Original Research Article

Macro- and trace elements in freshwater lake sediments in the south of West Siberia

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ABSTRACT

Aims: Recently lake sediments and their studies have been drawing increasing attention due to organic farming and environmental engineering. This pilot study examined chemical element content in sediments of several shallow freshwater lakes in the forest-steppe zone in the south of West Siberia, Russia.

Study design: Lake bottom sediments were collected at random by corer at 5-cm increments down to 75 cm deep, then stored at field moisture in anaerobic conditions at +4°C until analysed.

Place and Duration of Study: Institute of Soil Science and Agrochemistry and Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia, between June 2013 and September 2014.

Methodology: We studied sediments of shallow freshwater lakes by measuring macro- and trace elements contents and performing principal components analysis with the data obtained.

Results: The studied lakes were found to store substantial amounts of carbon and nitrogen in their sediment organic matter, namely 2.2 Tg C and 0.2 Tg N in the top 40-cm layer. The PCA analysis of the elemental composition of lake sediments discriminated them from each other, revealing the unique biogeochemical nature of lake sediments even within one and the same biome.

Conclusion: The estimates underscore the importance of lake sediments in the carbon budget of the Novosibirsk region and West Siberia with *ca.* 3,000 and 22,000 lakes, respectively. Unique chemical nature of lake sediments questions their potential as fertilizer and soil conditioners in agriculture and bioremediation, requires standardization and development of the adequate technologies.

Keywords: bottom sediments; freshwater lakes; organic carbon stock; organic nitrogen stock; elemental composition; forest-steppe zone; West Siberia

1. INTRODUCTION

Recently freshwater lake sediments, especially organic matter rich ones called sapropels, have been attracting growing attention of both researchers and practitioners due to increasing demands from organic agriculture, decontamination, remediation, alternative energy, medicine, veterinary and so on. For example, the European Commission approved technical report, stating consistency of sapropels with objectives and principles of organic production [1].

Interestingly, almost a century ago in 1919 the Russian Academy of Sciences established the Sapropel Committee to study the nature and composition of lake sediments, develop research programs and set up field experiment stations in the regions rich in sapropels. The Committee worked actively till 1932. Since then its activity gradually subsided, and sapropels and other sediments had received less attention.

Organic matter rich sediments from surface fresh water bodies are known to be abundant mostly in temperate climate zone in Europe and Asia, including Russia. Intensive sedimentation and sediment formation in Russian lakes is one of their characteristic features, with sediment formation currently increasing in many freshwater ecosystems. Despite the efforts of the aforementioned Committee, Russian freshwater sediments have been insufficiently studied, especially in the Asian part of the country, where, for instance, only the south of West Siberia enjoys more than 20,000 lakes, varying in size, regime and salinity [2].

Currently the proposed vast use of lake sediments for diverse economic purposes makes it increasingly imperative to study fresh water lake sediments in many aspects. Firstly, lakes and other intercontinental water bodies have notably received much less attention than peatlands, soils, oceanic and sea sediments in global carbon cycle studies and regional carbon budget estimates [3]. However, freshwater lake sediments were estimated to accumulate annually more organic carbon than oceanic sediments [4], and some researchers suggested that small inland aquatic ecosystems may play unexpectedly major role in the global carbon cycle [5]. To our knowledge, there are no estimates of C storage in freshwater lake sediments for most of the Asian part of Russia obtained on sediments stored at anaerobic conditions at original moisture content, which allows obtaining estimates pertaining to regional carbon budget.

So the aim of this small pilot study was to estimate chemical elements pool in sediments of various shallow freshwater lakes in the south of West Siberia in the Novosibirsk region with a view to assess their C and N stocks and elemental composition variability.

2. MATERIAL AND METHODS

2.1 Lakes and sampling

Sediments were collected in May-June 2012-2013 from several lakes to the west and south-west of Novosibirsk (Tab.1): Itkul, Kankul, Kachkulnya, Kusgan, Barchin and Kambala. All the lakes are small in area with maximal depths less than 3 m. The lake shores mainly consist of salinized and solodized soils and clay loams, often waterlogged. Soils in the lake catchment areas are formed on loess clay loams and clay alluvia. The parent rocks of the West Siberian Plain are well-homogenized, formed by the weathering of rocks in the Altai–Sayan Area and transportation and redeposition of weathering products along ancient sediments. Relief has a strong influence on the high concentration of dissolved organic matter in the lakes of the forest-steppe and steppe landscapes [2]. The catchment areas of most of the lakes are slopes of the ridges, due to the fact the lakes quickly get biogenic elements during short periods of discharge.

Depending on the source of organic matter input, contributing the most to the sapropel formation, the studied lakes were macrophytogenic (Kachkulnya), planctonogenic (Barchin) and mixed (Itkul, Kankul, Kusgan and Kambala). The area overgrown with macrophytes in the studied lakes was 1 to 60%. In predominantly planktonogenic lake Barchin, macrophytes usually occupy 1-2% of the area, while in macrophytogenic lakes plankton is typically scarce and unproductive [6], The waters in the lakes (Tab.1) varied from alkalescent with pH = 8.5 (lake Kusgan) to alkaline with pH = 9.3 (lakes Kachkulnya and Kambala).

Table 1. Some characteristics of the investigated West Siberian lakes [2]

Lake	N	E	Area, km^2	Catchment area, km^2	Maximal depth, m	Sapropel type
Kankul	55.144882	80.038032	11.2	65	1.9	Carbonate siliceous
Kachkulnya	55.014528	80.038791	1.2	11	2.4	Organic
Itkul	55.063231	81.008721	14.5	86	2.1	Carbonate siliceous
Kusgan	53.747087	77.884827	3.3	23	1.6	Mineral silt
Barchin	55.426203	78.093215	6.8	48	1.5	Organic carbonate
Kambala	55.408064	78.122058	3.6	21	1.8	Organic siliceous

The water in the low-salinity lakes (Kachkulnya and Kambala) and in the brackish lake Itkul are of hydrocarbonate-sodium composition, and lake Barchin water is of hydrocarbonate-sodium–magnium composition. The brackish water of Kankul lake can be attributed to the chloride-carbonate-sodium type, and that of lake Kusgan is of the chloride–sulfate–sodium nature.

Samples of lake sediments were taken with the help of cylindrical corer 82 mm in diameter and 70 cm long with a vacuum lock, constructed and manufactured by Taifun Company (Russia). Two core sediment samples ca. 1-2 m apart were taken from the bottom of each lake 200-300 m off the shore with water depth of 1.5-2.5 m. When extracted, the cores were quickly subsampled into 5-cm increments, subsamples from the two cores bulked together, put in plastic bags and after squeezing out the gaseous headspace packed air-tight and stored for 3-5 days in cooled containers; when in laboratory the samples were stored +4°C for 2-3 weeks until analysis. Simultaneously small subsamples were taken by plastic tubes to determined volumetric density of the sediments, which ranged from 1.3 to 1.6 g·cm-3 (105 ºC oven dried basis) and were used to estimate C and N stocks. The data shown in tables represent values averaged over 15 subsamples.

2.2 Laboratory determinations

The contents of C_{org} and inorganic C (C_{in}) were determined by loss on stepwise ignition method [7]: the loss on ignition (LOI) at 500 °C for 12 hours was used to estimate C_{org} content, by multiplying by 0,4, while the loss on the next step of ignition at 800 °C for 12 hours was used to estimate the C_{in} content [8]. To validate the results of LOI technique, we used a CHN-analyzer (Perkin Elmer 2400, Waltham, USA) to measure directly the total sediment C content. The comparison between both techniques performed on a subset of samples (11 per short core), resulted in a strong linear relationship between these two estimates ($R^2 = 0.84$, $p < 0.0001$) with elemental analyzer estimates being somewhat (3%) higher than the LOI-based estimates. As the automated elemental technique is significantly more expensive to run, and much less convenient to work with such highly water saturated samples as lake sediments, the stepwise LOI method, allowing in one run to determine both organic and inorganic carbon, recently has become increasingly popular among researchers and specialists in environmental and agrochemical agencies.

Total nitrogen was determined using CHN-analyzer Perkin Elmer 2400 (Waltham, USA) in air-dried samples. Organic nitrogen (N_{org}) content was calculated as the difference between total nitrogen and mineral nitrogen content, the latter determined according to procedure described by Silva and Bremner (1966) [9].

The content of labile forms of inorganic nitrogen were determined colorimetrically (NH_4^+, NO_3^-) and potentiometrically (NO_2^-) in water extracts from fresh sediments (5:1 v/v). The labile forms of Na and Ca were measured by atomic absorbance spectrometry. Electric conductivity (EC) and $pH_{(H2O)}$ were determined potentiometrically by Anion-7000® (Russia).The data are shown in Table 2.

Table 2. Physicochemical parameters and contents of rock-forming elements and total organic carbon (TOC) in lake water (from [6])

Lake	pH_s	Eh,	TOC	HCO^{3-}	SO_4^{2-}	Cl^-	Mg^{2+}	Ca^{2+}	Na^+	K^+	Salt
		mV	mg/L								g/L
Kankul	9.0	366	12.6	631	495	485	163	60	630	16	2.5
Kachkulnya	9.3	243	13.7	429	38	72	39	30	201	7	0.8
Itkul	8.9	280	3.3	935	32	345	102	22	397	16	1.9
Kusgan	8.5	308	6.8	357	555	384	98	85	320	28	1.8
Barchin	8.9	320	26.6	313	28	24	39	28	124	13	0.6
Kambala	9.3	333	16.5	227	46	86	32	40	93	9	0.5

Chemical elements were analyzed in the Analytical Center for multielement and isotope analyses (accreditation certificate ROSS RU.001.510590) of the Institute of Geology and Mineralogy SBRAS (Novosibirsk, Russia). Briefly, to determine the bulk content of macro- (Al, Fe, Ca, Mg, K and Na) and trace elements, including heavy metals (Cd, Pb, Cu, Zn, Mn, Cr, Ni, Co, V, Be, Ba, Sr, and Li), 1g of dried sediment was ignited at 900°C, transferred into a Teflon bomb, dissolved in 20 mL of hydrochloric and hydrofluoric acids (1:1 v/v) over heat, allowed to dry; the latter step was repeated thrice, reducing the volume of the added mixture. The resultant dry residue was dissolved in a minimal amount of hydrochloric acid, and then dissolved further to obtain *ca.* 5% concentration of hydrochloric acid in the end solution to be analysed by atomic absorption spectrometry (AAS) with flame. To mitigate the effect of ionization while determining K and Na by AAS, CsCl solution was used.

The concentrations of natural radionuclides ^{238}U, ^{232}Th and ^{40}K were measured by direct high-resolution semiconductor gamma spectrometry.

For total mercury determination [10] about 0.5 g of the sediment was weighed directly into Teflon tubes, 10 mL of concentrated HNO_3 (trace metal grade) was added and digestion carried out; Hg determination was performed by cold vapour AAS analysis of the obtained acid-digested samples using the flow injection mercury system from Perkin Elmer and 1.1% (m/v) stannous chloride as a reducing agent.

Element contents were expressed per oven-dried (105 ºC during 24 hrs) basis of sediment mass. Sediment samples for radionuclides (Th and Cs^{137}) determination by gamma spectrometry using HPGe well detectors (Ortec, Ametek, USA) were prepared by air-drying and thorough grinding.

2.3 Statistical analyses

The obtained analytical data were composed into a matrix with rows as objects (sediment samples) and columns as variables, both environmental and analytical. Then the matrix with original, non-transformed data was used to perform descriptive statistics, while the log-transformed matrix was used to perform principal components analysis (PCA, based on correlation) with the help of *Statistica v. 6.0* package.

3. RESULTS AND DISCUSSION

The studied sediments had neutral or slightly alkaline pH in their water extracts, and mostly quite high Na content and low labile P and mineral N content (Tab.3), thus making their potential application as fertilizers rather questionable. Sediments of the studied lakes had high C_{org} and N_{org} contents (Tab. 4, 5), that fall within the range reported for such lakes elsewhere [11, 12]. Our estimates of lake sediment C total stocks are comparable to those reported for other regions [13-16]. It is very important to emphasize that C_{org} content was determined in fresh samples, stored in air-tight containers at low temperature at original moisture prior to analyses, i.e. according to the routine adopted in many countries for environmental monitoring purposes, while the common procedure in Russia is to air-dry sediments prior to such analyses, which may result in serious underestimation of carbon content due to its mineralization to CO_2 in aerobic conditions due to drying and storing. So most of the data on C_{org} content in sapropel published in Russia, even the recent ones, refer to the mostly recalcitrant organic matter, residual in the sapropel after some time of air-drying (see, for instance, [2, 6]. Often researchers even do not seem to be aware of the importance of analyzing sediments stored anaerobically at field moisture [17]. Thus those C_{org} estimates have nothing to do with raw sapropelic C_{org} content, and hence with C stock pertaining to regional C balance.

Table 3. Labile elements content, pH and electrical conductivity (EC) of water extracts from the sediments of the investigated West Siberian lakes (means, n=15)

Lake	pH	EC, mS/cm	Na, mg kg^{-1}	Ca, mg kg^{-1}	P_2O_5, mg kg^{-1}	N_{in}, mg kg^{-1}
Kankul	8.5	0.81	1745	58	4.3	32
Kachkulnya	7.2	0.20	964	60	3.8	76
Itkul	8.4	0.42	997	107	1.4	10
Kusgan	6.8	0.92	579	399	0.4	16
Barchin	7.5	0.35	734	82	1.6	39
Kambala	7.4	0.78	811	75	9.7	47

We took 40 cm to estimate carbon storage in lake sediments because such were the shortest cores we managed to obtain while sampling sediments. Estimation of C_{org} content only in the upper 40 cm of the studied lake sediments gave significant values (Tab.4), much higher than in the adjacent soils, where the C_{org} storage in the upper 40 cm ranged from 1 ÷ 5 kg C m^{-2} in typical solonchak, solonets and solodic soils to 10 ÷ 30 kg C m^{-2} in the southern and leached chernozems in the study region (our data, unpublished). Among the studied lakes the sediment organic C stock was maximal in Kachkulnya lake due to its macrophytogenic nature, as macrophytes contribute the major part of the autochtonous organic matter input into the sediments as compared to phytoplankton and epiphytes [2, 18], and organic matter decomposition slows down in shallow lakes in winter. Organic C stock in Kachkulnya lake exceeded almost 2-fold the stock reported for peatlands of the similar region [19]. Several times higher storage of carbon in inland lake sediments as compared to the adjacent soils is rather common [16, 20].

Overall these lakes store about $2.2 \cdot 10^9$ kg C_{org} in the top 40 cm of their sediments. This result can be used to assess the relative importance of lake sediments C stocks at a regional scale. Assuming that the sediment organic matter storage variability in the studied lakes roughly embraces the respective variability in the total amount (*ca.* 3000) of lakes in the Novosibirsk region or the south of West Siberia (*ca.* 22000 lakes), we can estimate sediment organic carbon storage in those lakes as 1.1 and 8.1·10^{12} kg C, respectively. The first regional estimate of sediment carbon pool in all Alberta lakes those lakes as 1.1 and 8.1·10^{12} kg C, respectively. The first regional estimate of sediment carbon pool in all Alberta lakes. (Canada) reached 2.3 Pg C, or 2.3·10^{12} kg C [13], being lower, but comparable to our estimate for the south of West Siberia, which in area is comparable to Alberta. Noteworthy, this estimate was obtained in assumption that all Alberta lake sediments the same organic matter content, which, according to the authors, did not appear to depend strongly on lake size or other limnological parameters. Our estimates are calculated for just the top 0-40 cm of bottom sediment, because, due to some technical problems, it was the shortest sediment profile sampled. In addition, the organic matter content in the studied lake sediments does not decline drastically with depth below 40 cm (Fig.1), hence the C stock estimate in lake sediments can be safely at least doubled to 16·10^{12} kg C, and if extrapolated to the total sediment thickness, often exceeding 1 m, can be quite comparable with 70·10^{12} kg C of organic matter estimated to be stored in the West Siberian peatlands [21].Thus the regional carbon budget should be reviewed with a special focus on the role of lake sediments. The task is quite challenging, as due to the global climate change in some regions inland lakes may serve as carbon sinks during periods of increased precipitation [20], or as carbon source during increased droughts [22].

Table 4. Sediment organic matter C content in the investigated West Siberian lakes (mean ± s.d.)

Lake	C_{org}, %	C_{org} storage in 0-40 cm	
		kg C m^{-2}	10^9 kg C $lake^{-1}$
Kankul	6.3 ± 1.6	45	0.50
Kachkulnya	30.5 ± 1.8	177	0.22
Itkul	5.8 ± 0.8	38	0.55
Kusgan	4.9 ±4.1	34	0.10
Barchin	15.4 ± 2.2	72	0.49
Kambala	19.0 ± 3.1	97	0.35

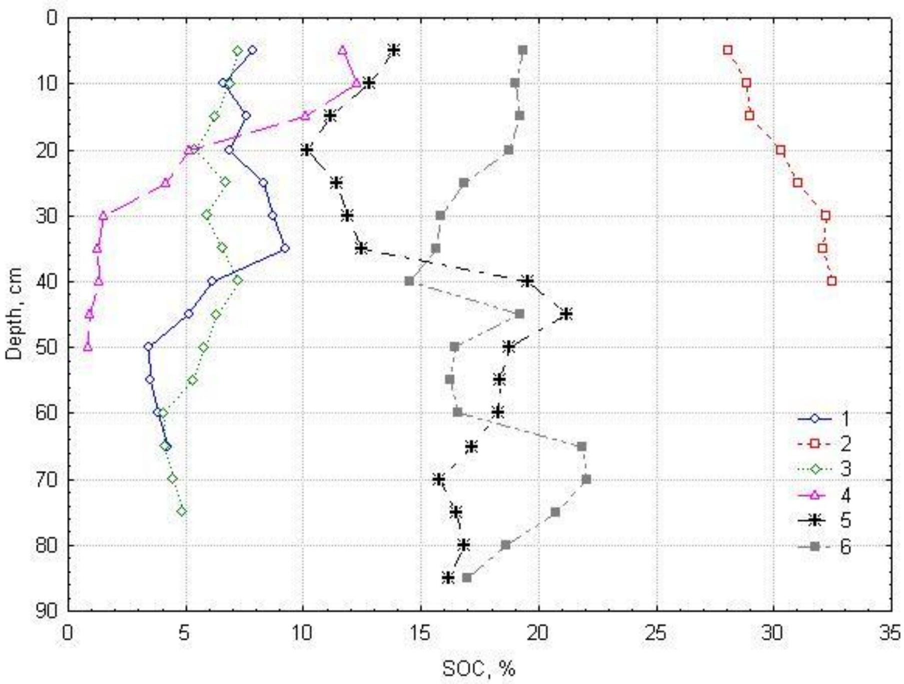

Fig. 1. Sediment profile distribution of organic carbon content

Lakes: 1- Kankul, 2 – Kachkulnya, 3 – Itkul, 4 – Kusgan, 5 – Barchin, 6 – Kambala. SOC – sediment organic carbon content

Organic N sediment profile distribution is shown in Fig.2. Similar to carbon, organic N stock in the studied lakes was also found to be high: minimal estimate for the upper 0-40 sediment layer totaled 162,000 ton N, being almost equal to the annual requirement of all arable land in the Novosibirsk region in fertilizer N input. Both N concentration and storage in lake sediments exceeded significantly the ones in the soils of the adjacent territories, where N_{org} storage in the upper 40 cm ranged 0.9-1.6 kg N m^{-2} in chernozems (our data, unpublished).The sedimentary organic matter C/N atomic ratio in the studied lakes ranged from 9,0 to 13,2, averaging 11,7. This relative enrichment of sediment organic matter in N most likely results from N fixation by cyanobacteria in lakes, i.e. the flux that almost absolutely lacks any regional estimates.

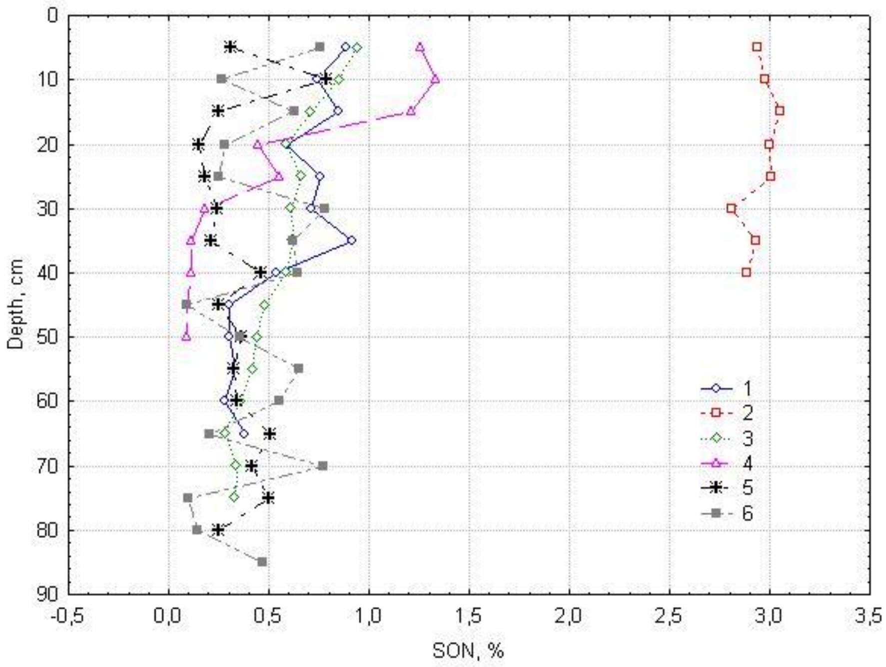

Fig. 2. Sediment profile distribution of organic nitrogen content

Lakes: 1- Kankul, 2 – Kachkulnya, 3 – Itkul, 4 – Kusgan, 5 – Barchin, 6 – Kambala. SON – sediment organic nitrogen

Table 5. Sediment organic N content in the investigated West Siberian lakes (mean ± s.d.)

Lake	N_{org}, %	N_{org} storage in 0-40 cm	
		kg N m^{-2}	10^6 kg N $lake^{-1}$
Kankul	0.58 ± 0.19	4.3	50
Kachkulnya	2.94 ± 0.08	17.0	20
Itkul	0.55 ± 0.14	4.0	60
Kusgan	0.54 ± 0.11	3.7	10
Barchin	0.34 ± 0.11	1.8	12
Kambala	0.45 ± 0.11	3.0	11

Once again assuming that the sediment organic matter storage variability in the studied lakes roughly embraces the respective variability in the total number (*ca.* 3000) of lakes in the Novosibirsk region, we can estimate N stock in sediment organic matter as $81 \cdot 10^9$ kg N for the Novosibirsk region and $0.6 \cdot 10^{12}$ kg N for the south of West Siberia.

We are fully aware that our estimates of C and N sticks in lake sediments are quite rough. But we believe it is important to present such pilot estimates in order to draw attention to the fact that several thousands lakes in the south of West Siberia play important, yet poorly evaluated role in the regional carbon budget, their significance exceeding that of adjacent soils and being comparable to peatlands. Thus our data comply with the emerging (albeit slowly!) vision that small lakes may be very – if not the most! - important sites in the biosphere for organic carbon sequestration [5, 23].

As increase in vegetation productivity due to increased growing season length in West Siberia is expected in the future [22], the role of lake sediments as organic matter sink may further increase. At the same time, as weather extreme events such as high temperatures and draughts in the southern forest-steppe zone are projected to occur more often by the 2050 [24], less burial or organic carbon may occur in sediments as they may serve as a substantial source of carbon dioxide emission [25, 26], as lakes are shallow and hence drastically fluctuating in area depending on regional weather conditions. Accurate estimation of sediment volume, lake shape and area is also exacerbating the challenge of accurate estimation of element pools in sediments [16]. All these urge for long-term, well-targeted and well-planned investigation of carbon turnover components and processes in lake sediments in particular and lake ecosystems on the whole to assess and document the importance of inland lake ecosystems both regionally and globally.

Location of sediments from different lakes in the plane of the first two principal components, extracted from the matrix with C and N content of sediment organic matter, labile mineral N and P_2O_5 content as variables and lake sediment samples as objects, showed 3 distinct groups (Fig.3).

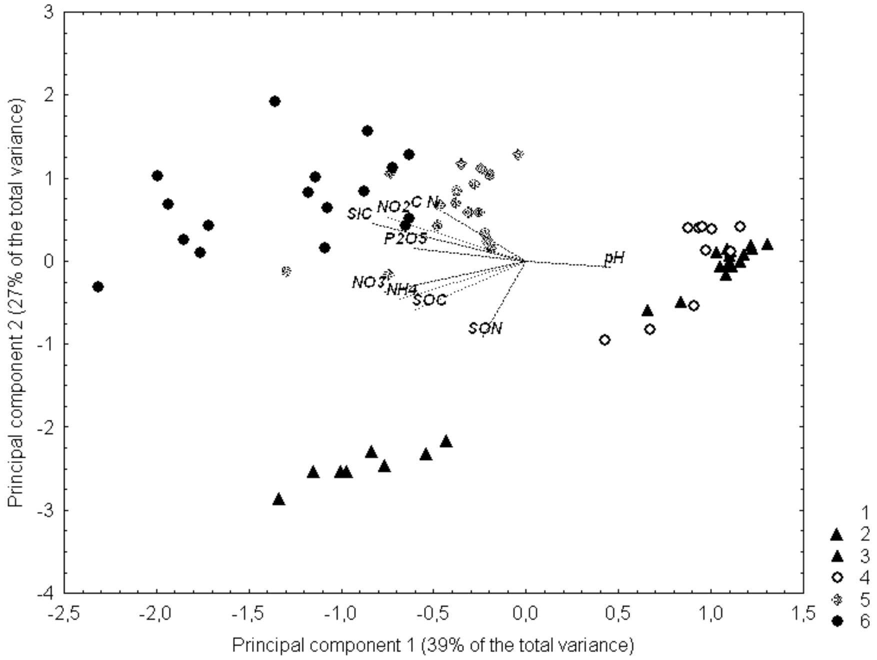

Fig.3. Principal components analysis of sediment properties: location of different properties and sediments in the plane of the first two principal components. *Lakes: 1-Kankul, 2 – Kachkulnya, 3 – Itkul, 4 – Kusgan, 5 – Barchin, 6 – Kambala. Abbreviations: SOC – sediment organic carbon, SIC – sediment inorganic carbon, SON – sediment organic nitrogen.*

The 1st principal component differentiated between sediments with increased pH and relatively low organic matter content, and, *vice versa*, lower pH and higher organic matter content, while the 2nd principal component separated organic matter rich sediment with increased organic nitrogen content from mineral sediments. Although the studied lakes are located in different subzones of the forest-steppe zone, no latitudinal gradient can be discerned in their location in the plane of the first two principal components.

The PCA performed on the data on chemical elements content in sediments (Tab.6) grouped together most elements, from Be, Na and K to Fe and some heavy metals, on the positive extreme of the 1st principal component, while placing Sr and Ca on its negative extreme

(Fig.4). The PCA supplementary variables allow concluding that increased content of elements was observed when organic matter content was lower. The 2nd principal component was determined mostly by alkaline earths, being balanced on the negative pole by Cd. Sediments from every lake grouped separately (Fig.4), shows the most characteristic variable for each sediment. For example, the increased Cd content separating lake Kambala sediments on the negative pole of the 2nd principal component (Fig.4) is most likely due to surface runoff from the adjacent fertilized agricultural land. More light-textured and poor in organic matter sediment of the Kusgan lake had higher concentrations of metals, while increased total alkaline earths content correlated with increased pH in sediment extracts from Kankul, Itkul and Barchin lakes (Fig.4).

So biogeochemically each lake ecosystem seems to be unique. Lakes collect water discharge from vast areas, and characteristic features of the latter (climate, parent rocks, vegetation, land use, etc.) determine lake water properties, including sediment properties [27]. All the lakes we studied are located within the forest-steppe biome, and as such, are undoubtedly dependent on the biome functioning. However, as each lake catches its waters from its own specific terrain with specific conditions and

Table 6. Chemical elements content (% and ppm) in sediments of the investigated West Siberian lakes (mean ± s.d., n=15)

	Kankul	Kachkulnya	Itkul	Kusgan	Barchin	Kambala
			%			
Fe	1.9 ± 0.1	0.5 ± 0.1	2.7 ± 0.1	3.7 ± 0.4	0.7 ± 0.1	2.2 ± 0.1
Al	4.4 ± 0.1	0.8 ± 0.2	4.6 ± 0.7	7.8 ± 0.9	1.0 ±0.2	3.5 ± 0.2
Ca	8.3 ± 0.5	2.1 ± 0.1	6.5 ± 0.4	1.6 ± 0.6	12.3 ± 0.9	1.8 ± 0.3
Mg	1.9 ± 0.1	0.8 ± 0.0	2.0 ± 0.0	1.2 ± 0.2	0.8 ± 0.0	0.7 ± 0.0
Na	1.1 ± 0.1	0.3 ± 0.0	1.0 ± 0.0	1.1 ± 0.1	0.2 ± 0.0	0.4 ± 0.0
K	1.1 ± 0.0	0.2 ± 0.0	1.4 ± 0.0	2.2 ± 0.2	0.3 ± 0.1	0.8 ±0.0
			ppm			
U*	2.8 ± 0.5	2.6 ± 0.4	2.8 ± 0.3	3.4 ± 0.6	4.4 ± 0.7	2.4 ± 0.4
Th*	4.1 ± 0.2	0.8 ± 0.3	6.0 ± 0.3	8.5 ± 0.6	2.5 ± 0.6	5.7 ± 0.5
Cd	0.16 ± 0.04	0.14 ± 0.02	0.14 ± 0.02	0.28 ±0.09	0.12 ± 0.02	0.24 ± 0.02
Pb	10.0 ± 1.0	5.5 ± 1.7	13.3 ± 0.8	14.8 ± 0.6	3.8 ± 1.3	8.2 ± 1.0
Cu	18.8 ± 1.4	12.9 ± 1.7	27.3 ±3.0	29.4 ± 1.7	8.8 ± 1.0	25.6 ± 1.5
Zn	52.2 ±3.6	29.2 ± 4.1	75.6 ± 2.7	78.8 ±3.2	36.4 ±2.5	64.1 ± 2.3
Mn	657 ±14	319 ± 15	838 ± 28	244 ± 21	975 ±51	462 ± 55
Cr	45 ± 3	20 ±4	66 ± 2	62 ± 4	19 ± 4	52 ± 2
Ni	27 ± 2	9 ± 1	40 ± 1	41 ± 4	9 ± 1	28 ± 1
Co	8.6 ± 0.5	3.6 ± 0.7	3.0 ± 0.3	10.8 ± 1.4	3.1 ± 0.5	7.5 ± 0.8
V	52 ± 2	13 ± 2	77 ± 2	89 ± 8	14 ± 2	48 ± 3
Hg	0.025 ± 0.005	0.032 ± 0.006	0.027 ± 0.012	0.018 ± 0.005	0.042 ± 0.012	0.029 ± 0.004
Be	1.2 ±0.1	0.3 ± 0.1	1.7 ± 0.1	2.0 ± 0.1	0.4 ± 0.0	1.1 ± 0.0
Ba	214 ± 30	67 ± 11	322 ± 40	232 ± 48	147 ± 7	51 ± 4
Sr	816 ± 70	282 ± 10	453 ± 22	115 ± 28	863 ± 80	138 ± 14
Li	22.2 ± 1.5	24.4 ± 13.2	30.3 ± 1.3	31.4 ± 3.4	9.3 ± 0.9	14.1 ± 1.4
Cs	12.9 ± 8.1	14.6 ± 5.1	7.5 ± 7.0	14.6 ± 8.7	22.0 ± 12.4	8.2 ± 4.7

** natural radionuclides*

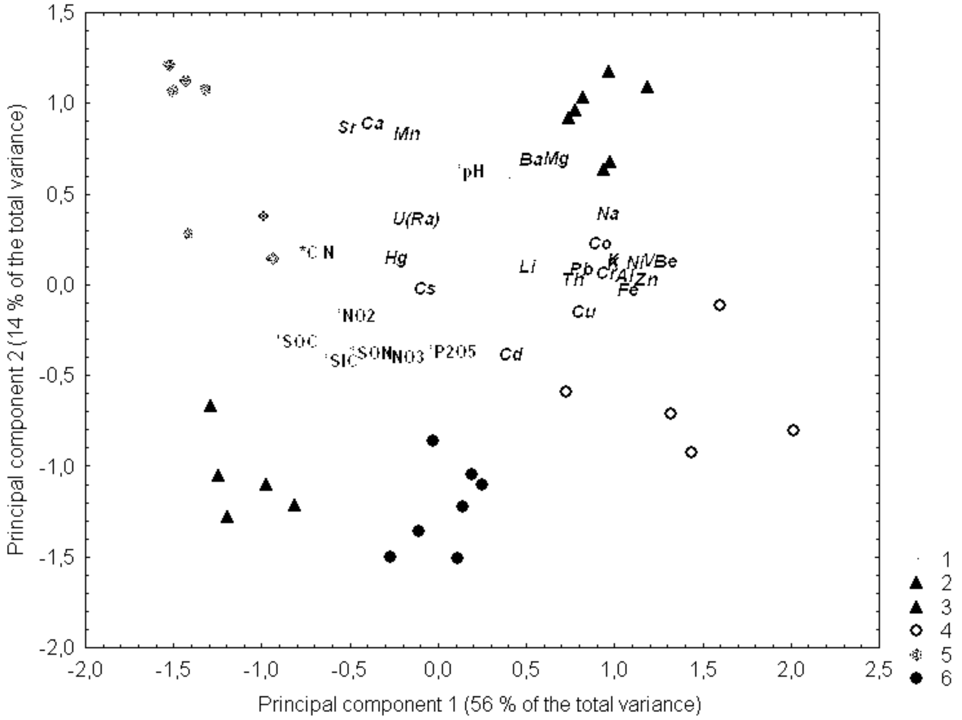

Fig.4. Principal components analysis of chemical elements content in lake sediments: location of elements (variables) and sediment samples in the plane of the first two principal components extracted from the matrix with 24 elements as variables *Supplementary variables are shown in red. Lakes: 1- Kankul, 2 – Kachkulnya, 3 – Itkul, 4 – Kusgan, 5 – Barchin, 6 – Kambala. Abbreviations: SOC – sediment organic carbon, SIC – sediment inorganic carbon, SON – sediment organic nitrogen*

history of land use, all affecting the quantity and quality of water and other input into a lake, and hence, via the chain of interactions, the quality and quantity of lake sediments. Almost half of sediment organic matter may result from terrestrial plant material [28]. Recently it was shown that sediment properties may be affected even when the adjacent forests are under the pest attack which brings about changes in the quantity and quality of organic matter input into the lake with surface water flow [29]. Thus all kinds of different environmental processes in lake catchment area result in specific chemical nature of lake sediments even within one and the same biome. We are well aware that any statement about lakes and their sediment uniqueness is a truism; however, this apparent truism is seldom explicitly articulated or addressed, although it explains often inconsistent or negative results concerning the effect of sediment/sapropel amendment on crop yields.

CONCLUSION

With results of this small pilot study we wanted to underscore two important aspects pertaining to the current functioning and potential use of inland lake sediments. Firstly, the obtained estimates of organic matter carbon and nitrogen content in lake sediments in the forest-steppe biome of West Siberia emphasize the importance of lake ecosystems in the regional carbon budget, hence necessitating more thorough a) evaluation of carbon and nitrogen components and fluxes in inland lake ecosystems and b) intensive thinking about the economic use of sediments in principle as it may result in lake ecosystem disturbance and subsequently to drastic disrupting of the regional carbon balance. Secondly, our results on the elemental composition the studied lake sediments highlighted the unique biogeochemistry of lakes located within one and the same biome. This fact should be taken into account while contemplating potential sediment use as fertilizer and soil conditioner in agriculture and bioremediation due to multiple unknown and therefore unforeseen interactions with crops, soils, agricultural practices, etc.

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