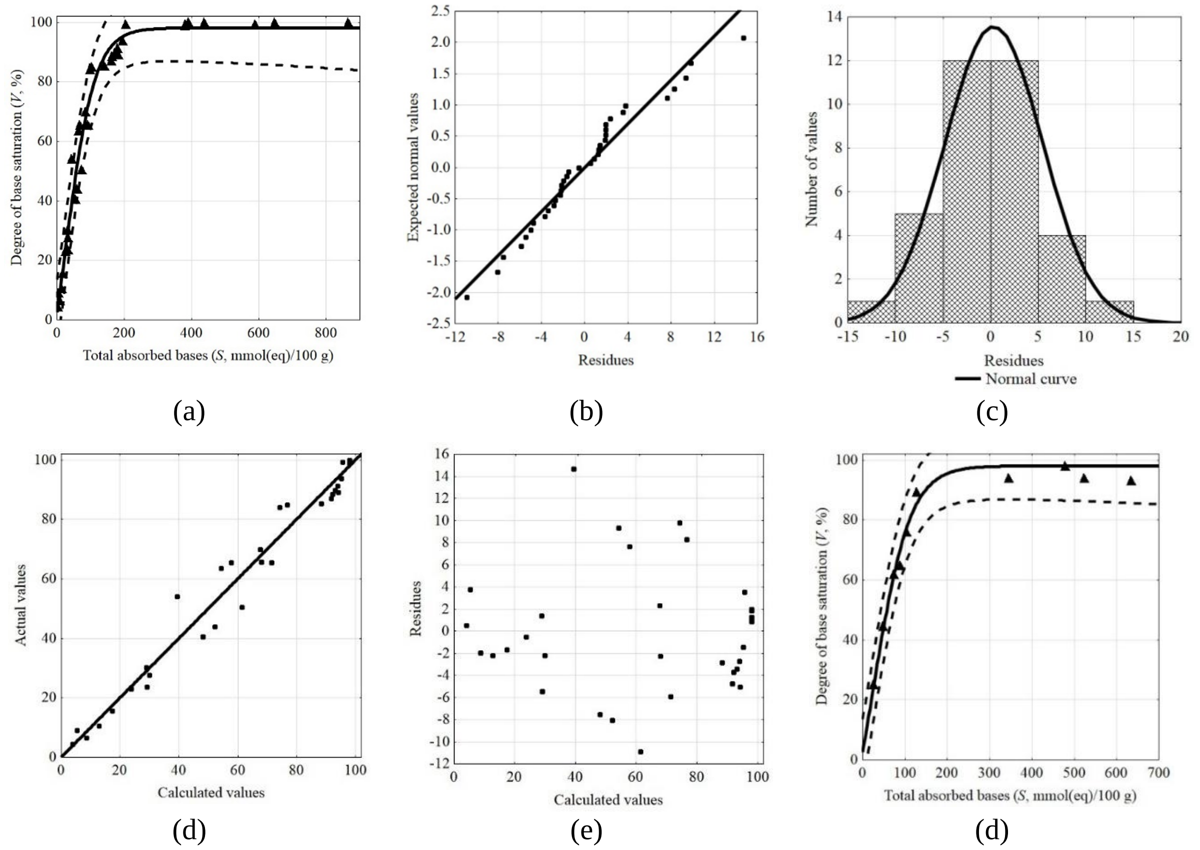

Figure 3. Nonlinear regression model of the relationship between the total absorbed bases and the degree of base saturation (a); a regression residual plot on the normal probability paper (b); a residue distribution histogram with a superimposed normal curve (c); the dependence of the actual values of the degree of base saturation on the calculated values (d); the dependence of the residues on the calculated values of the degree of base saturation (e); regression model verification according to the forecast of the degree of base saturation: ▬ – the predicted values;— — — – a confidence band with a confidence level of 0.99; ▲ – empirical data (f).

The iterative method of minimizing the Hook-Jeeves loss function (the least-square function was used as the loss function) was applied to determine the coefficients of the nonlinear regression equations. The following regression equations (1)-(2) have been obtained:

$$V = 50 + 50\,\mathrm{th}(\mathrm{pH}_{(\mathrm{KCl})} - 4.81274) \tag{1}$$

$$V = -51.033 + \frac{83.5565}{0.560475 + e^{-0.0231124S}} \tag{2}$$

Regression model quality assessment for (1): R^2=0.976 (1), R^2=0.973 (2); actual values of the Fisher's criterion F_{act}=838 (1), F_{act}=1208 (2); regression mean-square error 5.18 (1), 5.34 (2).

High statistically significant determination coefficients, whose values serve as indicators of the degree of model fitting, indicate a close relationship between the effective features and the features-factors: 97.6% of the variability in the degree of base saturation (V) is explained by the variability of the pH of the salt extract ($\mathrm{pH}_{(\mathrm{KCl})}$) (1), and 97.3% of the variability in the degree of base saturation (V) is explained by the variability of total absorbed bases (S) (2).

The table values of the Fisher's criterion for the constructed regression models with the significance level of $p=0.001$ are as follows: F_{tabl}=22.89 (1), F_{tabl}=19.56 (2). Since for both models: $F_{act}>F_{tabl}$, the statistical reliability of the obtained regression equations is recognised.

To check the adequacy of the developed models, i.e. to establish whether they correspond to the field data and whether the conditions for using the least-square method (LSM) are met, we resorted to the procedure of residuals analysis (the difference between the experimental data and the values, calculated using regression equations). The correctness of the application of regression curves in data analysis is indicated by the residuals distribution that is approximated to the normal law.

First, the points of both diagrams on normal probability paper line up into a straight line, corresponding to the expected normal distribution without extreme values (figure 2b, figure 3b). Second, the histogram of the residuals distribution is almost symmetrical with respect to zero (approximately, the residuals equally as often take both positive and negative values), and the polyline, connecting the midpoints of the upper sides of the rectangles, is close to the probability density plot of the expected normal distribution (figure 2c, figure 3c).

Another step that needs to be taken to check the stability of the regression models under consideration is to visually analyse the correspondence of the calculated values of the response functions to the actual values and to exclude the possibility of the presence of systematic errors. The constructed graphs of the dependencies of the actual response variables on the calculated ones (figure 2d, figure 3d) and the residuals from the calculated values (figure 2e, figure 3e) point to a fairly accurate coincidence of the calculated and actual values and to the fact that the errors are not systematic. Indeed, the graphs of the dependence of the calculated values on the actual ones are similar to the linear one, which has the form of the bisector of the first coordinate angle. The second graphs show that the residuals do not show a dependence on the values of the response functions (correlation coefficients r=-0.046 (1), r=-0.9.97·10^{-6}) and, consequently, the proposed regression models are free from systematic errors.

To verify the operability of the regression models (1) and (2), we used the values of the features of those units of the statistical population that had not participated in the modeling. The observed indicators are entirely within the confidence intervals of the regression equations, which also confirms the high predictive properties of the models (figure 2f, figure 3f). The accuracy of the forecast was calculated according to the formula (3), proposed by the author in [27]:

$$\bar{\varepsilon} = \frac{\frac{1}{n}\sum_{i=1}^{n}\left|\hat{Y}_i - Y_i\right|}{\bar{Y}} \qquad (3)$$

where $\bar{\varepsilon}$ is an approximation mean error, %, $\hat{Y}_i$ and Y_i are for each i-th statistical unit: the value calculated by the model and actual value of the simulated feature, respectively, %, $\bar{Y}$ is an average level of the simulated feature, %.

The mentioned formula determines the only correct procedure for calculating the mean relative linear (modulo) error of approximation of the regression model. The latter is the ratio of the mean absolute error (modulo) to the average level of the simulated feature. Only the homoscedastic absolute error is used in this calculation. It is subject to averaging, and, as a result, the mean absolute error is included in the calculation of the mean relative error. There are no violations of the LSM requirements, and there is no addition of non-homogeneous values.

The known methods of calculating the mean approximation error, described in most literature sources and currently widely used in practice, are incorrect. They dramatically overestimate the value of the mean error and grossly violate the requirement for homoscedasticity of deviations [28,29].

The mean approximation errors of the developed regression models are 5.23% (1), 6.42% (2) and are in the range of 5-7%, which also characterises the high accuracy of the forecast and indicates a good selection of models for the initial data.

4. Conclusion

The physico-chemical characteristics of peat of the raised bogs, transitional bogs and fens of the Altai mountainous region have been determined. A comparative analysis has been made for the plain peat of the European territory of Russia; a number of peculiarities of the physico-chemical indicators of peat, determined by their genesis, have been revealed.

The heterogeneity of the indicators of ash content, exchangeable acidity, hydrolytic acidity, absorption capacity, the degree of base saturation of mountain peat (Ca^{2+}, Mg) is manifested within various agroclimatic zones (low-mountain, medium-mountain and high-mountain) of the Altai mountainous region. The research results allowed identifying the influence of local natural factors on the specific conditions of peat formation in the conditions of the mountainous region. The differences of the physico-chemical indicators of peat in different agroclimatic zones, as well as within the same zone (Central Altai, South-Eastern Altai) are conditioned by the local peculiarities of meso- and microclimates, slope exposure, underlying deposits, and other factors that in their aggregate have a certain influence on the process of peat formation.

The reliable interrelations between the exchangeable acidity pH_{KCl} and the degree of peat base saturation V, between total absorbed bases S and the degree of peat base saturation V have been revealed. Using the method of nonlinear regression analysis, regression equations of the interdependencies of the above-mentioned acid-base indicators of peat of the Altai mountainous region have been obtained.

The adequacy and stability of the developed models have been verified. The calculated mean errors of approximation of regression models characterise the high accuracy of the forecast and are indicative of a good selection of models for the initial data.

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References

[1] Stepanova V A, Pokrovsky O S, Viers J, Mironycheva-Tokareva N P, Kosykh N P and Vishnyakova E K 2015 Elemental composition of peat profiles in western Siberia: Effect of the micro-landscape, latitude position and permafrost coverage. *Appl. Geochem.* **53** 53 doi: org/10.1016/j.apgeochem.2014.12.004

[2] Makoshev A P 2009 *Issues of Territorial Organisation of Altai Mountain Livestock Farming:* (Gorno-Altaisk: RIO GASU) p 323 [In Russian]

[3] Semenov Yu M and Lysanova G I 2016 Mapping of geosystems for landscape planning of areas in the altai republic. *Geography and Natural Resources* **37**(4) 329 doi: 10.1134/S1875372816040077

[4] Fuchsman C 1980 *Peat. Industrial Chemistry and Technology* (New York: Acadrmic Press) p 298

[5] Wang S, Gu J, Shan R, Yuan H and Yong C 2021 Catalytic toluene steam reforming using Ni supported catalyst from pyrolytic peat. *Fuel Process. Technol.* **224** 107032 https://doi.org/10.1016/j.fuproc.2021.107032

[6] Bambalov N N 2012 Use of peat as an organic raw material for chemical processing. *Solid Fuel Chemistry* **46**(5) 282 doi: 10.3103/S0361521912050023

[7] Enev V, Sedlaeek P, Kubikova L, Sovova S, Doskocil L, Klucakova M and Pekar M 2021 Polarity-based sequential extraction as a simple tool to reveal the structural complexity of humic acids. *Agronomy* **11**(3) 587 doi: 10.3390/agronomy11030587

[8] Paleckiene R, Navikaite R and Slinksiene R 2021 peat as a raw material for plant nutrients and humic. *Substances* **13** 6354 https://doi.org/10.3390/su13116354

[9] Drobnik J and Stebel A 2020 Central European ethnomedical and officinal uses of peat, with special emphasis on the Tołpa peat preparation (TPP): An historical review. *J. Ethnopharmacol.* **246** 112248 https://doi.org/10.1016/j.jep.2019.112248

[10] Larina G V, Maslov S G, Porokhina E V, Dyryn V A and Egorova A V 2018 Properties of peat of mountainous Altai and directions of their use. *The Bulletin of Irkutsk State University. Series: Earth Sciences* **26** 60 doi: 10.26516/2073-3402.2018.26.60
[11] Groven M and Pizzorno J E 2020 Peat Therapeutics and Balneotherapy *Textbook of Natural Medicine – E-Book* eds Pizzorno J E, Murray M T (Netherlands: Elsevier Health Sciences) chapter 45 pp 371-408
[12] Migon P 2014 *Geomorphological Landscapes of the World* (Netherlands: Springer) p 375
[13] Kosykh N P, Mironycheva-Tokareva N P and Kirpotina L D 2010 Productivity of fen in Gorno-Altai. *Proc. Conf. Biodiversity and Ecological Problems in the Altai and Adjacent Regions: Present, Past, Future* (20-24 September, Gorno-Altaisk, Russia) p 396 [In Russian]
[14] Zolnikov I D and Mistryukov A A 2008 Quaternary deposits and relief of Chuya and Katun valleys (Novosibirsk: Parallel) p 82 [In Russian]
[15] Shvartsev S L 2000 Hydrogeochemistry of the hypergenesis zone. *Geochem. Int.* **38** S260
[16] GOST 27894.0-88 1989 *Peat and its products of processing for agriculture. Methods of analysis: Collection* (Moscow: Publishing House of standards, Russia), available at: https://docs.cntd.ru/document/1200024260
[17] Bazin E T *Technical Analysis of Peat* 1992 (Moscow: Nedra) p 431
[18] Kobzar A I 2006 *Applied mathematical statistics. For Engineers and Scientists* (Moscow: FIZMATLIT) p 816
[19] Selyanina S B, Trufanova M V, Yarygina O N, Orlov A S, Ponomareva T I, Titova K V, Zubov I N 2017 Peculiarities of the biotransformation of organic matter under the conditions of northern mire ecosystems(by the example of Ilasskoe mire massif, Russia). *Transactions of Papanin Institute for Biology of Inland Waters RAS* **79**(82) 200 doi: 10.24411/0320-3557-2017-10040
[20] Tiuremnov S N 1976 *Peat Deposits* (Moscow: Nedra) p 488
[21] Huang X *et al.* 2018 Holocene vegetation and climate dynamics in the altaimountains and surrounding Areas. *Geophy. Res. Let.* **45**(13) doi: 10.1029/2018GL078028
[22] Efremova T T, Efremov S P, Melenteva N V and Avrova A F 2018 Altitudinal differentiation of acid-base properties of the river valley peat soils in the Kuznetsk Alatau. *Tomsk State University Journal of Biology* **41** 135 doi: 10.17223/19988591/41/8
[23] Lishtvan I I and Korol N T 1975 *Basic Properties of Peat and Methods of their Determination* (Minsk) p 320
[24] Larina G V, Kaizer M I and Shurova M V 2015 Physico-chemical properties of mountain peat. *Bogs and Biosphere: Proc. of the IX All-Russian Sci. School* (September 14-18, Vladimir/Ivanovo: PresSto, Russia) p 307
[25] Larina G V, Bezgina M A, Shurova M V and Yalbacheva O A 2018 Technical and physico-chemical characteristics of peat of the Altai Mountains. *Bogs and Biosphere: Proc. of the X All-Russian Sci. School with Int.* (September 17-21, Tver: LLC 'Knowledge intensive technologies', Russia) p 311 [In Russian]
[26] Kozlova S A, Shurova M V and Larina G V 2010 Chemical composition of swamp waters of the Central part of the Altai Republic. *Bogs and biosphere. Proc. of the 7th All-Russian Sci. School* (September 13-15, Tomsk, TSPU, Russia) p 284 [In Russian]
[27] Malova N N 2017 Malova N N 2017 About one approach to the calculation of the average error of approximation of the regression models. *International Technical and Economic Journal* **5** 54 [In Russian]
[28] Eliseeva I I, Kurysheva S V, Kosteeva T V, Babaeva I V and Mikhailov B A 2003 *Econometrics* (Moscow: Finance and Statistics) p 344
[29] Afansiev V N 2005 *Econometrics* (Moscow: Finances and Statistics) p 256