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INFLUENCE OF DRAINAGE AREA FACTORS ON THE WATER QUALITY OF SMALL LAKES IN THE KOUTAJOKI RIVER BASIN WITH SPECIAL REFERENCE TO METALS

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The purpose of this work is to ascertain the extent to which the quality of water in small lakes depends on the physical and chemical properties of the immediate drainage area. Special attention will be given to metals. The material consists of water quality data on 131 lakes more or less in a natural state, which were obtained from the basic survey of water quality in the watercourses of this area. The research area consists of the Koutajoki river basin in Kuusamo, where five sub-systems have been investigated. The area is divided into three classes on the basis of the quality of the bedrock and into four classes on the basis of the quality of the soil. The findings of the work clearly indicate that the geochemical properties of both the bedrock and the soil influence the water quality of the lakes. As regards the other drainage area factors, the percentages of mire and lake coverage were highly influential in some cases. The wintertime heavy metal concentrations of some lakes suggest a need to explore the bedrock for possible exceptionally high metal contents.

Index words: lake, water, geochemistry, soil, bedrock, sediments, metals, trace elements.

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1. INTRODUCTION

The water quality survey of the Kuusamo lakes was begun in 1983, when the lakes 1 km^2 or more in area were investigated in both winter and summer (Heinonen and Myllymaa 1974, Myllymaa 1978). The lakes 0.5—0.99 km^2 in area were surveyed in 1977 (Myllymaa and Ylitolonen 1980, Piispanen and Myllymaa 1982). The lakes 0.1—0.49 km^2 in area were covered during the years 1977—1984, of which the lakes of the Koutajoki river basin to be dealt with here were gone through during 1978—1979.

It has been noted that the bedrock and soil of the research area crucially contribute to some aspects of water quality (Heinonen and Myllymaa 1974, Myllymaa and Ylitolonen 1980, Piispanen and Myllymaa 1982). The large lakes of the Koutajoki river basin and the basin of the river Kemjoki discharging in the White Sea typically have high electrolyte contents and alkalinity values and low colour values and phosphorus concentrations of the water. The medium-sized lakes (0.5—0.99 km^2) of the Koutajoki river basin turned out to have high magnesium concentrations, while the iron and manganese values were low (Myllymaa and Ylitolonen 1980). The differences between the Koutajoki and Iijoki river basins were great, which was found to be due largely to the quality of the bedrock and in some cases to the mire percentage of the drainage area (Piispanen and Myllymaa 1982).

The basic differences in water quality were due to differences in the bedrock and the soil. The characteristics of the bedrock were most clearly reflected in the bottom waters, while in the surface waters the material concentrations were lower. The reasons for this include dilution, changes of pressure, oxidation, chemical and biochemical reactions, etc. (Hartikainen 1976). As the electrolyte concentration of the bottom water increases, the concentration of calcium bicarbonate increases most (Lahermo 1969). In areas of basic bedrock this results in high pH values. In the drainage basins of the rivers Koutajoki and Kemjoki, the high calcium concentration of the water is due to e.g. lime deposits. There are also several bog lime deposits in Kuusamo (Vasari and Näykki 1972).

The bog lime deposits are not only due to the presence of limestone, but large amounts of calcium also enter the water upon the erosion of other basic rock types (Lahermo 1970). Rock types containing alkaline and alkaline-earth minerals are abundant at Kuusamo (Simonen 1964, Piispanen 1972, Piispanen and Myllymaa 1982).

The heavy metal concentrations of the waters in this area have not been determined prior to the present work. A program of monitoring the heavy metal concentrations at the flow observation sites on the rivers Kitkajoki and Oulankajoki, which have been established in a state-wide project, was started at the same time. The sulfide ore deposits found in this area (Piispanen 1972, Silvennoinen 1972) give rise to an assumption that higher-than-average heavy metal concentrations might possibly be encountered in the lakes.

We can postulate, in general, that small lakes represent small and well delimited drainage basins, and that the quality of water therefore reflects the quality of the bedrock and the soil of the immediate drainage area (Myllymaa and Ylitolonen 1980). The results now obtained can be applied to the development of e.g. water supply and fish farming. The ionic relations of the soil and the water are also assumed to affect the general state of health of the population through food and drinking water (Piispanen and Myllymaa 1982). The heavy metal concentrations of water have also been utilized in ore prospecting (Chisholm 1950, Kleinkopf 1960, MacDonald 1969, Cameron 1976 and 1977).

2. RESEARCH AREA

The Koutajoki river basin, which constitutes the present research area, is located in the northern part of the Kuusamo municipality in the Koillismaa highlands (Fig. 1). The entire area lies more than 200 meters above the sea level, and the maximum altitude of the lakes covered here is 318 meters. The topography is highly variable as regards altitude, and lakes are numerous in the area.

Owing to the cool climate, the small and shallow basins are being paludified. The absolute and relative altitude relations seem to depend somewhat on the rock type. The highest hills consist of quartzite. In addition to tectonic factors, erosion by flowing water also significantly contributes to the topographic irregularity. Tectonic factors and

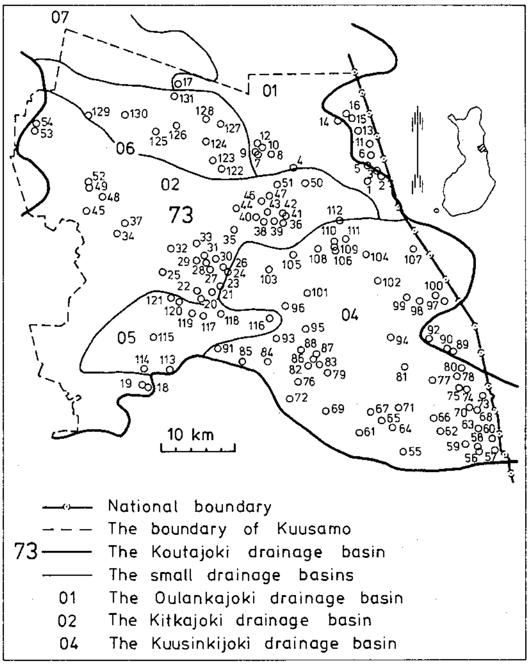


Fig. 1. Research area and observation stations.

the direction of glacial trasportation are largely responsible for the direction of the lakes in this area, which is generally between east-west and northwest-southeast. The drumlins, and in some cases the eskers, are also similar in direction. The most unambiguous drumlin scenery is encountered on the headwaters of the rivers Kuusinkijoki and Kitkajoki. The most regularly shaped water courses and the largest and most regular lakes occur in the drumlin area. There are fewer lakes near the major Oulanka valley than on the clear-cut highland regions.

As regards the bedrock, northern Kuusamo belongs to the Karelidic belt of eastern and northern Finland (Simonen 1980). Conglomerates, quartzites, dolomites and mica schists are the most common rock types there.

The sedimented rock types are interlaid with parallel and transgressive sills, lava beds and plutonic rocks which have low-grade metamorphism.

That the research area will remain at least partly in a natural state is guaranteed by the presence of the Oulanka National Park, the lakes Kitkajärvi and the river Oulankajoki, which belong to the Project Aqua (Luther 1966), and the Kitkanniemi National Park planned to be located in the area. The present findings can also later be used as reference for evaluating the effects of human activities.

3. MATERIAL AND METHODS

The present investigation deals with the lakes of the Koutajoki river basin 0.1—0.49 km^2 in area (Appendix 1). The field work was carried out in March — April and August — September 1978—1979. Only a few lakes with exceptionally difficult access or loaded by fish farming have been excluded (Myllymaa 1981). The data on the lakes and their immediate drainage area (area of the lake, height above sea level, and area, mire percentage and lakes of the drainage basin) were determined with the aid of the base maps of the National Survey Board.

Since the depth charting of lakes of this size has not yet been completed, the volume of the lake has been calculated as the volume of a cone. When calculating the volume-weighted means of the quality parameters, the following formulas were applied (Lappalainen 1977):

$$\frac{V_i}{V} = (1 - \frac{h_i}{h})^3 \qquad (1)$$

h_i = depth of observation
h = maximum depth (observed)
V_i = volume below depth level V_i
V = total volume

The following weight coefficients are obtained for the observation values, when calculated from the surface:

$$k_1 = 1 - (1 - \frac{H_2}{2h})^3 \qquad (2)$$

$$k_2 = (1 - \frac{H_2}{2h})^3 - (1 - \frac{h_2 + h_3}{2h})^3 \qquad (3)$$

$$k_3 = (1 - \frac{h_2 + h_3}{2h})^3 - (1 - \frac{h_3 + h_4}{2h})^3 \qquad (4)$$

$k_{1,2,3}$ = weight coefficients for sampling depths
$h_{1,2,3}$ = sampling depths
h = maximum depth

The water samples were analyzed in the laboratory of the Water District office of Oulu and the research laboratory of the National Board of Waters, using the methods currently applied in water administration (Erkomaa et al. 1977).

4. RESULTS

4.1 Variation by rock and soil classes

The classes that were used in this work correspond to those proposed by Lahermo (1969). Dolomite, which occurs as a specialty in this material, was classified as belonging to the alkaline (mafic) rocks due to the lack of silica. The data on the bedrock were obtained from Hackman (1918) and Hackman and Wilkman (1929), Piispanen (1972) and Silvennoinen (1972 and 1973). The data on the soil are mostly based on the findings reported by Aario et al. (1974).

Rock types
K1 = felsic (siliceous)
  — albite diabase
  — granit
  — gneiss
  — quartzite
K2 = mafic (alkaline)
  — dolomite

— green schist
— mica schist
— hornblende schist
— amphibolites
K3 = felsic and mafic rock types

Soil types
M1 = sand and gravel
M2 = moraine
M3 = moraine and peat
M4 = peat

The figures 2—4 show the mean of the variables, the standard error of the mean and the number of observations in each rock and soil class. The tables 1—2 show the differences in the concentrations of metals, silicic acid and sulfate at a depth of 1 meter between the rock and soil classes. The differences between the soil classes within each rock class are presented in Table 3. The water quality variables 1—8 (Turbidity-P) are shown on the Tables 1—3 as weighted means of the water mass, which means that they are influenced by processes of both the epilimnion and the hypolimnion.

The potassium, calcium and copper concentrations are significantly higher in areas with mafic rocks than in areas with felsic rocks (Table 1 and Figs 3—4). The difference in the sulphate concentration is almost significant (Fig. 5). The significant or almost significant differences in conductivity, alkalinity and pH (Fig. 1) are mostly due to the differences in potassium and calcium (Fig. 4). There is an interesting difference in the values of colour and COD (Fig. 2) reflecting the presence of humus, which are significantly or highly significantly highest in class K1. The concentrations of nitrogen and phosphorus are also highest in areas of felsic rocks (Fig. 3).

In the rock class K2 the values of COD and potassium are significantly higher than in class K3 (Figs 2—3). The difference in the nitrogen concentration is almost significant (Fig. 3).

Sodium ($p < 0.01$) and silicic acid ($p < 0.05$) are more abundant in sandy areas (M1) than in areas of moraine (M2) (Table 2 and Figs 3 and 5), whereas moraine areas have more calcium and magnesium ($p < 0.01$) (Fig. 4). Since, moreover, peat often occurs in moraine areas (M3), the iron and manganese concentrations are significantly or almost significantly higher than in sandy areas (Fig. 3). Calcium is significantly and magnesium highly significantly more abundant in class M2 than i class M3 (Fig. 4), while sodium is significantly less abundant (Fig. 3). The iron, manganese, potassium and magnesium concentrations of water are higher in peaty areas (M4) than in sandy areas (M1) (Figs 3—4). Compared with moraine areas, sodium and silicic acid are more abundant, but magnesium less abundant (Figs 3—5). The zinc values are highest in class M3 and lowest in class M4 (Fig. 4). Silicic acid is least abundant in the moraine areas M2 and M3, the difference from the peatland area M4 being significant (Fig. 5).

Conductivity and alkalinity are highest in the area M2 and lowest in the area M1 ($p < 0.01$ and < 0.001). The areas M1, M3 and M4 also differ significantly (Fig. 2). The difference in pH is only significant between the classes M2 and M3 (Fig. 2). The colour and COD values increase in the order $M1 < M2 < M3 < M4$ (Fig. 2).

Within the rock class K1, silicic acid is significantly more abundant in sandy than in moraine areas (Table 3 and Fig. 5). The concentrations are even higher in the peatland areas M3 and M4, but the small number of the observations results in low significance. Zinc is most abundant in the classes K1M1 and K1M3. The difference between K1M2 and K1M3 is significant (Fig. 4). The lead concentration increases in the order $K1M4 < K1M3 < K1M2 < K1M1$. The classes K1M2 and K1M3 differ significantly (Fig. 4). The differences in pH, alkalinity and colour between the classes M3 and M4 are also more significant in the rock class K3 than in the whole material (Fig. 2).

Within class K2, significant or almost significant differences are obtained for Fe, Mn, Na, K, Ca, Mg and SO_4 (Table 3 and Figs 3—5). Iron and manganese are most abundant in class K2M4 and least abundant in class K2M1. Sodium is most abundant in class K2M4 and least abundant in class K2M3. The calcium and magnesium values are highest in the moraine areas K2M2 and lowest in class K2M3.

The significances of the other elements are generally also lesser in each class than in the analysis of the soil classes in the whole material. The differences between the classes M3 and M4, however, are slightly more significant for the variables expressing electrolyte content, buffering capacity and humus (Table 3 and Fig. 2).

It is interesting that in the rock class K2 zinc is scarce in the sandy areas M1 compared with the moraine and peatland areas (Table 3 and Fig. 4). The difference is statistically highly significant, but only two lakes of sandy areas were included in this rock class, which means that the result is uncertain.

The effect of the soil in the rock class K3, which includes both felsic and mafic rock types, is highly significant for the calcium and magnesium concentrations (Table 3 and Fig. 4). The potassium concentrations differ almost significantly (Fig. 3).

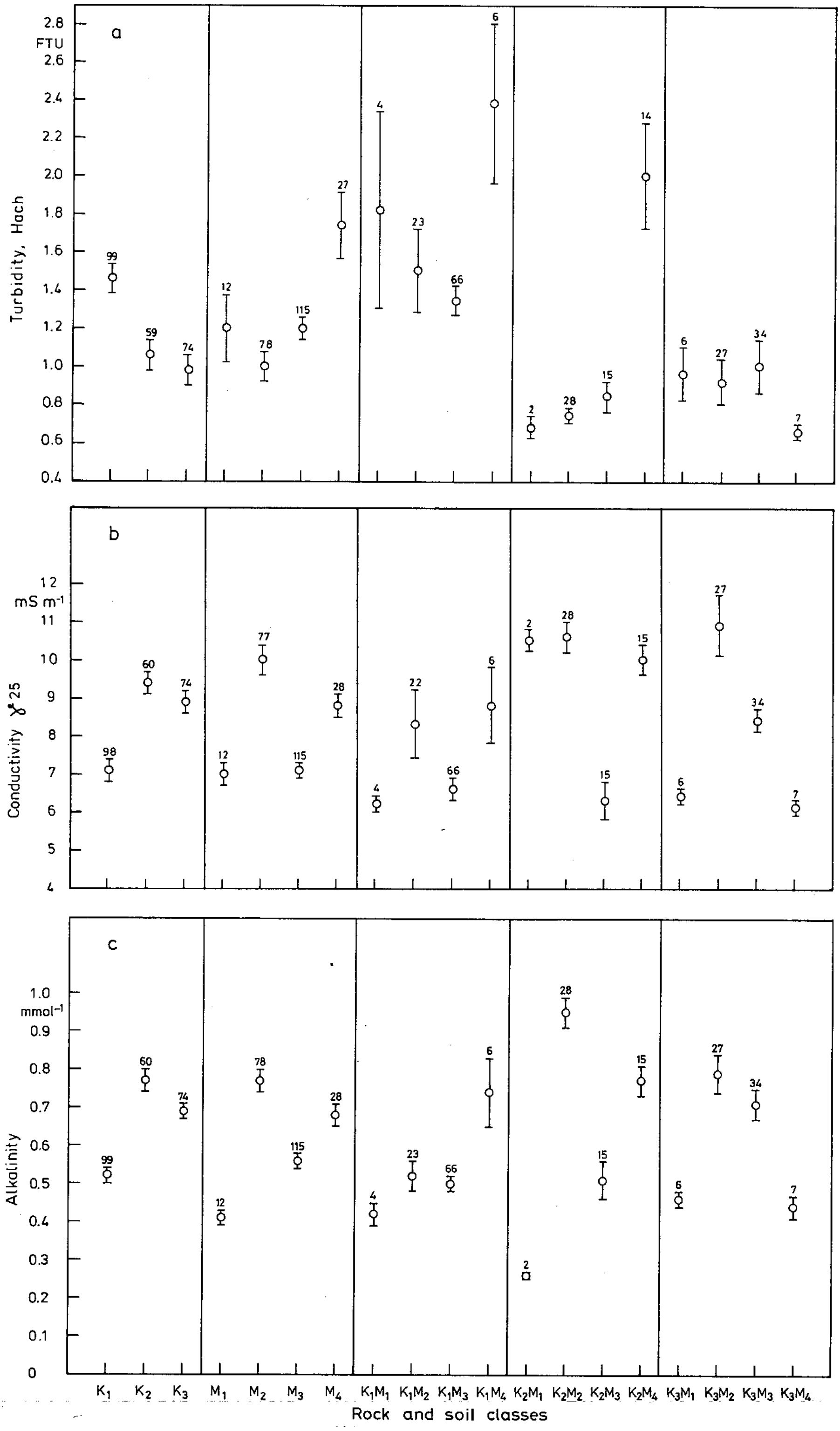
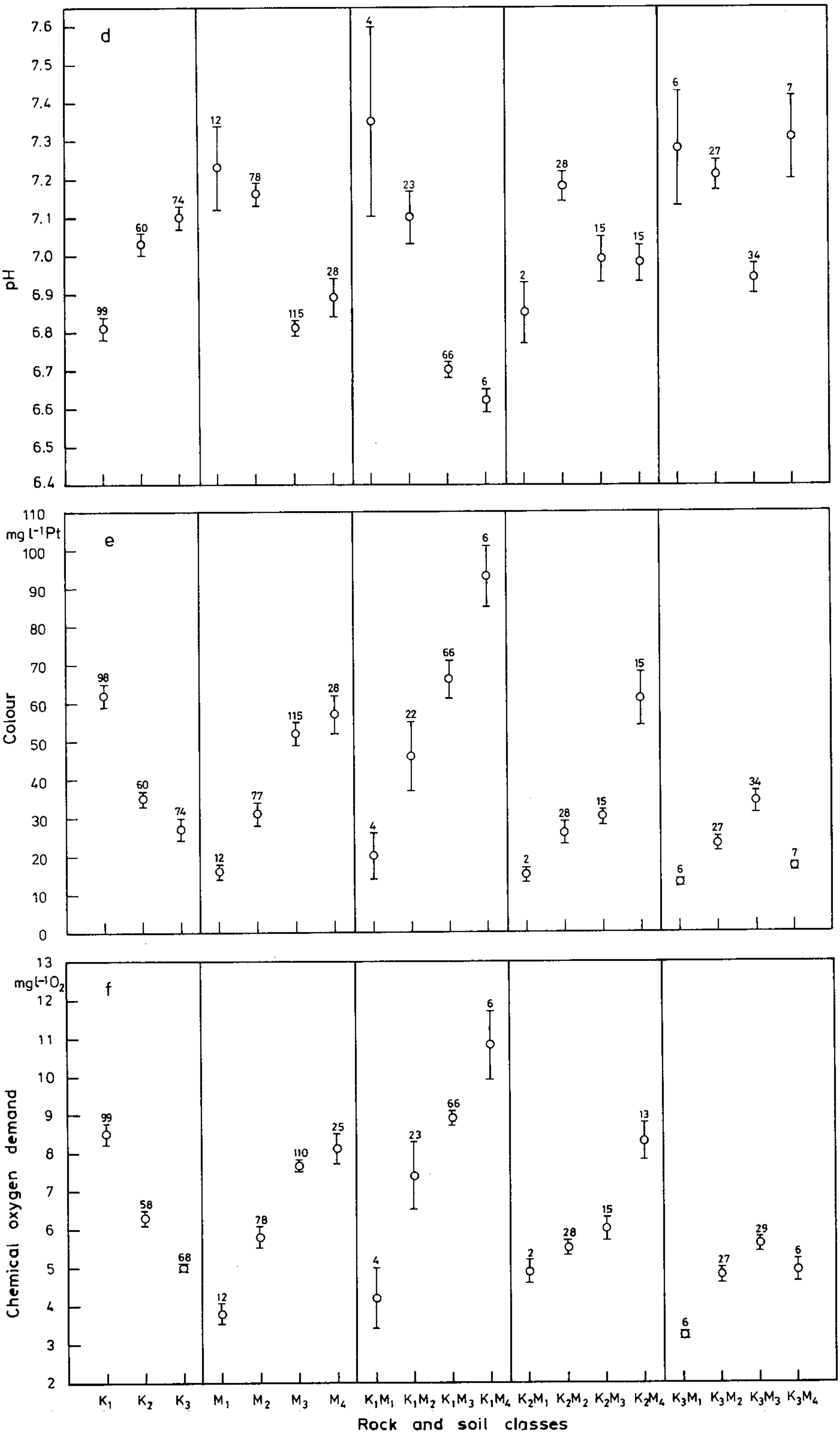


Fig. 2. Average concentrations, standard errors of the means and sample size for turbidity (a), conductivity (b), alkalinity (c), pH (d), colour (e) and chemical oxygen demand (f) in the different rock and soil classes.



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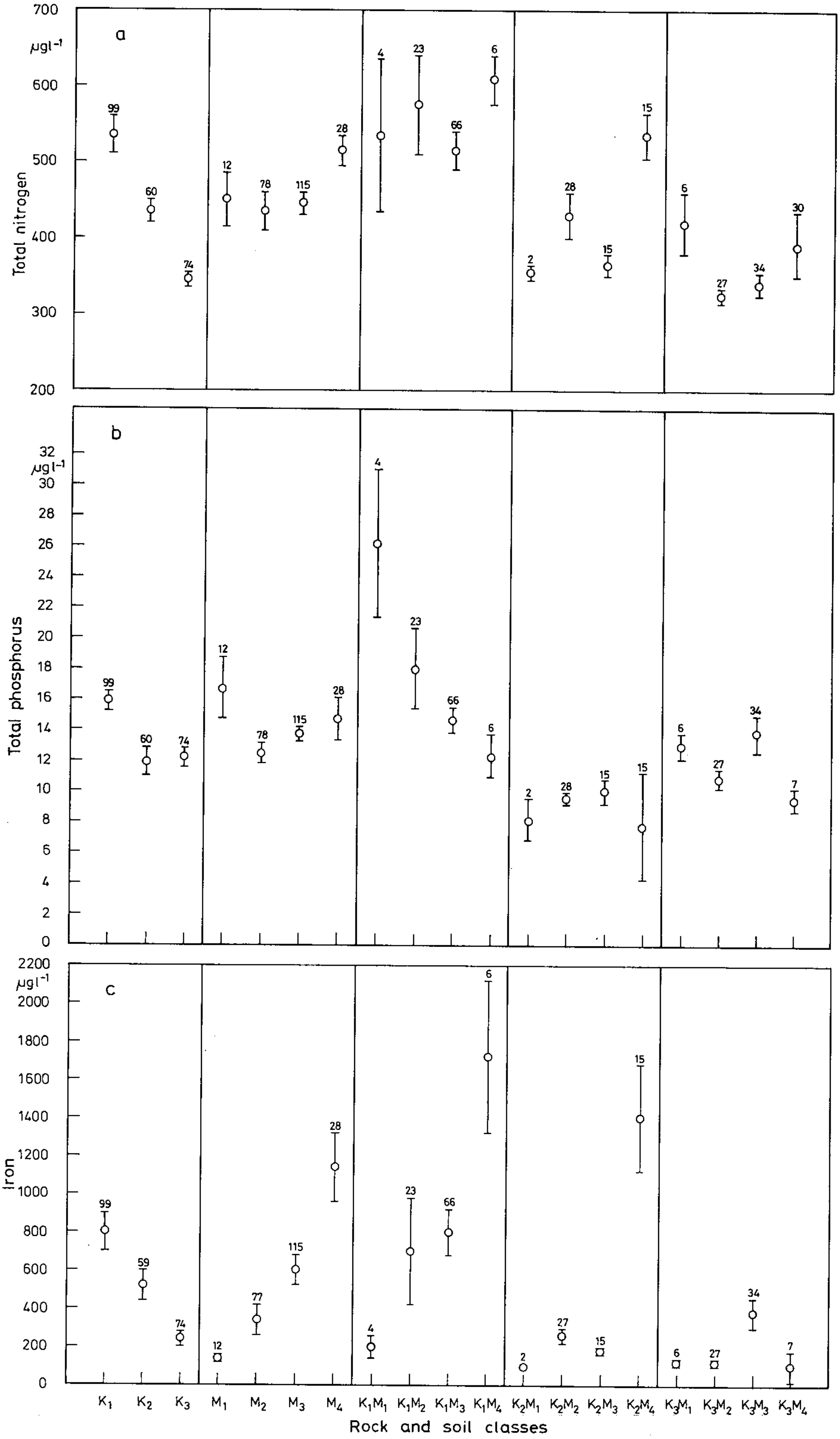
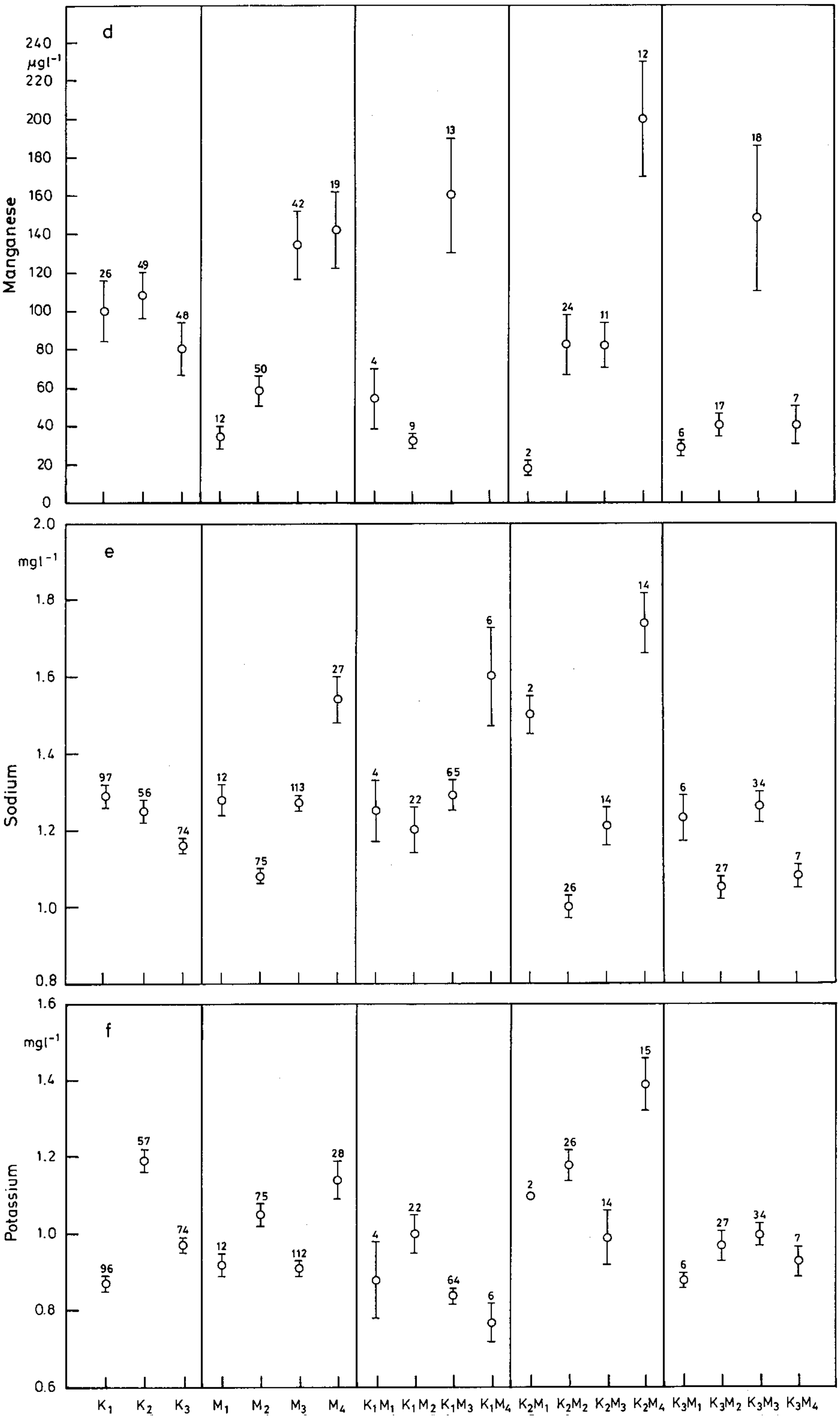


Fig. 3. Average concentrations, standard errors of the means and sample size for nitrogen (a), phosphorus (b), iron (c), manganese (d), sodium (e) and potassium (f) in the different rock and soil classes.



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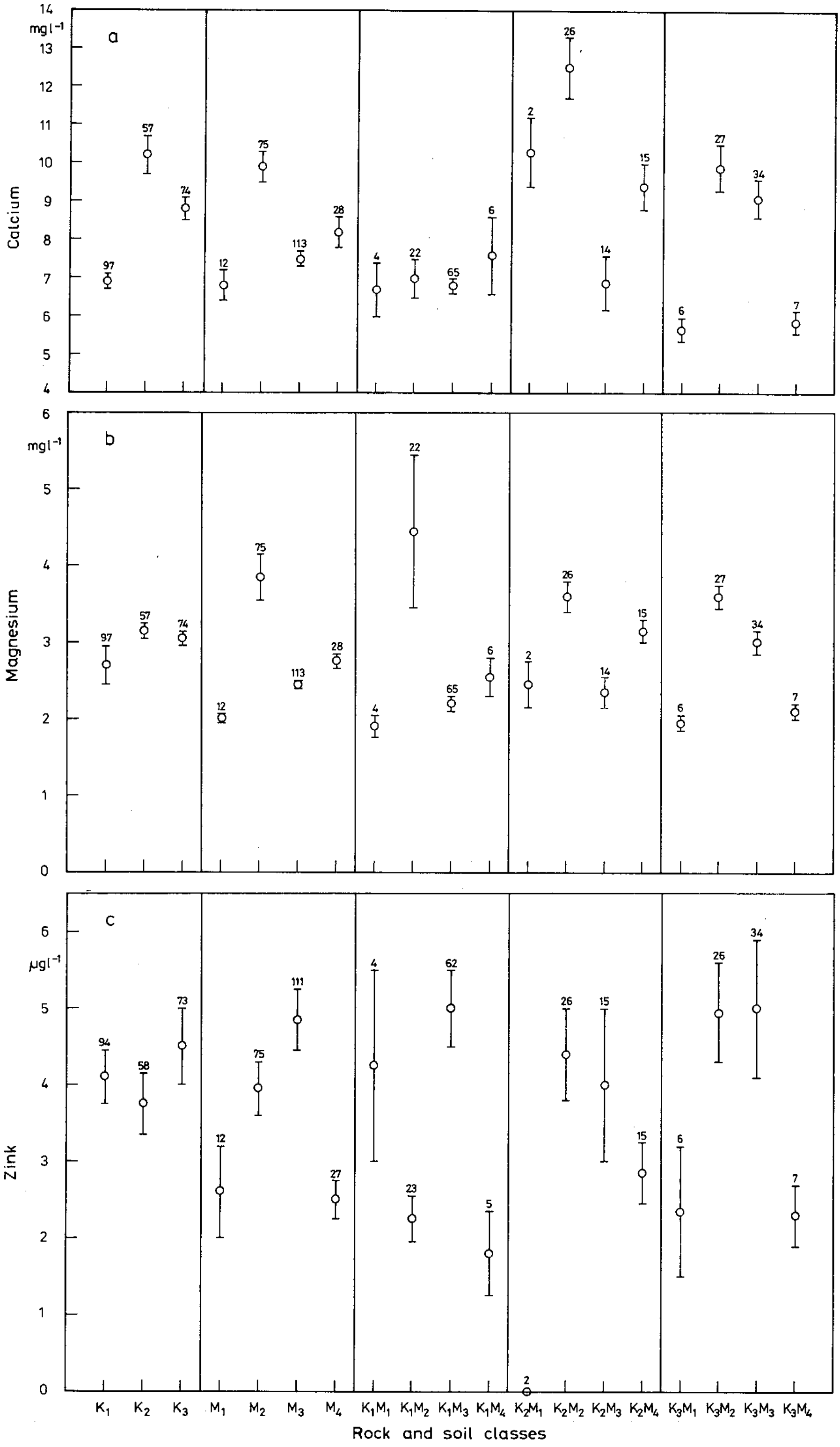
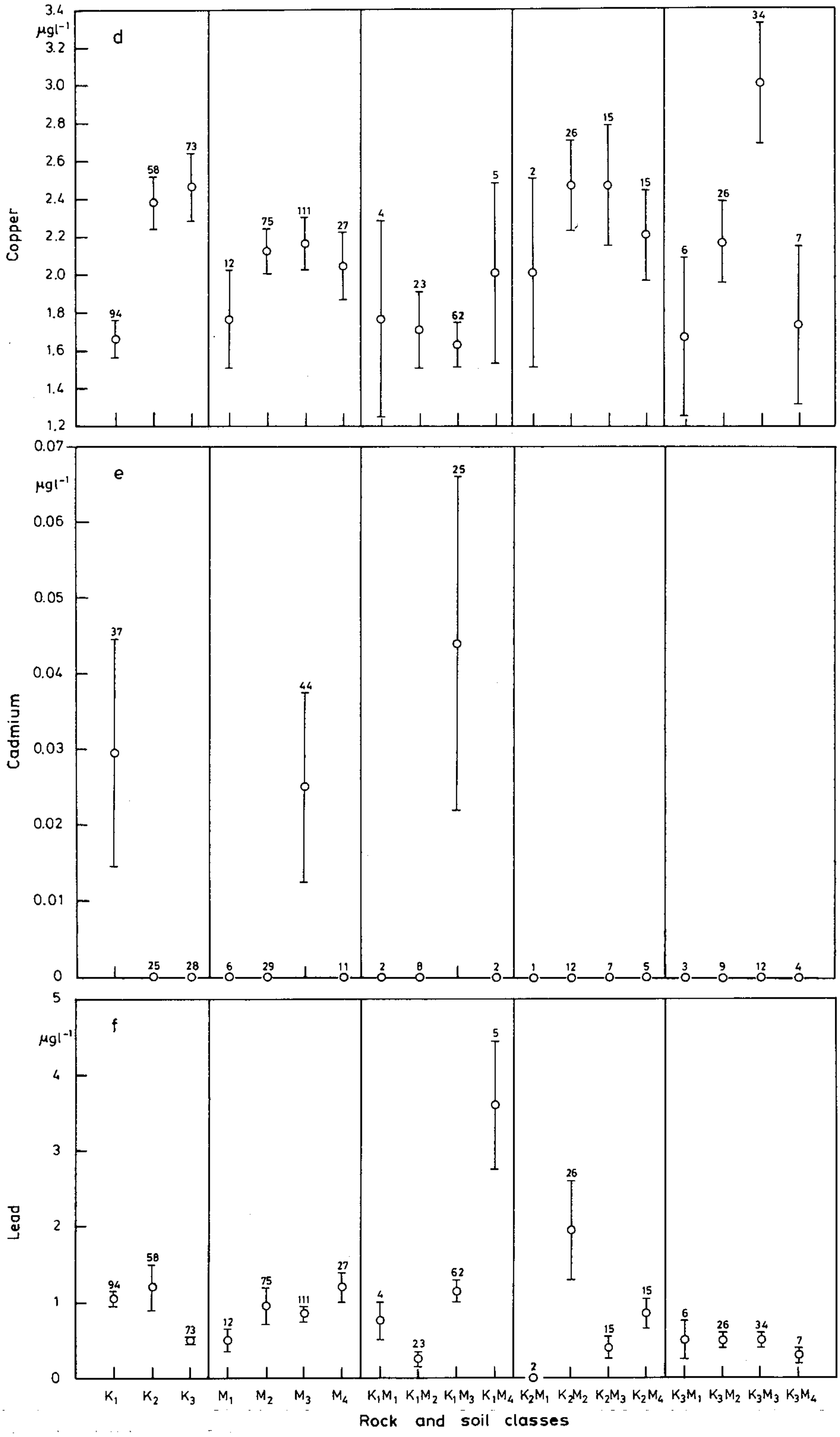


Fig. 4. Average concentrations, standard errors of the means and sample size for calcium (a), magnesium (b), zinc (c), copper (d), cadmium (e) and lead (f) in the different rock and soil classes.



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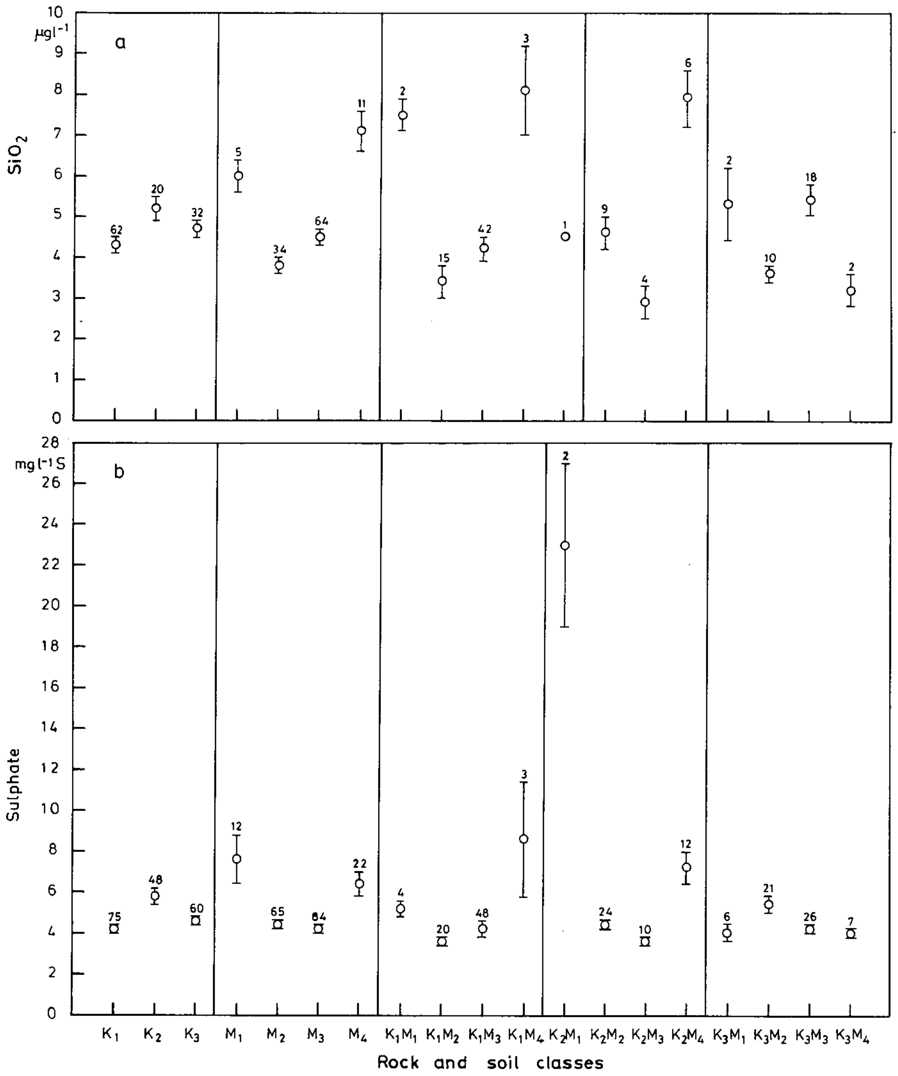


Fig. 5. Average concentrations, standard errors of the means and sample size for silica (a) and sulfate (b) in the different rock and soil classes.

The difference between the iron and SiO_2 concentrations is marginal (Figs 3 and 5). Particularly within class K3, the waters of the moraine areas M2 contain significantly more calcium and magnesium than the waters of the sandy and peaty areas (Table 3 and Fig. 4).

The iron concentration hence depends highly significantly on the quality of the bedrock and significantly on the quality of the soil. The potassium concentration depends almost significantly on the quality of the soil. The potassium concentration depends almost significantly on the bedrock, while the sodium concentration is significantly related to the quality of the soil. The calcium concentration is highly significantly dependent on the quality of the bedrock and significantly on the soil. The dependence of the magnesium concentration on the soil is significant. The copper and lead concentrations depend almost significantly on the bedrock. Within the rock class

Table 1. Water quality in the rock classes and the statistical significance (F) of the differences. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ∘ $p < 0.1$; K1 = silicic rocks, K2 = alkaline rocks, K3 = both silicic and alkaline rocks. The values of variable 1—8 (Turbidity — Tot. p) are given as a mean of the water mass weighted with the volume. The other values (Fe — SO_4) are those of the epilimnion (1 m depth).

		K1			K2			K3			F		
		Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	K1/K2	K1/K3	K2/K3
Turbidity FTU		1.5	9.1	0.17	1.1	7.6	0.21	0.98	9.8	0.21	∘	*	
Conductivity	mS m^{-1}	7.1	44.0	0.90	9.4	19.2	2.00	8.9	41.2	1.3	**	*	
Alkalinity	mmol l^{-1}	0.52	1.55	0.02	0.77	1.94	0.07	0.69	2.16	0.01	***	**	
pH		6.8	8.6	5.9	7.0	8.3	6.3	7.1	8.5	5.7	**	***	
Colour		62	490	5	35	210	4	27	150	5	**	***	
COD_{Mn}	mg l^{-1} O_2	8.5	42.0	0.8	6.3	16.0	1.2	5.0	10.0	1.2	***	***	**
Tot. N	µg l^{-1}	535	3 200	110	437	1 308	136	345	790	144	∘	***	*
Tot. P	µg l^{-1}	16	72	4	12	77	2	12	54	1	*	*	
Fe	µg l^{-1}	809	14 000	21	524	8 200	11	239	5 400	7		*	
Mn	µg l^{-1}	99	790	0	109	720	0	79	1 400	0			
Na	mg l^{-1}	1.3	3.3	0.4	1.3	3.1	0.5	1.2	2.3	0.4		∘	
K	mg l^{-1}	0.9	2.3	0.3	1.2	2.8	0.4	0.97	2.1	0.4	***	∘	**
Ca	mg l^{-1}	6.9	18.0	0.9	10.2	40.0	0.9	8.8	7.8	0.1	***	*	
Mg	mg l^{-1}	2.7	46.0	0.4	3.1	8.6	0.4	3.1	8.6	0.3			
Zn	µg l^{-1}	4.1	42.0	0	3.8	26.0	0	4.5	60.0	0			
Cu	µg l^{-1}	1.7	10.0	0	2.4	9.0	0	2.5	19.0	0	*	∘	
Cd	µg l^{-1}	0.03	1.1	0	0	0	0	0	0	0			
Pb	µg l^{-1}	1.0	10.0	0	1.2	33.0	0	0.5	3.0	0		*	
SiO_2	mg l^{-1}	4.3	14.0	0.2	5.2	12.0	0.9	4.7	14.0	0.2			
SO_4	mg l^{-1}	4.2	27.0	0	5.7	31.0	1.7	4.6	16.0	1.3	∘		

Table 2. Water quality in the soil classes and the statistical significance (F) of the differences. M1 = sand or gravel, M2 = till, M3 = till and peat, M4 = peat. The other explanations are same as in Table 1.

	M1			M2			M3			M4			F					
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	M1/M2	M1/M3	M1/M4	M2/M3	M2/M4	M3/M4
Turbidity FTU	1.20	4.90	0.29	1.02	9.07	0.21	1.20	9.80	0.17	1.73	7.60	0.42					o	
Conductivity mS m^{-1}	7.0	11.0	5.0	10.1	44.0	2.1	7.1	20.0	0.9	8.8	16.0	3.8	**		*	**		*
Alkalinity mmol l^{-1}	0.41	0.57	0.25	0.77	2.16	0.09	0.56	1.89	0.01	0.60	1.53	0.27	***	**	***	**		
Ph	7.2	8.5	6.5	7.2	8.6	6.1	6.8	8.2	5.7	6.9	8.5	6.3		o		***	*	
Colour	16	55	5	31	400	5	52	490	7	57	210	4	*	***	***	**	*	
COD_{Mn} mg l^{-1} O_2	3.8	7.8	0.8	5.8	42.0	1.2	7.7	18.3	1.3	8.1	18.0	3.4	**	***	***	**	*	
Tot. N μg l^{-1}	449	1 127	180	435	3 200	136	443	2 931	110	515	1 100	208						
Tot. P μg l^{-1}	17	57	5	12	65	1	14	72	2	15	77	3						
Fe μg l^{-1}	146	420	27	336	13 000	10	600	14 000	7	1 142	8 200	29		**	*		o	
Mn μg l^{-1}	35	140	0	59	610	0	134	1 400	0	141	720	6		*	*	o	o	
Na mg l^{-1}	1.3	1.7	0.9	1.1	2.3	0.5	1.3	3.3	0.4	1.5	3.1	0.8	*		*	**	***	*
K mg l^{-1}	0.9	1.3	0.5	1.1	2.3	0.4	0.9	2.1	0.3	1.1	2.8	0.5			o	*		*
Ca mg l^{-1}	6.8	12.0	3.4	9.9	40.0	0.9	7.5	28.0	0.1	8.2	16.0	1.1	**			**		
Mg mg l^{-1}	2.0	3.0	1.3	3.8	46.0	0.4	2.5	7.8	0.3	2.8	5.0	1.1	**	*	**	*	o	
Zn μg l^{-1}	2.6	10.0	0	3.9	26.0	0	4.9	60	0	2.5	10.0	0					o	*
Cu μg l^{-1}	1.8	5.0	0	2.1	9.0	0	2.2	19.0	0	2.0	6.0	0						
Cd μg l^{-1}	0	0	0	0	0	0	0.03	1.1	0	0	0	0						
Pb μg l^{-1}	0.5	3.0	0	0.9	33.0	0	0.8	10.0	0	1.2	9.0	0						
Si O_2 mg l^{-1}	6.0	8.3	3.5	3.8	12.0	0.5	4.5	14.0	0.2	7.1	12.0	2.2	o				*	*
SO_4 mg l^{-1}	7.6	31.0	1.8	4.5	16.0	1.3	4.1	27.0	0	6.4	20.0	1.9					o	o

Table 3. The stastistical significance of the differences of the soil classes M1, M2, M3 and M4 in the rock classes. For explanations, see Table 1.

	Rock class K1					Rock class K2						Rock class K3					
	M1/M2	M1/M3	M1/M4	M2/M3	M3/M4	M1/M2	M1/M3	M1/M4	M2/M3	M2/M4	M3/M4	M1/M2	M1/M3	M1/M4	M2/M3	M2/M4	M3/M4
Turbidity								*		*	o						
Conductivity							**		**		**	**	*			**	**
Alkalinity						***	*	***	**		o	**	**			**	**
pH										*					*		
Colour							o	**		*	*		***		o		**
COD_{Mn}								**		*	o	**	***	*			
N								*			*						*
Fe		*				o	**	*		o	o						o
Mn				o		o	*	*		o	o				o		
Na						o			o	***	*				*		o
K											*		o				
Ca								o	*			**	**			**	**
Mg									*			***	**			**	*
Zn				*	o	***	o	***								o	
Pb				**				*									
Si O_2	*	o						*		o	*						
SO_4	o									o	*				o		

Table 4. Mercury concentrations of four lakes. The numerical symbols are the same as in Fig. 1 and Appendix 1.

Lake	No.	Date	Rock class	Soil class	Hg $\mu g\ l^{-1}$
Ruoppilampi	8	15.3.78	2	2	19
		25.3.80			0.2
Viipusjärvi	27	1.8.78	1	2	0.2
Syväjärvi	54	16.3.78	3	3	0.4
Alimmainen Kiekerölampi	99	22.3.79	2	4	0.1

K1, the lead concentration depends significantly and the zinc concentration almost significantly on the soil.

The pH, conductivity and alkalinity values indicative of the electrolyte concentration and buffering capacity vary, depending on the quality of both the rock and the soil. The colour and COD values, which reflect the presence of humus, generally vary parallel to the variations of soil quality. The differences in these properties between the different rock classes, however, justify more detailed analyses.

Within the rock class K1, the differences in the water quality parameters between the different soil classes are the smallest.

Mercury was determined in the epilimnion of every third lake ($n = 42$). Four of these lakes had detectable mercury concentrations ($< 0.1\ \mu g\ l^{-1}$) (Table 4).

No explanation has been found for the high concentration of Lake Ruoppilampi, 19 $\mu g\ l^{-1}$. A re-measurement yielded a mercury value of 0.2 $\mu g\ l^{-1}$. The lakes presented in Table 4 are distributed between all the three rock classes. Three of them are located close to each other. No mercury was detected in the lakes of the sandy and gravel areas.

4.2 Correlations

4.21 Oxygen

Oxygen correlates negatively with most of the measured properties (Tables 5—10). This is due to e.g. the oxygen depletion by several materials and the dependence of the solubility of the materials on the redox potential. In summer, oxygen has a highly significant positive correlation with pH and chlorophyll a due to photosynthesis, in addition to which it has a marginal correlation with turbidity, nitrogen and phosphorus (Tables 9—10).

In the hypolimnion, oxygen correlates highly significantly negatively (Tables 6, 8 and 10) with total depth, while the corresponding wintertime correlation in the epilimnion is positive (Table 7). The main factors contributing to this correlation are the oxygen consumption by the bottom sediment and the thermal stratification of deep lakes. Oxygen has a marginal negative correlation with the mire percentage of the drainage area (Table 5).

4.22 Turbidity, colour, COD and chlorophyll a

Turbidity correlates negatively with oxygen in the hypolimnion ($p < 0.001$) and positively with colour, COD, nitrogen, iron, sodium and potassium (Table 6). The factors explaining turbidity depend on the wintertime oxygen deficiency as well as the summertime primary production and the alloctonic runoff into the lake. The correlations in the epilimnion hence further include alkalinity, sodium, magnesium, and SiO_2 (Table 5). There is a highly significant summertime correlation with chlorophyll a (Tables 5 and 9). The correlations are stronger in winter than in summer (Tables 7—8).

In winter, the turbidity of the epilimnion correlates (Table 7) negatively ($p < 0.001$) with total depth. The summertime correlation with the mire percentage of the drainage area is positive ($p < 0.01$) in the hypolimnion (Table 10) and negative ($p < 0.001$) in the epilimnion (Table 8). The correlation in the hypolimnion is probably due to sedimentation and accumulation of alloctonic material in the bypolimnion. In the epilimnion, humus seems to inhibit turbidity due to algal growth. In winter, there is a negative correlation ($p < 0.001$) with total depth in the epilimnion (Table 7), which is probably due to sedimentation.

Chlorophyll a was measured from the epilimnion (0—2 m) in summer (Table 9). Highly significant correlations emerged for oxygen, turbidity, pH, nitrogen and phosphorus. The first three of these correlations are due to photosynthesis, while the last two are factors of primary production. There is a minor negative correlation between chlorophyll a and the mire percentage and lake depth.

Colour and COD mainly depend on the quantity of humus in lakes which are in a natural state. Humus generally also contains abundant nitrogen, phosphorus and iron. In our material, moreover, manganese, sodium and silicic acid generally correlate with colour and COD (Tables 5—6). It is interesting that the variables indicative of the humus quantity have a highly significant positive correlation with cadmium. The correlation

Table 5. Correlations and their statistigal significance ($p < 0.1$) between the water quality and drainage basin variables. This tabel consists of the winter and summer values of the epilimnion (1 m). A = area of lake; F = area of drainage basin; Peat = percentage of peatlands; L = percentage of lakes.

	O_2	Turbidity	Conductivity	Alkalinity	pH	Colour	COD	N	P	Fe	Mn	Na	K	Ca	Mg	Zn	Cu	Pb	SiO_2	SO_4	Chlor. a	A	Depth	F	Peat
Turbidity	.240 ***																								
Conductivity	−.351 ***	.130 *																							
Alkalinity	−.376 ***	.180 **	.820 ***																						
pH	.651 ***	.156 *	—																						
Colour	−.436 ***	.534 ***	—	134 *	−.313 ***																				
COD	−.196 **	.279 ***	—	−.119 °	−.211 ***	.779 ***																			
N	−.408 ***	.442 ***	—	—	−.181 **	.679 ***	.679 ***																		
P	—	.401 **	—	—	.110 °	.429 ***	.482 ***	.430 ***																	
Fe	−.439 ***	.512 ***	.201 **	.256 ***	−.271 ***	.886 ***	.574 ***	.607 ***	.413 ***																
Mn	−.589 ***	−.484 ***	.326 ***	.313 ***	−.285 ***	.637 ***	.354 ***	.498 ***	.251 ***	.634 ***															
Na	−.545 ***	.241 ***	.372 ***	.373 ***	−.328 ***	.384 ***	.191 **	.236 ***	—	.385 ***	.278 ***														
K	−.324 ***	.156 *	.540 ***	631 ***	—	.153 *	—	—	.143 *	.285 ***	.238 **	.540 ***													
Ca	−.295 ***	—	.708 ***	.849 ***	—	—	−.117 °	—	—	.111 °	.270 ***	.291 ***	.595 ***												
Mg	−.288 ***	.178 **	.445 ***	.516 ***	—	.442 ***	.418 ***	.529 ***	.210 ***	.518 ***	.277 ***	.271 ***	.364 ***	.471 ***											
Zn	−.334 ***	—	.231 ***	.225 ***	−.208 ***	—	—	—	—	−.129 *	.142 °	.273 ***	.187 **	.227 ***											
Cu	−.486 ***	—	.185 **	.232 ***	−.357 ***	—	—	—	−.132 *	.201 **	.274 ***	.273 ***	.219 ***	.199 **	—	.618 ***									
Cd	—	—	—	—	—	.374 ***	.325 ***	.187 °	.406 ***	.158 *	—	—	—	—	—	—									
Pb	−.249 ***	—	.194 **	.242 ***	−.171 **	.105 °	—	—	—	.150 *	—	.115 *	.146 *	.186 **	—	.307 ***	.240 ***								
SiO_2	−.574 ***	.492 ***	.598 ***	.582 ***	−.248 **	.293 ***	—	.163 °	.152 °	.415 ***	.311 *	.628 ***	.453 ***	.400 ***	.358 ***	.384 ***	.312 ***	.296 ***							
SO_4	—	—	.319 ***	.162 *	—	—	—	—	—	—	—	.220 **	.188 **	.319 ***	.133 *	—	—	—	.185 **						
Chlor. a	.393 ***	.836 ***	—	−.124 °	.526 ***	.182 °	.174 °	.628 ***	.526 ***	—	—	—	—	−.176 °	—	—	—	—							
A	—	—	−.146 *	−.160 **	—	—	—	—	—	—	—	—	−.145 *	−.173 **	—	—	—	—	−.181 *	−.216 **					
Depth	.296 ***	−.229 ***	—	—	.276 ***	−.360 ***	−.406 ***	−.316 ***	−.274 ***	−.220 ***	−.253 **	−.218 ***	—	—	—	—	—	—	—	—					
F	—	—	.128 *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.269 ***	−.111 °		
P	−.138 *	—	—	—	−.250 ***	.128 *	.186 ***	—	—	—	.201 ***	.240 ***	.127 *	—	—	—	—	—	.170 °	—	−.257 ***	—	−.312 ***		
L	—	—	−.312 ***	−.330 ***	—	—	—	.125 °	—	—	—	—	−.133 *	−.280 ***	—	—	—	—	−.275 ***	−.126 *	—	.241 ***	—	−.202 ***	−.253 ***

Table 6. Correlations and their statistical significance ($p < 0.1$) between the water quality and drainage basin variables. This table consists of the winter and summer values of the hypolimnion (2h − 1 m).

	O_2	Turbidity	Conductivity	Alkalinity	pH	Colour	COD	N	P	Fe	Na	K	Ca	Mg	Zn	SiO_2	A	Depth	F
Turbidity	−.447 ***																		
Conductivity	−.350 ***																		
Alkalinity	−.396 ***	.147 °	.870 ***																
pH	.392 ***	—	.357 ***	.421 ***															
Colour	−.406 ***	−.539 ***	—	.236 **	−.168 *														
COD	—	.345 ***	—	—	—	.773 ***													
N	−.468 ***	.358 ***	.216 **	.327 ***	—	.572 ***	.455 ***												
P	−.274 ***	.215 **	—	—	—	—	—	.715 ***											
Fe	−.403 ***	.472 ***	.149 °	.261 ***	−.141 °	.978 ***	.718 ***	.588 ***	.183 *										
Mn	−.356 ***	.194 °	.541 ***	.653 ***	—	.207 °	—	.364 ***	—	.194 °									
Na	−.512 ***	.256 *	.595 ***	.618 ***	—	—	—	.263 *	.235 °	.255 *									
K	−.503 ***	.280 *	.677 ***	.757 ***	−.311 **	—	−.251 *	.299 °	.358 **	—	.755 ***								
Ca	−.407 **	—	.865 ***	.842 ***	.377 **	—	−.279 *	—	—	—	.725 ***	.727 ***							
Mg	−.376 **	—	.854 ***	.949 ***	.516 ***	—	−.393 ***	—	—	—	.516 ***	.682 ***	.839 ***						
SiO_2	—	—	.610 ***	.590 ***	—	—	—	—	—	—	.631 ***	.604 ***	.695 ***	.490 **					
SO_4	—	—	.816 ***	.745 ***	.511 **	—	—	—	—	—	.331 °	.680 ***	.746 ***	.810 ***	.526 **				
Chlor. a	—	—	—	—	—	—	—	—	—	—	—	—	−.226 °	−.250 *	—				
A	.158 °	—	−.141 °	−.148 °	—	—	—	—	—	—	.298 *	.345 *	—	—	—				
Depth	−.150 °	—	—	—	—	−.166 *	−.431 ***	—	—	—	—	—	—	—	—	.157 *			
F	—	—	—	—	—	—	—	—	—	—	.298 *	.345 **	—	—	—	.225 **			
Peat	—	.203 **	—	—	—	.192 *	.367 ***	—	−.246 **	.144 °	.234 °	—	—	—	.388 °	—	−.314 °	.184 °	
L	.174 *	—	−.201 **	−.190 *	—	—	—	—	—	—	—	−.242 *	.292 *	−.289 *	−.434 *	.158 *	—	−.323 ***	−.319 ***

Table 7. Correlations and their statistical significance ($p < 0.1$) between the water quality and drainage basin variables. This table consists of the winter values in the epilimnion (1 m).

	O_2	Turbidity	Conductivity	Alkalinity	pH	Colour	COD	N	P	Fe	Mn	Na	K	Ca	Mg	Zn	SiO_2	SO_4	A	Depth	F	Peat
Turbidity	−.531 ***																					
Conductivity	−.234 **	.236 **																				
Alkalinity	−.279 **	.363 ***	.757 ***																			
pH	.501 ***	−.273 **	.347 ***	.413 ***																		
Colour	−.568 ***	.737 ***	—	.182 *	−.426 ***																	
COD	−.499 ***	.386 ***	—	—	−.511 ***	.811 ***																
N	−.547 ***	.447 ***	—	—	−.394 ***	721 ***	793 ***															
P	−.501 ***	.437 ***	—	—	−.234 **	.522 ***	.551 ***	.454 ***														
Fe	−.521 ***	.713 ***	.172 *	.255 **	−.306 ***	.933 ***	.715 ***	.663 ***	.598 ***													
Mn	−.649 ***	.761 ***	.354 **	.335 **	—	.651 ***	.443 ***	.613 ***	.358 **	.628 ***												
Na	−.317 ***	.406 ***	.280 **	.290 **	—	.407 ***	.319 ***	.218 *	—	.350 ***												
K	−.250 **	.273 *	.471 ***	.602 ***	.239 **	.219 *	—	—	.300 ***	.312 ***	.274 *	.526 ***										
Ca	—	—	.619 ***	.802 ***	.474 ***	—	—	—	—	—	.252 *	—	.558 ***									
Mg	−.244 *	.278 *	.348 ***	.431 ***	—	.496 ***	.601 ***	.641 ***	.371 ***	.527 ***	.256 *	.204 *	.314 ***	.378 ***								
Zn	—	—	—	.186 *	—	—	—	—	—	—	—	—	—	.202 *								
Cu	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.246 *						
Pb	—	—	—	.192 *	—	—	—	—	—	—	—	—	—	—	—	.244 **						
SiO_2	−.388 ***	.522 ***	.495 ***	.489 ***	—	.395 ***	250 *	—	.374 ***	.399 ***	.311 *	.535 ***	.314 **	.288 **	.317 **	.226 *						
SO_4	—	—	.321 ***	—	—	—	—	—	—	—	—	.182 *	—	.268 **	—	—						
A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	−.224 *				
Depth	.555 ***	−.364 ***	−.180 *	−.196 *	.542 ***	−.351 ***	−.349 ***	−.336 ***	−.252 **	−.273 **	−.351 **	−.322 ***	−.192 *	—	—	—	−.289 **					
F	—	—	.197 *	—	.186 *	—	—	—	—	—	—	—	—	—	—	—	—	—	.262 **			
Peat	—	—	—	—	−.196 *	—	—	—	—	—	.233 *	.249 **	—	—	—	—	—	—	—	−.322 **		
L	—	—	−.373 ***	−.391 **	−.287 **	—	—	—	—	—	—	—	—	−.261 **	—	—	−.404 ***	—	.238 *	—	−.205 *	−.229 *

Table 8. Correlations and their statistical significance ($p < 0.1$) between the water quality and drainage basin variables. This table consists of the winter values of the hypolimnion (2 h − 1 m).

	O_2	Turbidity	Conductivity	Alkalinity	pH	Colour	COD	N	P	Fe	Na	K	Ca	Mg	SiO_2	SO_4
Turbidity	−.438 **															
Conductivity	−.347 ***	—	.896 ***													
Alkalinity	−.329 **	—	.896 ***													
pH	.431 ***	—	.401 ***	.450 ***												
Colour	−.550 ***	.677 ***	—	.208 °												
COD	—	.225 *	—	—	—	.489 ***										
N	−.487 ***	.277 *	.312 **	.471 ***	—	.606 ***	.229 *									
P	−.448 ***	.433 ***	—	—	—	.454 ***	—	.616 ***								
Fe	−.544 ***	.517 ***	—	.282 **	—	.926 ***	.337 **	.674 ***	.507 ***							
Mn	−.343 *	—	.662 ***	.776 ***	—	.409 ***	—	.696 ***	—	.426 **						
Na	−.553 **	—	.871 ***	.750 ***	—	—	—	.337 *	.330 °	—						
K	−.717 ***	.439 **	.803 ***	.811 ***	—	—	−.343 °	.338 °	.430 *	—	.853 ***					
Ca	−.443 *	—	.971 ***	.822 ***	.308 °	—	−.307 °	—	.454 **	—	.881 ***	.746 ***				
Mg	−.433 *	—	.932 ***	.947 ***	.523 **	—	−.386 *	—	.572 ***	—	.736 ***	.747 ***	.857 ***			
SiO_2	—	—	—	—	−.721 **	—	—	−.600 °	—	—	—	.575 °	.547 °			
SO_4	—	—	.841 **	.838 **	—	.574 °	.686 *	—	—	—	.713 **	.590 *	.756 **	.868 ***		
A	.218 °	—	—	−.174 °	—	—	.312 **	—	—	—	—	—	—	−.320 °	−.632 *	
Depth	−.387 ***	—	—	.244 *	—	−.494 ***	−.494 ***	—	—	—	—	—	—	—	—	
F	—	—	—	—	—	—	.221 *	—	—	—	—	—	—	—	—	.754 **
Peat	—	—	—	—	—	—	.456 ***	—	−.242 *	—	.335 °	—	—	—	.803 **	—

Table 9. Correlations and their statistical signifiance ($p < 0.1$) between the water quality and drainage basin variables. This table consists of the summer values of the epilimnion (1 m).

	O_2	Turbidity	Conductivity	Alkalinity	pH	Colour	COD	N	P	Fe	Mn	Na	K	Ca	Mg	Zn	Cu	Pb	SiO_2	SO_4	Chlor. a	A	Depth	F	Peat
Turbidity	.192 *																								
Alkalinity	—	—	.957 ***																						
pH	.506 ***	.523 ***	.463 ***	.452 ***																					
Colour	—	—	.183 °	—	−.341 ***																				
COD	—	—	—	—	−.311 ***	.875 ***																			
N	.232 *	.490 ***	−.189 °	−.208 *	.190 °	.472 ***	.504 ***																		
P	.196 *	.374 ***	—	—	.171 °	.382 ***	.370 ***	.545 ***																	
Fe	−.212 **	—	−.195 *	−.205 *	−.351 ***	.723 ***	.686 ***	.318 ***	.346 ***																
Na	—	—	.257 **	.203 *	—	.227 *	.272 **	—	.243 *	.255 **															
K	—	—	.631 ***	.605 ***	.403 ***	−.260 **	−.206 *	−.198 *	—	−.230 *	—	.469 ***													
Ca	—	—	.896 ***	.912 ***	.317 ***	—	—	−.227 *	—	−.165 °	—	.313 **	.583 ***												
Mg	—	—	.890 ***	.896 ***	.344 ***	—	—	−.183 °	—	−.186 °	—	.240 *	.515 ***	.867 ***											
Zn	—	—	—	—	—	—	—	—	—	—	—	.164 °	.175 °	—											
Cu	—	—	—	—	—	—	—	—	—	—	—	.149 °	—	—	—	.887 ***									
Cd	—	—	—	—	—	.576 ***	.363 ***	.229 *	.424 ***	.617 ***	—	.366 **	—	—	—	—									
Pb	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.884 ***	.905 ***								
SiO_2	.176 °	−.321 ***	.627 ***	.640 ***	.453 *	—	−.321 °	−.419 *	—	—	—	—	.612 ***	.638 ***	.413 *	—	—								
SO_4	—	—	.290 **	.185 °	—	—	—	—	—	—	—	.376 ***	.230 *	.417 ***	.276 *	—	—	—	.536 **						
Chlor. a	.393 ***	.836 ***	—	—	.526 ***	.184 °	.174 °	.627 ***	.526 ***	—	—	—	—	.176 °	—	—	—	—	—						
A	—	—	−.194 *	−.193 *	—	—	—	—	—	—	—	—	−.193 *	−.216 *	−.158 °	—	—	—	−.460 *	−.199 °					
Depth	—	—	—	—	.188 °	−.494 ***	−.526 ***	−.313 **	−.335 ***	−.398 ***	—	—	.225 *	—	—	—	—	.160 °	.391 *						
F	−.229 **	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.387 °	—	—	.277 **			
Peat	−.184 *	−.256 ***	—	—	−.320 **	—	.222 *	—	—	.239 *	—	—	—	—	—	.164 °	—	—	.413 *	—	−.257 *	.179 °	−.295 °		
L	—	—	−.304 **	−.317 **	—	−.245 *	−.274 ***	—	—	—	—	−.182 *	—	−.366 ***	−.301 **	—	—	—	−.498 *	—	—	.246 **	—	−.198 *	−.288 **

Table 10. Correlations and their statistical significance ($p < 0.1$) between the water quality and drainage basin variables. This table consists of the summer values of the hypolimnion (2 h – 1 m).

	O_2	Turbidity	Conductivity	Alkalinity	pH	Colour	COD	N	P	Fe	Mn	Na	K	Ca	Mg	SiO_2	SO_4	A	Depth	F	Peat
Turbidity	–.438 ***																				
Conductivity	–.347 **	—																			
Alkalinity	–.329 **	—	.896 ***																		
pH	.431 ***	—	.401 ***	.450 ***																	
Colour	–.550 ***	.677 ***	—	.208 ○	—																
COD	—	.225 *	—	—	—	.489 ***															
N	–.487 ***	.277 *	.312 **	.471 ***	—	.606 ***	.229 *														
P	–.448 ***	.433 ***	—	—	—	.454 ***	—	.616 ***													
Fe	–.544 ***	.517 ***	—	.282 **	—	.926 ***	.337 **	.674 ***	.507 ***												
Mn	–.343 *	—	.662 ***	.775 ***	—	.409 ***	—	.696 ***	—	.426 **											
Na	–.553 **	—	.871 ***	.750 ***	—	—	—	.337 *	.330 ○	—	—										
K	–.717 ***	.439 **	.803 ***	.811 ***	—	—	–.343 ○	.338 ○	.430 *	—	—	.853 ***									
Ca	–.443 *	—	.971 ***	.822 ***	.308 ○	—	–.307 ○	—	.454 ***	—	—	.881 ***	.746 ***								
Mg	–.433 *	—	.932 ***	.947 ***	.523 **	—	–.386 *	—	.572 ***	—	—	.736 ***	.747 ***								
SiO_2	—	—	—	—	–.721 **	—	—	–.600 ○	—	—	—	—	.575 ○	.547 ○							
SO_4	—	—	.841 **	.838 **	—	.574 ○	.686 *	—	—	—	—	.713 **	.590 *	.756 **	.868 ***						
A	.218 ○	—	—	–.174 ○	—	—	—	—	—	—	—	—	—	—	–.325 ○	–.632 *					
Depth	–.387 ***	—	—	.244 *	—	—	–.494 ***	—	—	—	.291 *										
F	—	—	—	—	—	—	.221 *	—	—	—	—	—	—	—	—	—	.754 **	.258 *			
Peat	—	—	—	—	—	—	.456 ***	—	–.242 *	—	—	.335 ○	—	—	—	.803 **	—	—	–.289 **	.181 ○	
L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	–.507 ○	.187 ○	—	–.265 *	–.328 **

with magnesium is positive in the epilimnion (Table 5) and negative in the hypolimnion (Table 6).

Colour and COD correlate positively with the mire percentage of the drainage area (Tables 5—6). The correlation with lake depth is negative owing to dilution caused by volume.

4.23 Nitrogen and phosphorus

Nitrogen generally correlates similarly to colour and COD, because it is bound to organic matter (Tables 5—6). The correlation is stronger in the epilimnion than in the hypolimnion. Phosphorus has a roughly similar correlation, in addition to which it also correlates highly significantly with potassium in the epilimnion in winter. This is probably due to the effect of the redox potential on the solubility and mobilization of metals.

A negative correlation ($p < 0.001$) with total depth emerges for nutrients in the epilimnion (Table 5) and for phosphorus in both the epi- and hypolimnion (Table 6). This indicates that the dissolution of phosphorus in these lakes generally does not increase along with increasing depth. The negative correlation ($p < 0.001$) in the hypolimnion between phosphorus and the mire percentage is unexpected, but weak ($r = -0.249$).

4.24 Conductivity

Conductivity indicates the total amount of salts dissolved in the water. It has strong correlations with nearly all of the metals analyzed here as well as with both sulfate and SiO_2 (Tables 5—6).

Conductivity correlates negatively with the lake percentage of the drainage basin (Tables 5—6). This is due to the sedimentation that comes about while the water remains in the lake. The same is suggested by the weak correlation with the lake area.

4.25 pH and alkalinity

pH and alkalinity correlate with potassium, calcium and magnesium (Tables 5—6). In the epilimnion, they further correlate with phosphorus, iron, sodium, zinc, lead and SiO_2 (Table 5). In the hypolimnion, alkalinity correlates with the aforesaid factors positively, while pH correlates negatively (Tables 5—6).

It hence seems that the decline of pH dissolves metals and increases their leaching into the watercourse. In the hypolimnion, both have positive correlations. There is a further correlation with sulfate.

In the epilimnion, pH has a negative correlation ($p < 0.001$) with the mire percentage in summer (Table 9) and a positive correlation with the depth and a negative one with the lake percentage in winter (Table 7). Alkalinity correlates negatively with the area of the lake and the lake percentage of the drainage area. The pH and alkalinity values are hence influenced by the increase of sedimentation as a function of the retardation.

4.26 Cations

4.261 Iron and manganese

Iron has a significant or highly significant correlation with most of the water quality variables in the epilimnion (Table 5), because it is generally present in erosion and leaching phenomena. There is a negative correlation with oxygen and pH, which, even in general, affect the dissolution and precipitation of iron. There is no observable correlation with calcium, zinc or sulfate. The correlation with cadmium is highly significant in summer (Table 9).

The correlations are weaker in the hypolimnion (Table 6). The highly significant negative correlation with oxygen is due to the dependence of the solubility of iron on the redox potential. In the hypolimnion there are correlations with the parameters clearly reflecting the humus content and the effect of the bottom sediments (Table 6).

Epilimnic iron (Table 5) correlates negatively with total depth, which is related to sedimentation and the material exchange between the water and the sediments. There is a highly significant summertime correlation with the mire percentage of the drainage area (Table 9).

Managenese correlates with the water quality parameters more or less similarly to iron (Tables 5—8). Summertime observations are lacking. Similarly to iron, manganese correlates negatively with the depth of the lake and positively with the mire percentage of the drainage area.

4.262 Alkaline metals

There are significant or highly significant epilimnic correlations with variables other than phosphorus, cadmium and lead (Table 5). As the oxygen concentration and pH increase, the sodium concentration decreases. The hypolimnic correlations (Table 7) are not equally obvious. In the epilimnion, sodium has a negative ($p < 0.001$) correlation with the depth of the lake and a positive correlation ($p < 0.001$) with the mire percentage particularly in winter (Table 7).

In the annual material, potassium correlates near the bottom highly significantly with oxygen (negative), conductivity, alkalinity, manganese, sodium, calcium, magnesium, SiO_2 and sulfates and significantly with pH and phosphorus (Table 6). In the epilimnion (Table 5), there are further highly significant correlations with iron, zinc and copper, but not sulfate.

The summertime observations also reveal some correlation with colour and COD at a depth of 1 meter (Table 9). No corresponding wintertime correlation is seen (Table 7).

The correlations of potassium with the drainage area factors are very weak (Tables 5—10). An increase of the lake percentage seems slightly to diminish the potassium concentration ($p < 0.05$).

4.263 Alkaline-earth metals

In the annual material, calcium correlates in the hypolimnion (Table 6) with oxygen (negative), conductivity, alkalinity, pH, sodium, potassium, magnesium, silica and sulfate. In the epilimnion, there are further correlations with manganese, magnesium, zinc, copper and lead (Table 5).

In the annual material, magnesium correlates in the hypolimnion (Table 6) with oxygen (negative), conductivity, alkalinity, sodium, potassium, calcium and sulfate. In the epilimnion, there are further correlations, particularly in winter (Table 5), with turbidity, colour, COD, Nitrogen, phosphorus, iron and manganese. Unlike in the case of calcium the correlation with heavy metals is lacking.

Calcium in the epilimnion correlates negatively ($p < 0.001$) (Table 5) with the lake percentage. Magnesium has no such correlation, which indicates that calcium precipitates faster. This is shown in the hypolimnion (Table 6) by the slightly positive ($p < 0.05$) correlation of calcium and the equal negative correlation of magnesium with the lake percentage. In the summertime observations both calcium and magnesium correlate negatively with the lake percentage in the epilimnion (Table 9). Calcium has a stronger correlation ($r = -0.366$; $p < 0.001$).

4.264 Heavy metals

Zinc as well as the other heavy metals were only analyzed in the epilimnion (Tables 5, 7 and 9). They have a negative correlation with oxygen and alkalinity and significant or highly significant positive correlations with conductivity, alkalinity, sodium, potassium, calcium, copper, lead and silica.

Copper correlates in the same way as zinc, but further has correlations with iron and manganese.

Cadmium correlates highly significantly with colour, COD, phosphorus and SiO_2 (Table 5). There is, moreover, a highly significant summertime correlation with iron (Table 9).

Lead correlates negatively with oxygen and pH and positively with calcium, zinc, copper and SiO_2 (Table 5).

There are no observable correlations with the drainage area factors, one reason for this being that observations were only made in the epilimnion, where the concentrations are generally lower than in the hypolimnion. The number of observations is also smaller than in the case of the other materials. The concentrations are low in waters in a natural state, being near or below the detection limit for some metals. The possible anomalies increase the dispersion and detract from the statistical significance.

4.27 Anions

4.271 Silicate

The concentration of silicic acid is expressed as a silica, SiO_2, concentration. There are positive correlations (Tables 5—6) with conductivity, alkalinity, colour, sulfate and nearly all of the metals analyzed, which means that many other materials are liberated from minerals along with the silicates. The influential factors include the pH and E_h status, which means that there is a negative correlation between oxygen and pH. SiO_2 has a minor positive correlation with the mire percentage and a negative correlation with the area and the lake percentage.

4.272 Sulfate

Sulfate correlates with conductivity, pH, alkalinity and alkaline and alkaline-earth metals (Tables 5—6). There is a minor negative correlation in the epilimnion (Table 5) with the area of the lake and the lake percentage of the drainage basin. In the hypolimnion there is a correlation with the area of the drainage basin (Table 6).

4.3 Dependence of water quality on drainage area factors

Marginal or almost significant correlations with the lake area are recorded for hypolimnic oxygen, conductivity, alkalinity, calcium and magnesium (Table 6). With the exception of oxygen, the correlations are negative. In the epilimnion (Table 5), significant or almost significant negative correlations emerge for conductivity, alkalinity, potassium, calcium, SiO_2 and sulfate. The smallest (negative) correlation occurs in the epilimnion in winter (Table 7), when only the sulfate concentration depends on the area of the drainage basin ($p < 0.01$).

Colour ($p < 0.01$) and COD ($p < 0.001$) correlate negatively with the total depth of the lake in the hypolimnion (Table 6). In the epilimnion (Table 5), there are corresponding significant or highly significant additional correlations with oxygen, turbidity, pH, nitrogen, phosphorus, iron, manganese and sodium. With the exception of oxygen and pH, the correlation is negative, which means that as the depth of the lake increases, the water quality becomes more diluted.

The area of the drainage basin cannot in itself be considered a factor explaining the quality of the water. The lake percentage, which depends on it, correlates in the epilimnion (Table 5) negatively with conductivity, alkalinity, potassium, calcium, SiO_2 and sulfate. These parameters naturally also correlate with the area of the lake.

The mire percentage correlates positively with the parameters reflecting the presence of humus (colour, COD) (Tables 5—6). There are further positive correlations with manganese, sodium, potassium and, in the hypolimnion, with turbidity. Negative correlations emerge, mainly in the summer, for oxygen, ph and chlorophyll and, in the hypolimnion, unexpectedly, for phosphorus.

5. DISCUSSION

5.1 Cations

5.11 Iron and manganese

Iron and manganese behave in roughly the same manner in both the ground and the water. Their precipitation and dissolution depend most on the pH and E_h conditions. The critical redox potential is higher for manganese. The bedrock concentrations do not essentially influence the water concentrations (Kämäri 1984). In the Koutajoki river basin, the iron concentration is almost significantly different in the rock classes K1 and K3 ($p < 0.05$), which means that more iron seems to dissolve from rock types rich in silicic acid than from rock with a low silicic acid content. In a review by Kämäri (1984) of the lakes of Kuusamo, which was partly made on the same material as the present work, no dependence on the bedrock was seen. The bedrock has no effect on the manganese concentration.

The effect of the bedrock and soil on the iron and manganese concentrations is more obvious. The concentrations are higher in peaty than in sandy areas.

Iron and manganese correlate with most water quality parameters, which means that they are generally present in the leaching and binding phenomena. Iron and manganese are abundant in humus, and correlations with the parameters reflecting the presence of humus and the mire percentage are therefore natural. The negative correlation with oxygen and pH is due to their effect on the solubility of iron and manganese.

The survey of rock ground water by Rönkä (1983) indicated that the iron concentration was about twofold (1400 $\mu g\ l^{-1}$) in an area of siliceous schists compared with an area of felsic plutonic rocks and mafic rocks (600—700 $\mu g\ l^{-1}$). The concentrations in the small lakes of the Koutajoki river basin are 809 and 524 $\mu g\ l^{-1}$ (Table 1).

According to Hartikainen (1976), the most important factors contributing to the iron concentration of ground water are the geologic structure of the bedrock and soil and the hydrologic conditions. In areas of permeable soil, where the rain and melt waters are able, having been oxidized, to penetrate down to the ground water, the iron concentration is low.

Hyyppä (1965) suggested that the variations of the iron concentration in ground water are mostly due to variations of the oxygen supply, which means that the flow conditions are of crucial importance. According to Lahermo (1969), the composition of the mineral material present in the bedrock and soil is important. It is therefore possible that in the lakes where the iron concentration seems to depend on the quality of the bedrock, the role of ground waters may be notable.

In waters with high colour values, most of the iron is bound in humus. Most of the humic materials combine with metals to make permanent compounds soluble or insoluble in water, humates and fulvates. The mechanisms include complex formation, adsorption and ion exchange (Gjessing 1976). According to Reinikainen (1983), the iron concentration and the colour of the water are not directly correlated, although coloured waters almost always contain more iron than usual and vice versa (Ghassemi and Christman 1968, Pennanen 1980). Vanhanen (1981) pointed out that the iron concentration explains 73 % of the colour of water in ground waters. Iron and manganese bacteria are able to utilize even organically bound iron and manganese (Steinberg and Stabel 1978).

5.12 Alkaline metals

The potassium concentrations in the Koutajoki river basin are highest in areas where silicic acid is scant in the rocks (Table 1). The difference compared with areas of highly siliceous rocks is significant. In his survey of the whole Kuusamo area, however, Kämäri (1984) did not see any correlation between potassium and the bedrock, possibly because of the smaller number of observations.

The Na/K ratio is 1.5 in class K1 and 1.1 in class K2. The two concentrations and the Na/K ratio are both notably lower than the values reported by Wetzel (1975) for the different continents. The low potassium concentrations are partly due to the scant weathering of the bedrock (cf. Rönkä et al. 1980). The mafic rocks in this research area contain less potassium than the siliceous rocks (cf. Sederholm 1925). Mafic rocks, in turn, are more susceptible to weathering, whereupon more cations are released from them.

The sodium concentrations are mostly influenced by the quality of the soil. The research area has never been in contact with the sea, which means that it has not been affected by salt water. According to Englund and Myhrstad (1980), calcium is the dominant cation above the late postglacial water line, while sodium is dominant in the ground waters below this line. The highest sodium concentrations occur in peaty soil and the lowest in moraine areas (Table 2). The difference is highly significant. The corresponding difference in potassium concentrations is almost significant. The Na/K ratio is 1.4 in sandy areas, 1.0 in moraine areas and 1.3 in peaty areas.

According to Hartikainen (1976), the potassium concentrations are of the same order as the sodium concentrations in the bedrock, but ground water generally contains more sodium than potassium. This is probably due to the more notable ability of potassium to restrict to clay minerals and other secondary products of weathering and disintegration. The Na/K ratio of the Koutajoki river basin is close to the corresponding ratio of the bedrock.

On the basis of the tables presented by Myllymaa (1978), the average Na/K ratio has been 2.1 at the Jurmu observation site on the river Iijoki and 1.6 at the Kiutaköngäs site on the river Oulankajoki. The ratio is clearly higher than that recorded in the small lakes of the Koutajoki river basin. This suggests that the sedimentation of potassium is more effective especially in the Iijoki watercourse, where the water remains for a longer time. The same assumption is also suggested by the correlation between the epilimnic potassium concentration on the one hand and the lake area and the lake percentage of the drainage basin on the other (Tables 5—6). No corresponding negative correlation was noted for sodium.

5.13 Alkaline-earth metals

Piispanen and Myllymaa (1982) have noted that, apart from the Koutajoki river basin, the lakes of Kuusamo 0.5—0.99 km^2 in area have lower Ca and Mg concentrations than the lake waters in the world in general. The differences ($p < 0.50$) between the Koutajoki and Iijoki river basins were found to be due to qualitative differences of the bedrock. In a corresponding manner, alkalinity and pH differed highly significantly from each other.

Kämäri (1984) found no dependence between the basic cations and the rock classes in a material collected in southern Finland. In the control area of Kuusamo, however, where the proportion of basic rocks is notable, a strong dependence was seen between the alkaline-earth metals and the rock classes. The apparent reason for this is the significant proportion of easily disintegrated rock types in the drainage area (cf. Lahermo 1970).

In the present investigation, the areas of felsic (K1) and mafic (K2) rocks differed highly significantly with regard to the Ca concentrations. The difference in the Mg concentrations was not significant. Both Ca and Mg correlated highly significantly with alkaline metals, pH, conductivity, silica and sulfate. The Ca and Mg concentrations were highest in moraine areas. The difference in comparison with the sandy and peaty areas was significant. The Ca/Mg ratios in the different rock and soil classes were as follows:

Rock			Soil			
K1	K2	K3	M1	M2	M3	M4
2.6	3.3	2.9	3.4	2.6	3.1	2.9

According to Kämäri (1984), the alkaline-earth metal concentrations in southern Finland are only affected by soil in gravel and sandy areas. The highly significant correlation of calcium and magnesium with sulfates in the southern Finnish material is postulated by Kämäri to indicate that the leaching of alkaline-earth metals as sulfates increases as a function of the strong acids deposited in the drainage area. Kämäri (1984) also postulates, however, that Kuusamo is outside the reach of acid deposition. The highly significant correlation with sulfate now observed would therefore rather be due to simultaneous disintegration and mobilization of alkaline-earth metals and sulfate.

5.14 Heavy metals

5.141 Mercury

The distribution of the detectable mercury concentrations between the different rock and soil areas (Table 5) reveals no dependence on these factors. The possible actual differences are therefore explained by local differences in the structure and utilization of the drainage area. Mercury is known to be washed into watercourses along with e.g. humus. The humus content in the research area is generally low.

Hyyppä (1981) has analyzed the mercury concentrations of ground waters in areas with sulfidic ores and in the regions where the surveys by the National Board of Waters revealed maximum mercury concentrations. The mercury concentration has not always been found to depend directly on the concentration in the bedrock. The drill samples obtained from the Seinäjoki area of antimony, tin and gold mineralization contained most mercury, although the mercury concentration of the bedrock in that area was below the mean of the earth's crust. The copper, pyrite and zinc concentrates obtained from the Pyhäsalmi ore, on the other hand, contain abundant mercury, which explains the ground water concentrations of 0.3—0.5 $\mu g\ l^{-1}$.

The variations of the bedrock in the Koutajoki river basin are great. Sulfidic ores may give rise to the kind of mercury concentrations now recorded (cf. Pankka and Vanhanen 1984).

The Hg concentrations recorded for the lakes, 8, 27, 54 and 99 (Table 4) correspond to the ground water concentrations of mining areas reported by Hyyppä (1981). In the research area, sulfidic minerals occur with quartz as narrow veins in albitites (Piispanen 1972). Of these lakes, the Viipusjärvi area has been found by Silvennoinen (1972) to contain albitic diabases.

As the material is so scant, the occurrence of mercury in the lakes of the Koutajoki river basin requires further investigations. The fish caught from lake Ruoppilampi show no accumulation in the nutrient chain. This is due not only to the possible low concentrations of the water, but also to the high water pH, which slows down methylation (cf. Mannio 1983 and Verta 1981). The average mercury concentration of the 10 perches caught from Lake Ruoppilampi in late winter 1979 was 0.05 mg kg^{-1}. The range was 0.04—0.08 mg kg^{-1}. The mercury concentrations of two burbots were 0.04 mg kg^{-1}, while the corresponding concentration of a control burbot caught from the river Oulankajoki was 0.08 mg kg^{-1} (Table 4).

5.142 Zinc

Zinc present in natural waters makes for weak complex ions, being mainly present as hydroxy and carbonate complexes. A notable portion of the hydroxy complexes are possibly in the form of colloids or adsorbed on solid particles (Asplund 1979).

In the present material, zinc was not found to correlate with organic matter. The highly significant correlations with some metals, alkalinity and pH (Table 5) suggest complex formation. The strongest correlation ($r = 0.618$) emerges for copper. The correlation with calcium is highly significant ($r = 0.227$), but there is no correlation with magnesium.

Generally speaking, the zinc concentrations in the lakes of the research area are low, which is due to e.g. the high alkalinity and the low organic matter contents. The concentration is 0—60 $\mu g\ l^{-1}$. No distinct differences are seen between the different rock and soil classes in the whole material. In the area of mafic rocks (K2), however, the concentrations of sandy areas are highly significantly lower than the corresponding values of moraine and peatland areas (Table 3).

The highest zinc concentrations are generally recorded in winter, and they hence probably originate from the bottom of the lake. They may therefore also be descriptive of the bedrock of the nearby areas. It has not, however, been possible to demonstrate any definite connection with the known pyritic ore deposits (Fig. 6), which means that the bedrock in the surroundings of these lakes should be explored in more detail. The differences do not seem to be explained by land utilization, either. Most of these lakes are located far away from the population and farming. More detailed investigated should be carried out on certain groups of high concentrations, mainly the lakes 18, 19, 22, 23, 24, 26, 34, 37, 65, 67, 79, 82, 83, 89 and 90. In many cases, the lakes are connected by brooks.

5.143 Copper

The form in which copper is present is regulated by the physico-chemical, hydrodynamic and biological factors of the watercourse (Moore and Ramamoorthy 1984). In a water environment, copper may be present as bound to particles, colloid or dissolved. If dissolved, it may occur as free ions or be complexed with organic or inorganic ligands.

Copper enters into complexes with e.g. carbonates, nitrates, sulfates, chlorides, ammonium and hydroxides. Copper has a strong correlation with sulfides, and it forms complexes with nitrogen- and sulphur-containing ligands. Humic materials bind more than 90 % of the fresh water copper. In sea water, calcium and magnesium, owing to their high concentrations, replace copper in humus (Moore and Ramamoorthy 1984). According to Asplund (1979), most of the copper present in natural waters is in a colloidal form or adsorped on particles.

Balsberg et al. (1981) report copper concentrations of 0.2—3 $\mu g\ l^{-1}$ for the unloaded lakes of Sweden, which corresponds to the average concentrations recorded at Kuusamo. Recent surveys of the small lakes in Norrland, however, show the background concentrations to be 1 $\mu g\ l^{-1}$ (Balsberg et al. 1981).

According to Lahermo et al. (1979), the lithologic sources of copper in ground water are pyritic minerals, particularly copper pyrite. The aforesaid investigation revealed no dependence of copper on the general composition of the bedrock. This was assumed to suggest that a notable portion of the highest concentrations were due to contamination. According to Rönkä (1983), copper tends to accumulate in ground waters in areas where the bedrock consists of mafic rocks or siliceous schists. Accordingly, the ground waters in the Kuusamo research area should contain abundant copper, which might also be reflected in the quality of the lake waters.

No definite connection between the rock and soil quality and the copper concentration was noted in the Koutajoki river basin, either. The lowest concentrations, however, were generally recorded in areas of felsic rock types and in lakes located in sandy areas. Similarly to zinc, copper was also found in detectable quantities only in winter. At that time, zinc can be assumed to have been dissolved into the water from the bottom of the lake. The highest concentrations (Fig. 6) turn out to accumulate in certain areas, which should, justifiably, be investigated in more detail.

Copper precipitates easily, remaining in the sediments near its origin (Kontas 1979). It could therefore be assumed that high concentrations indicate the source of copper fairly accurately. Concentrations suggestive of anomaly have been seen in the sediments of lake Kitkajärvi (Myllymaa et al. 1985), which might be due to albite diabases around the lake. Piispanen (1972) noted that copper accumulates in these.

The lakes 38, 40 and 46 are located near the Säkkilänvaara pyritic ore deposit, which contains Cu, Co, Fe and S. A larger grouping of Cu concentrations $\geq 5\ \mu g\ l^{-1}$ was seen in the lakes 20, 22, 26, 27, 28, 30 and 121 west of Valtavaara and Rukatunturi, which are relatively close to the Säynäjävaara pyritic ore deposit (Fig. 6).

Typical exposures of an albite diabase formation are seen northwest of the Rukatunturi syncline near lake Viipusjärvi (27). The water of lake Viipusjärvi was also found to contain mercury (Table 4). The copper accumulations occur partly in the same areas as the high zinc concentrations, although the two concentrations are not always high in the same lakes. This is natural, because the mobilization and precipitation of copper and zinc depend on different factors, whose effects partly counteract each other. Zinc and copper accumulations are seen around e.g. pyrite deposits and in the lakes 53 and 54, which are close to a deposit containing iron and sulphur.

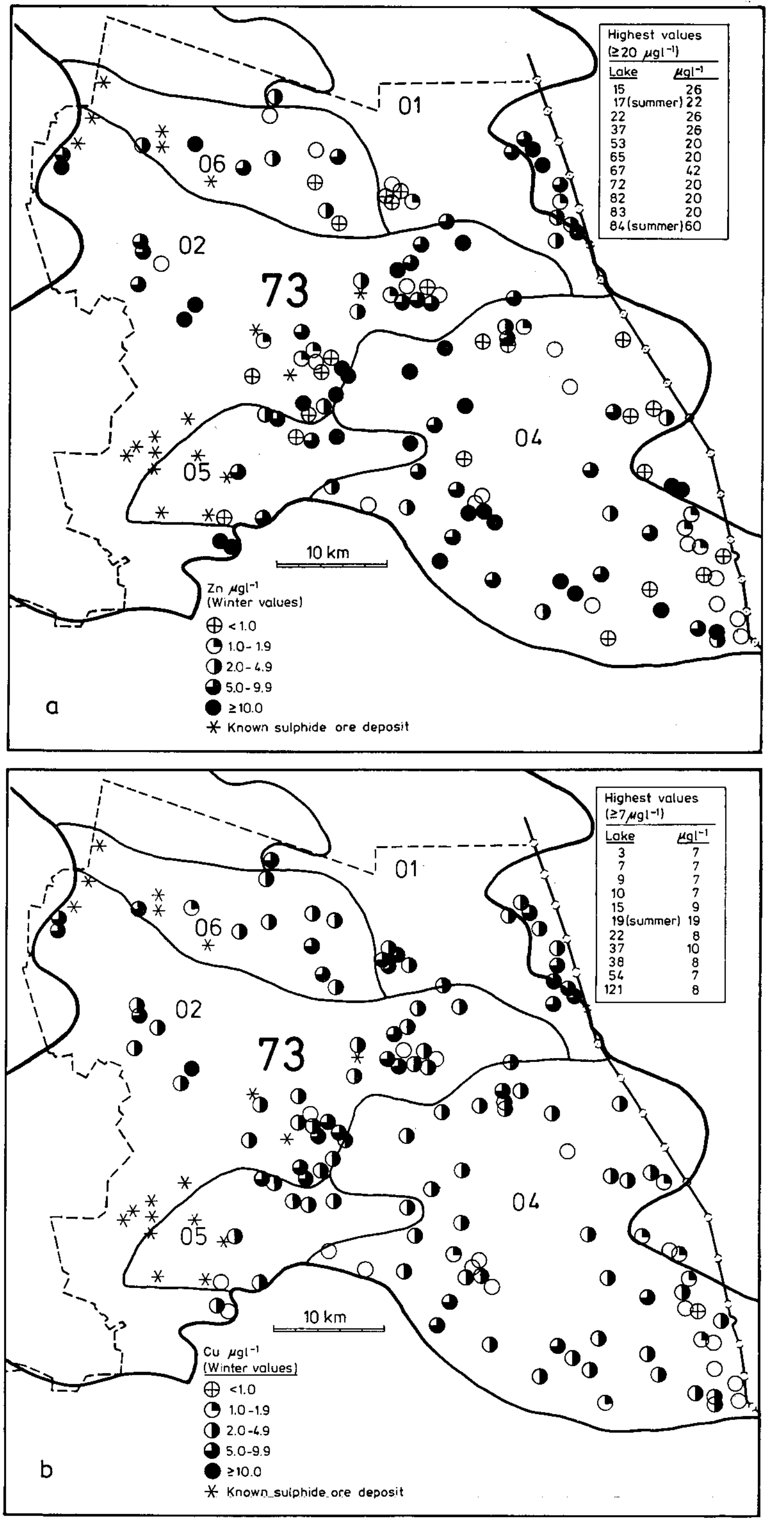
No definite correlation emerges between the Cu concentrations of lake water and the known ore deposits. Nor are the differences explained by cultural effects, as land utilization around these lakes is hihgly variable.

5.144 Cadmium

The stable state of cadmium in nature is Cd^{2+}. It is characterized by high solubility in lipids, bioaccumulation and toxicity. Cadmium seems to replace zinc in several enzymatic functions, causing dysfunctions and diminishing activity (Moore and Ramamoorthy 1984).

Cadmium is mostly present associated with zinc in carbonates and sulfidic ores. It is also obtained as a by-product when other metals are refined (Moore and Ramamoorthy 1984). According to Lahermo (1979), the cadmium concentrations in ground waters were below the detection sensitivity (0.5 $\mu g\ l^{-1}$). No differences accordant with the variations of the bedrock were seen. It was therefore concluded that the few higher concentrations were due to contamination.

In the present material, cadmium is only seen in two lakes located in an area rich in silicic acid. The drainage areas of both of these lakes consist of peat



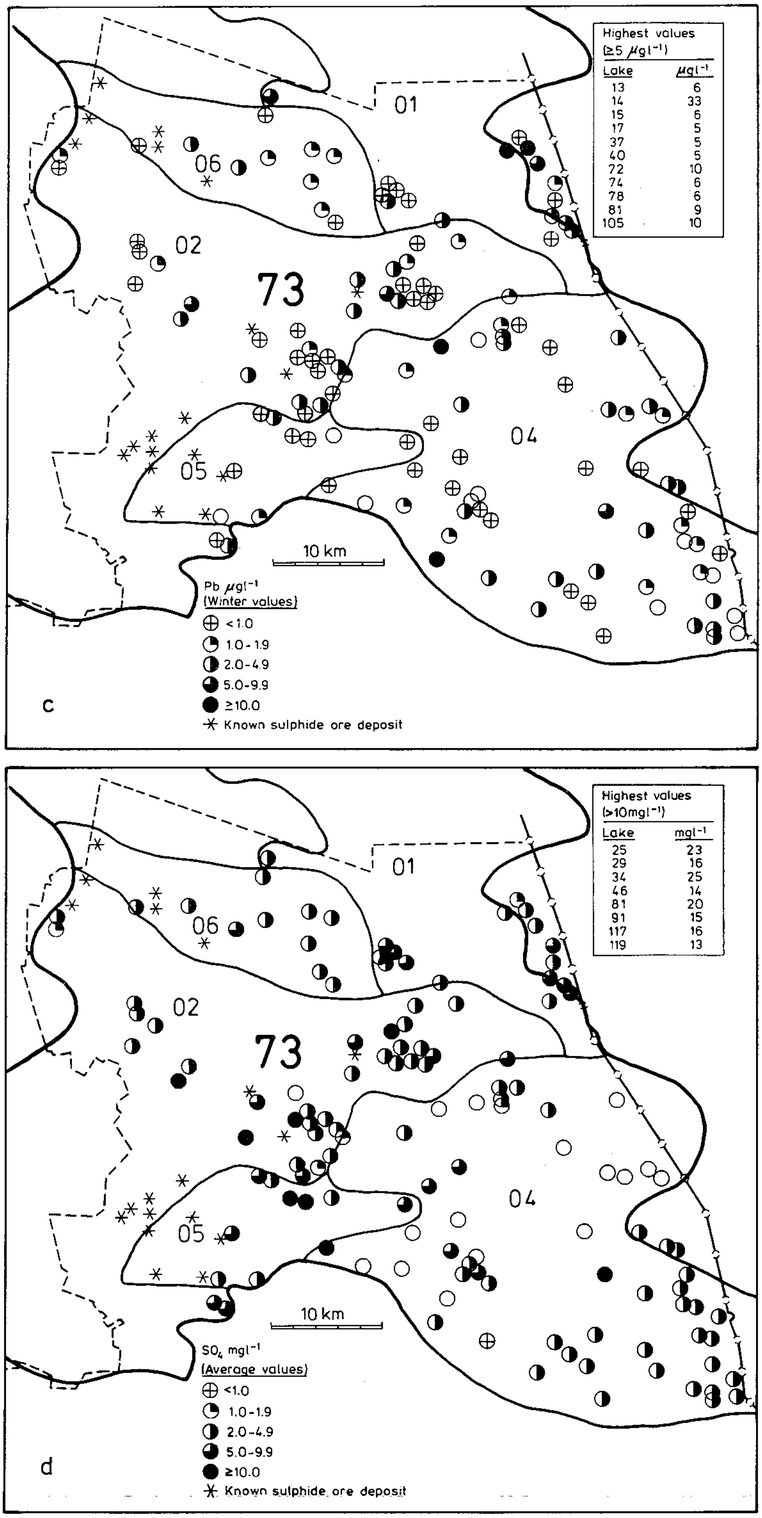
Highest values (≥20 μgl⁻¹)

Lake	μgl⁻¹
15	26
17 (summer)	22
22	26
37	26
53	20
65	20
67	42
72	20
82	20
83	20
84 (summer)	60

Highest values (≥7 μgl⁻¹)

Lake	μgl⁻¹
3	7
7	7
9	7
10	7
15	9
19 (summer)	19
22	8
37	10
38	8
54	7
121	8

Fig. 6. Concentrations of zinc (a), copper (b), lead (c) and sulfate (d) in lake waters and known sulphide ore deposits.



Highest values (≥5 $\mu g l^{-1}$)

Lake	$\mu g l^{-1}$
13	6
14	33
15	6
17	5
37	5
40	5
72	10
74	6
78	6
81	9
105	10

Highest values (>10 $mg l^{-1}$)

Lake	$mg l^{-1}$
25	23
29	16
34	25
46	14
81	20
91	15
117	16
119	13

Fig. 6. Continued.

and moraine. The concentrations are low, the maximum being 1.1 $\mu g\ l^{-1}$. These lakes, 66 and 77 (Fig. 6), contain abundant humus. In summer, when the concentrations of 1.1 and 0.9 $\mu g\ l^{-1}$ were measured, the colour value was 150.

It seems that cadmium occurs in brown runoff waters. The lakes in this research area are generally so clear-watered that the method of analysis now applied did not reveal the concentrations. The lakes for which detectable concentrations were obtained are located near roads, close to population and farming. The higher values may therefore reflect an effect of cultural factors. Low cadmium concentrations similar to those recorded at Kuusamo were also recorded in the sediment of the lakes Kitkajärvi (Myllymaa et al. 1985). The maximum concentration was 1.0 mg l^{-1}, while Tummavuori and Aho (1978) recorded 2.45 mg l^{-1} as the mean concentrations of some lakes in Central Finland.

5.145 Lead

The lead present in natural waters mainly occurs in the form of carbonate complexes. Adsorption on particles is of great significance. According to some findings, a notable part of the lead in waters in a natural state is bound to organic complexes (Asplund 1979).

According to Förstner and Wittman (1979), the concentrations of dissolved lead in unpolluted waters are generally $\leq 3\ \mu g\ l^{-1}$. Much higher concentrations generally occur near highways and population centres as a consequence of gasoline combustion.

Lahermo et al. (1979) point out that the main lithologic source of lead, as well as nickel and copper, consists of pyritic minerals, of which lead glance is the most important. According to Lahermo, the lead concentrations in ground waters are lower than the nickel or copper concentrations. Most of the concentrations are below the detection limit (1 $\mu g\ l^{-1}$), and values exceeding 5 $\mu g\ l^{-1}$ are rare.

The findings by Rönkä (1983) indicated that the differences in the copper concentrations of the rock ground waters in Finland are so small as to warrant no conclusions. The mean concentration is 1.5 $\mu g\ l^{-1}$ and the maximum concentration 20 $\mu g\ l^{-1}$.

The present findings reveal no dependence of lead on the rock classes, nor any explainable dependence on the soil classes (Tables 1—2). Three of the lakes for which the highest concentrations were obtained are located close to each other on Liikasenvaara (Fig. 6). The lakes 15 and 37 also have high copper and zinc concentrations. The lake 22 has a high zinc concentration and the lake 72 a high copper concentration. Most of the lakes with high lead concentrations are located near the road, which may countribute to the high values (cf. Förstner and Wittman 1979).

The negative correlation of lead with pH and oxygen suggests that it is mobilized from the sediment when the pH and E_h values are low. It thereupon correlates similarly to mobilized calcium, copper and SiO_2. No dependence on humus is observed.

5.2 Anions

5.21 Silicate

Silica is present almost everywhere in more or less reactive forms. Silica may occur as dissolved undissociated silicic acid, orthosilicate ions or complex ions, in a colloid form and in mineral particles. The different forms seem to be transformed into each other, and it is possible that no soluble silica occurs in acid or neutral water (Hutchinson 1957). The major source of silica in natural waters consists of aluminosilicates, from which flowing water dissolves silica. It is also assumed that organic acids dissolve silica. When water is present, CO_2 reacts with silicates to form bicarbonates and silica. Silica produced in an acid environment, however, is immobile, while in alkaline water easily mobile silicate ions are formed (Hutchinson 1957).

The quantities of silica in natural waters do not vary much, and no correlation has been observed between the silica concentration of the water and the silicate concentration of the bedrock in Finnish rock ground waters. Lahermo (1970) has noted, however, that the silica concentration of flowing surface waters is significantly higher on acid than on basic bedrock. Davis (1964) and Polzer (1967) point out that the rock type in contact with the water is the most important factor contributing to the silica concentration.

In the Koutajoki river basin, no statistical dependence on the quality of the bedrock is seen. The silica concentrations of moraine and peatland areas differ almost significantly (Table 2). The concentrations are highest in the latter class and lowest in the former.

There is no difference in the area of rocks with low silicic acid concentrations (Table 3), which means that the bedrock does have an effect on the silica concentrations. The negative correlation with pH indicates that the dissolution is due to acidity (Table 5). The negative correlation with turbidity (Table 5), in turn, indicates that silica is not, to any notable extent, bound to seston. There is a highly significant epilimnic correlation between silica and colour. Silica hence appears to be partly bound with humus. Gjessing (1976) has similarly noted that silicates are also washed from the soil being bound with humus. Even in the areas with relatively low humus contents in southern Finland, the silica concentrations of waters have been found to depend strongly on the amount of organic matter dissolved in the water (Kämäri 1984).

The highly significant correlations of silica with metals in the epilimnion are probably mainly due to their solubility in an acid environment, but complex formation is also possible (Table 5).

5.22 Sulfate

In most fresh waters, the sulfate ion is the anion second or third in frequency, only bicarbonates and in some cases silicates being more frequent. The rainfall in areas in a natural state contains notably more sulfates than chlorides (Hutchinson 1957). In addition to natural precipitation, there are also other sources of sulfates. Some sediment rocks contain calcium sulfate, which is the main source of sulfate in many lakes. An equally important or even more notable source may be the oxidation of pyrite present in the sediment.

Sulfuric acid and other acid sulfates are significant causes of acidity of the rain water in Finland (Kämäri 1984). The hydrogen ion and sulfate concentrations of lake waters in Norway have been found to correlate significantly with the quality of deposition (Mohn et al. 1980). The regional surveys carried out in Norway have revealed a significant positive correlation between the sulfate and hydrogen ion concentrations (Wright and Henriksen 1978). In southern Finland, however, the summertime sulfate concentration correlates negatively with the hydrogen ion concentration (Kämäri 1984). The wintertime dependences were not significant. Mohn et al. (1980) have noted that the sulfate concentration and pH have a highly significant negative correlation within the different Ca concentration classes. Kämäri (1984) noted a slightly corresponding dependence in a material collected from southern Finland.

In the present material collected from northern Kuusamo, sulfate appears to correlate with conductivity, pH, alkalinity and alkaline and alkaline-earth metals. In the annual material, there is a significant or highly significant correlation in the epilimnion (Table 5) with conductivity, sodium, potassium, calcium and silica. The corresponding hypolimnic (Table 6) correlations obtain for conductivity, alkalinity, pH, potassium, calcium, magnesium and zinc.

The correlations are stronger in summer than in winter. This is probably due to leaching of sulfates from the drainage area rather than their liberation from the sediments. This assumption is supported by the positive correlation between sulfate and the area of the drainage basin and the negative correlation between sulfate and the lake percentage and the lake area (Tables 5 and 7—10).

SUMMARY

The small lakes of northern Kuusamo generally draw their waters from easily delimited drainage basins, which means that the quality of water reflects the properties of the immediate drainage area, e.g. the quality of the soil and the bedrock. The present study deals with the Koutajoki river basin, which is located in the northern part of the municipality of Kuusamo in the Koillismaa highlands. The quality of water in the 131 lakes covered was analyzed in March — April and August — September 1978—1979. The lakes varied in size within 0.1—0.49 km^2.

The bedrock in the area is highly variable, with dolomites as a special feature. The present classification of rocks into felsic and mafic depends on the silicic acid concentration. The third class is a combination of these. The classification of soils consists of sand and gravel, moraine, moraine and peat, and peat. The bedrock is classified on the basis of the silicic acid concentration into felsic and mafic rocks and a combination class. The soil classes consist of sand and gravel, moraine, moraine and peat, and peat.

The composition of the bedrock seems to affect the iron, potassium, calcium, copper and lead concentrations. The soil affects the concentrations of iron, manganese, sodium, calcium and magnesium. In areas of felsic rocks, the lead and zinc concentrations depend on the quality of the soil.

The pH, conductivity and alkalinity values, which are expressive of the electrolyte content and the buffering capacity, vary dependent on both the bedrock and the soil quality. The colour and COD values expressive of the humus concentration generally vary in accordance with the soil quality.

The differences in the water quality parameters between the different soil classes were smallest in the rock class K1 (felsic rocks). The lake area correlates marginally or almost significantly with hypolimnic oxygen, conductivity, alkalinity, calcium and magnesium. With the exception of oxygen, the correlation is negative. There is a significant or almost significant negative correlation in the epilimnion with conductivity, alkalinity, potassium, calcium, silica and sulfate. The smallest (negative) correlation in winter occurs in the epilimnion, where only the sulfate concentration depends on the area of the drainage basin.

There is a negative hypolimnic correlation between the total depth of the lake and the colour and COD values. In addition to these correlations, there are corresponding significant or highly significant correlations in the epilimnion for oxygen, turbidity, pH, nitrogen, phosphorus, iron, manganese and sodium. With the exception of oxygen and pH, the correlations are negative, which means that as the lake depth increases, the quality of the water becomes more diluted.

The lake percentage of the drainage basin and the lake area correlate in the epilimnion negatively with conductivity, alkalinity, potassium, calcium, silica and sulfate.

The mire percentage correlates positively with the characteristics expressive of humus (colour, COD). There are further positive correlations for manganese, sodium, potassium and, in the hypolimnion, turbidity. The correlations with oxygen, pH and chlorophyll are negative. Here, as elsewhere, the correlations are stronger in summer than in winter because of differences in the runoff values.

Iron and manganese correlate with most water quality parameters, which indicates that they are generally present in the erosion and leaching phenomena. Iron and manganese are abundant in humus, which is why the correlations with the parameters expressive of humus and the mire percentage are natural. The negative correlation with oxygen and pH is due to their effect on the solubility of iron and manganese.

The recorded mercury concentrations were distributed between the different rock and soil classes in such a way that the differences in the concentrations were not explained. The possible actual differences may hence be due to special features of the structure of the drainage area and the modes of land utilization. Mercury is known to be washed into watercourses from e.g. humus. The humus contents in the research area are generally low. The occurrence of mercury in some areas may be due to sulfidic ores. The observed concentrations correspond to the concentrations of some mining areas. No accumulation of mercury in the nutrient chain was noted at Kuusamo. One reason for this, in addition to the low mercury concentrations, is the high pH, which slows down methylation.

In the present material, zinc does not correlate with organic matter. There are highly significant correlations with some metals, alkalinity and pH. The strongest correlation emerges for copper. The correlation with calcium is highly significant, but no correlation with magnesium is seen. Owing to the alkalinity and the low organic matter contents, the zinc concentrations are low in the lakes of the research area.

The occurrence of the highest zinc concentrations in winter suggests that zinc is mobilized from the bottom sediment. That being the case, the zinc values are also able to provide some preliminary information on the quality of the local bedrock. It was not, however, possible to demonstrate any definite connections with the known pyritic ore deposits.

Copper is not seen to be clearly dependent on the quality of the bedrock or the soil. The lowest concentrations are, however, generally seen in areas of felsic rocks and in lakes located on sandy soils. Similarly to zinc, copper is also generally present in detactable quantities only in winter. Mobilization from the bottom appears obvious. The highest concentrations are seen to concentrate in certain areas, where a more detailed analysis of the bedrock seems warranted.

Copper precipitates easily and remains in the sediments close to its origin. It could therefore be assumed that the high concentrations indicate their origin relatively accurately. Concentrations suggestive of anomalies were recorded in sediments of the lakes Kitkajärvi, which might be due to albite diabases in the environment. Copper correlates in the same way with zinc, but additionally with iron and manganese.

The copper accumulations occur partly in the same areas as the high zinc concentrations. It may be due to the different precipitation and mobilization of the materials that the high concentrations do not always occur parallel in the same lakes. Zinc and copper accumulations are seen around the known pyritic deposits, though not always in their immediate vicinity. No obvious connections are seen between the concentrations and the known ore deposits. Nor are the differences explained by the effects of culture.

Cadmium was only seen in two lakes on the felsic area. The drainage areas of both of these lakes included peatland and moraine. The concentrations were low, the maximum being 1.1 $\mu g\ l^{-1}$. These lakes contained plenty of humus, which means that cadmium may enter the lake along with brown runoff waters. The influence of cultural factors is suggested by the presence of cadmium in roadside lakes close to population and farming.

Lead was not seen to depend on the rock classes, nor was there any connection between lead and the soil classes capable of explanation. The high concentrations may be due to the traffic on the nearby road.

The negative correlation of lead with pH and oxygen suggests mobilization from the sediment at low pH and E_h. Lead hence correlates with calcium, zinc, copper and SiO_2. No dependence on humus is seen.

In the Koutajoki river basin, the silicic acid concentration was not seen to depend on the quality of the bedrock. Almost significant differences emerge between the concentrations of moraine and peaty areas. The concentrations were highest in the latter class and lowest in the former. This difference is not seen, however, in areas where the rocks have low silicic acid concentrations. Silica does not seem to be bound with seston, but the silica present in the epilimnion is partly bound with humus.

The highly significant correlations of silicic acid with metals in the epilimnion are probably mainly due to their mobilization upon increasing acidity, but complex formation may also be possible.

Sulfate was found to correlate with conductivity, pH, alkalinity and alkaline and alkaline-earth metals. In the annual material, there was a significant or highly significant correlation in the epilimnion for conductivity, sodium, potassium, calcium, magnesium and zinc.

Corresponding hypolimnic correlations emerge for conductivity, alkalinity, pH, potassium, calcium, magnesium and zinc. The correlations are stronger in summer than in winter, which is due to leaching from the drainage area. Sulfate therefore also has a positive correlation with the area of the drainage basin and a negative correlation with the lake percentage and the lake area.

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TIIVISTELMÄ

Pohjois-Kuusamon pienet järvet saavat yleensä vetensä helposti rajattavalta valuma-alueelta, jolloin veden laatu kuvaa lähivaluma-alueen ominaisuuksia, mm. maa- ja kallioperän laatua. Tässä tutkimuksessa tarkastellaan Koutajoen vesistöaluetta, joka sijaitsee Kuusamon kunnan pohjoisosassa Koillismaan ylängöllä. Kohteena olevien 131 järven veden laatu tutkittiin maalis-huhtikuussa ja elo-syyskuussa v. 1978—1979. Niiden koko vaihteli 0.1—0.49 km^2.

Alueen kallioperä vaihtelee huomattavasti. Erikoisuutena ovat dolomiitit. Tässä tutkimuksessa kallioperä luokitellaan felsisiin ja mafisiin piihappopitoisuuden mukaan. Kolmas luokka on näiden yhdistelmä. Maalajiluokituksessa käytetään hiekka- ja sora-, moreeni-, moreeni- ja turve- sekä turvemaita.

Kallioperän koostumus näyttää vaikuttavan raudan, kaliumin, kalsiumin, kuparin ja lyijyn pitoisuuksiin. Maaperä vaikuttaa metalleista raudan, mangaanin, natriumin, kalsiumin ja magnesiumin pitoisuuksiin. Felsisten kivilajien alueella lyijy- ja sinkkipitoisuudet riippuvat maaperän laadusta.

Elektrolyyttipitoisuutta ja puskurikykyä ilmaisevat pH:n, sähkönjohtavuuden ja alkaliteetin arvot vaihtelevat sekä kallio- että maaperän laadun mukaan. Humusta ilmaisevat väri ja COD vaihtelevat yleisesti maaperän laadun mukaan.

Kallioperäluokassa K1 (felsiset kivilajit) vedenlaatumuuttujien erot maaperäluokkien kesken ovat vähäisimmät.

Järven pinta-alan kanssa korreloivat suuntaa-antavasti tai lähes merkitsevästi alusveden happi, sähkönjohtavuus, alkaliteetti, kalsium ja magnesium. Happea lukuunottamatta korrelaatio on negatiivinen. Päällysvedessä merkitsevä tai lähes merkitsevä negatiivinen korrelaatio on sähkönjohtavuuden, alkaliteetin, kaliumin, kalsiumin, piihapon ja sulfaatin kanssa. Vähäisin (negatiivinen) korrelaatio on talvella päällysvedessä, jolloin ainoastaan sulfaattipitoisuus riippuu valuma-alueen pinta-alasta.

Järven kokonaissyvyyden kanssa negatiivinen korrelaatio on alusvedessä värillä ja COD:llä. Päällysvedessä vastaavasti on merkitsevä tai erittäin merkitsevä korrelaatio edellisten lisäksi hapen, sameuden, pH:n, typen, fosforin, raudan, mangaanin ja natriumin kanssa. Happea ja pH:ta lukuunottamatta korrelaatio on negatiivinen, joten järven syvyyden lisääntyessä veden laatuominaisuudet laimenevat.

Järvisyys ja järven pinta-ala korreloivat päällysvedessä negatiivisesti sähkönjohtavuuden, alkaliteetin, kaliumin, kalsiumin, piihapon ja sulfaatin kanssa.

Suoprosentti korreloi positiivisesti humusta ilmentävien ominaisuuksien (väri, COD) kanssa. Positiivinen korrelaatio on lisäksi mangaanin, natriumin, kaliumin ja alusvedessä sameuden kanssa. Negatiivinen korrelaatio on hapen, pH:n ja klorofyllin kanssa. Tässä, kuten muissakin yhteyksissä, korrelaatiot ovat kesällä suuremmat kuin talvella ainevaluman eroista johtuen.

Rauta ja mangaani korreloivat useimpien vedenlaatumuuttujien kanssa, joten ne ovat mukana yleensä rapautumis- ja huuhtoutumistapahtumissa. Rautaa ja mangaania on runsaasti humuksessa, joten korrelaatio tätä ilmentävien ominaisuuksien ja suoprosentin kanssa on luonnollista. Negatiivinen korrelaatio hapen ja pH:n kanssa johtuu näiden vaikutuksesta raudan ja mangaanin liukoisuuteen.

Mitatut elohopeapitoisuudet jakautuivat eri kallio- ja maaperäalueille siten, etteivät nämä selittäneet eroja. Syynä mahdollisiin todellisiin eroihin ovat siten valuma-alueen rakenteen ja käytön erikoispiirteet. Elohopean tiedetään huuhtoutuvan vesistöihin mm. humuksessa. Tutkimusalueen humuspitoisuudet ovat yleensä alhaiset. Syynä elohopean esiintymiseen eräillä alueilla saattavat olla sulfidimalmit. Havaitut pitoisuudet vastaavat eräiden kaivosalueiden pitoisuuksia. Elohopean kertymistä ravintoketjussa ei Kuusamossa ole havaittu. Siihen vaikuttaa alhaisen pitoisuuden lisäksi korkea pH, mikä hidastaa metyloitumista.

Käsiteltävässä aineistossa sinkki ei korreloi orgaanisen aineen kanssa. Erittäin merkitsevä korrelaatio on eräiden metallien, alkaliteetin ja pH:n kanssa. Voimakkain korrelaatio on kuparin kanssa. Kalsiumin kanssa korrelaatio on erittäin merkitsevä, mutta magnesiumin kanssa korrelaatiota ei havaita. Alkaalisuudesta ja orgaanisen aineen vähäisyydestä johtuen sinkin pitoisuudet ovat alhaiset tutkimusalueen järvissä.

Suurimpien sinkkipitoisuuksien esiintyminen talvella viittaa sinkin mobilisoitumiseen pohjasedimentistä. Tällöin se voi antaa viitteitä myös lähialueen kallioperän laadusta. Selvää yhteyttä tunnettuihin kiisumalmiesiintymiin ei kuitenkaan voida osoittaa.

Kuparilla ei havaita selvää riippuvuutta kallio- ja maaperän laadusta. Pienimmät pitoisuudet tavataan kuitenkin yleensä felsisten kivilajien alueella ja hiekkaperäisillä mailla olevissa järvissä. Sinkin tapaan kupariakin tavataan mitattavina pitoisuuksina yleensä vain talvella. Mobilisoituminen pohjasta näyttää ilmeiseltä. Suurimpien pitoisuuksien havaitaan keskittyneen tietyille alueille, joiden kallioperän lähempi tutkiminen on aiheellista.

Kupari saostuu helposti ja jää sedimentteihin lähelle lähtöpaikkaansa. Tästä syystä voisi olettaa korkeiden pitoisuuksien osoittavan suhteellisen tarkasti lähtöpaikkaansa. Kitkajärvien sedimenteissä on havaittu anomaliaan viittaavia pitoisuuksia, jotka voisivat aiheutua ympäristön albiittidiabaaseista. Kupari korreloi sinkin tapaan mutta lisäksi raudan ja mangaanin kanssa.

Osittain kuparikeskittymät sijoittuvat samoille alueille kuin korkeat sinkkipitoisuudet. Aineiden erilaisesta saostumisesta ja mobilisoitumisesta voi johtua, että korkeat pitoisuudet eivät esiinny aina rinnakkain samoissa järvissä. Sinkin ja kuparin keskittymiä tavataan tunnettujen kiisuaiheiden ympäristössä, vaikka ei välittömässä läheisyydessä. Selvää yhteyttä pitoisuuksien ja tunnettujen malmiesiintymien välillä ei havaita. Erot eivät selity myöskään kulttuurin vaikutuksella.

Kadmiumia havaittiin vain kahdessa felsisellä alueella olevassa järvessä. Kummankin järven valuma-alueella oli suota ja moreenia. Pitoisuudet olivat alhaiset; maksimi oli 1.1 $\mu g\ l^{-1}$. Nämä järvet olivat humuksisia, joten kadmiumia saattaa tulla vesistöihin ruskeiden valumavesien mukana. Kulttuurin vaikutukseen viittaa kadmiumin löytyminen tien varrella olevista järvistä, joiden läheisyydessä oli asutusta ja maataloutta.

Lyijyllä ei havaittu riippuvuutta kallioperäluokista eikä myöskään selitettävissä olevaa riippuvuutta maaperäluokista. Korkeisiin pitoisuuksiin voi olla syynä maantien läheisyys.

Lyijyn negatiivinen korrelaatio pH:n ja hapen kanssa viittaa mobilisoitumiseen sedimentistä alhaisissa pH- ja E_h-asteissa. Tällöin se korreloi kalsiumin, sinkin, kuparin ja SiO_2:n kanssa. Riippuvuutta humuksesta ei havaita.

Koutajoen vesistöalueella ei havaittu piihappopitoisuuden riippuvuutta kallioperän laadusta. Moreeni- ja suoalueiden pitoisuuksien kesken on lähes merkitsevät erot. Jälkimmäisessä luokassa pitoisuudet ovat suurimmat, edellisessä pienimmät. Tätä eroa ei havaita kuitenkaan piihappoköyhien kivilajien alueella. Pii ei näytä olevan sitoutunut sestoniin, mutta päällysvedessä se on osittain humukseen sitoutunutta.

Päällysvedessä havaitut piihapon erittäin merkitsevät korrelaatiot metallien kanssa johtunevat pääasiassa näiden mobilisoitumisesta happamuuden lisääntyessä, mutta myös kompleksinmuodostus voi olla mahdollista.

Sulfaatin todettiin korreloivan sähkönjohtavuuden, pH:n alkaliteetin sekä alkali- ja maa-alkalimetallien kanssa. Koko vuoden aineistossa merkitsevä tai erittäin merkitsevä korrelaatio on päällysvedessä sähkönjohtavuuden, natriumin, kaliumin, kalsiumin ja piihapon kanssa. Alusvedessä vastaavat korrelaatiot ovat sähkönjohtavuuden, alkaliteetin, pH:n, kaliumin, kalsiumin, magnesiumin ja sinkin kanssa. Korrelaatiot ovat kesällä vahvemmat kuin talvella, mikä johtuu huuhtoutumisesta valuma-alueelta. Tästä syystä sulfaatilla on myös positiivinen korrelaatio valuma-alueen pinta-alan ja negatiivinen korrelaatio järviprosentin ja järven pinta-alan kanssa.

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Appendix 1. Data on the location and drainage areas of the lakes investigated. The ordinal numbers are the same as in Fig. 2. Drainage area data are lacking for some lakes near the state boundary and some out-of-the-way lakes. The data in parentheses ( ) in column 4 have been estimated on the basis of the base maps. The rock and soil classes have been explained in chapter 4.1. Other explanations are the same as in Table 5.

Lake					Drainage area				
		Area km²	Above sea level m	Depth m	F km²	Peatland %	L %	Rock class	Soil class
1	2	3	4	5	6	7	8	9	10
Drainage area 73.01									
1.	Siikauopajan lampi	0.12	(137)	2.8	3.33	16.92	5.86	3	3
2.	Suistojärvet (et.)	0.16	229.2	6.0	3.34	16.31	15.18	3	2
3.	Suistojärvet (pohj.)	0.16	231.6	11.5	2.56	17.58	13.57	2	2
4.	Karhujärvi	0.29	268.5	16.0	2.45	26.66	11.85	3	2
5.	Juhtilampi	0.22	217.5	2.0	1.12	12.33	19.73	2	2
6.	Iso Huotinlampi	0.28	236.2	10.9	3.83	28.20	12.14	1	2
7.	Sorsajärvi	0.32	249	5.0	1.57	18.18	20.41	3	2
8.	Ruoppilampi	0.12	224.1	19.0	1.54	9.93	7.82	2	2
9.	Lehtojärvi	0.12	(243)	4.0	2.08	16.27	21.20	3	2
10.	Kalliojärvi	0.30	237	29.0	4.63	16.70	18.38	3	3
11.	Kuivajärvi	0.17	224	7.0	3.31	18.67	6.05	3	2
12.	Kiutajärvi	0.47	225	23.0	9.02	14.30	14.77	3	3
13.	Sirkkalammit	0.10	285	6.0	0.94	16.98	14.32	2	2
14.	Autiolampi	0.13	(257)	8.5	1.78	17.58	13.67	2	2
15.	Matinjärvi	0.18	246.1	8.7	3.14	30.36	7.17	2	2
16.	Iso Kaarretuinen	0.12	267.0	5.2	0.92	17.89	16.26	2	2
17.	Kuolemajärvi	0.12	239.0	1.6	1.07	24.82	11.24	2	4
Drainage area 73.02									
18.	Pieni Vasaralampi	0.21	260.0	3.0	0.95	8.40	22.05	1	1
19.	Vasaralampi	0.24	254.6	3.5	3.33	10.82	14.35	3	1
20.	Kesäjärvi	0.35	289.1	4.5	3.45	29.06	13.62	2	3
21.	Talvijärvi	0.16	296	9.5	1.45	2.41	11.88	1	1
22.	Moisasenlampi	0.12	(296)	2.2	0.90	27.78	13.33	2	3
23.	Yli-Pessari	0.28	277	22	2.20	3.41	13.98	2	1
24.	Iso Pihlajalampi	0.11	276.2	8.5	1.73	8.09	7.36	3	1
25.	Kotalampi	0.10	(252)	11.0	0.42	2.40	23.95	2	1
26.	Ali-Pessari	0.33	260	31.5	4.02	5.11	16.19	2	2
27.	Viipusjärvi	0.22	250	8.0	5.30	5.89	10.33	3	2
28.	Palolampi	0.16	252	3.5	0.70	20.64	22.78	3	3
29.	Palolammit	0.12	(252)	3.0	0.70	44.84	17.08	2	4
30.	Hakojärvi	0.17	248	21.5	6.44	5.36	11.14	3	1
31.	Halmelampi (et.)	0.15	(247)	3.0	0.94	17.51	15.92	2	4
32.	Kukurtajärvi	0.10	(245)	2.8	10.84	47.81	5.65	2	4
33.	Kattavanlampi	0.12	(245)	15.0	0.59	28.81	20.34	2	3

Appendix 1. Continued.

2	3	4	5	6	7	8	9	10
34. Akanlampi	0.10	241.9	2.8	1.31	28.11	11.85	1	3
35. Taivallampi	0.11	245.8	7.1	0.21	10.71	52.38	3	1
36. Ahvenjärvi 1	0.18	240	5.0	2.96	26.31	11.51	2	1
37. Ristilampi	0.20	256.9	5.0	1.07	32.32	18.74	1	3
38. Lukkolainen	0.48	(247)	18.0	3.13	12.62	16.53	3	3
39. Kokkojärvi	0.39	252	5.0	1.86	32.75	21.43	2	2
40. Ahvenjärvi 2	0.23	(247)	7.5	2.04	33.91	11.30	1	3
41. Pikku-Kuopunki	0.04	(228)	22.0	0.33	15.27	12.21	2	3
42. Kuopunki	0.20	227	22.0	11.40	25.77	23.05	2	2
43. Kuivajärvi 1	0.27	246.1	0.6	9.54	20.93	20.46	3	4
44. Pohjaslampi	0.23	255	11.0	2.01	14.07	11.46	2	4
45. Elijärvi 2	0.41	253	1.5	1.73	23.70	23.70	1	3
46. Harjalampi	0.10	243.1	5.1	1.86	39.30	5.92	1	3
47. Ylipäänlampi	0.19	223.4	13.3	1.87	15.78	10.16	3	4
48. Lassinlampi	0.14	(260)	2.8	0.71	38.16	14.79	1	3
49. Paavonlampi	0.15	265	3.0	0.63	25.40	23.81	1	3
50. Isojärvi	0.46	279.1	10.2	3.61	41.18	12.73	2	3
51. Riekamojärvi	0.43	244	20.1	6.26	24.68	9.07	3	2
52. Latvalammit (pohj.)	0.10	264	2.0	1.08	36.34	11.81	1	3
53. Matalajärvi	0.12	(267)	2.9	2.56	26.44	16.20	3	3
54. Syväjärvi	0.20	279.5	6.0	1.14	17.58	21.10	3	3
Drainage area 73.04								
55. Kortelampi	0.26	(257)	1.0	1.35	13.33	19.26	1	2
56. Pikku-Sorva	0.42	262.6	4.8	0.83	6.00	50.60	1	2
57. Likolampi	0.29	262.5	1.0	..	..	..	1	3
56. Iso-Sorva	0.45	262.6	3.0	..	..	..	1	3
59. Taivaljärvi	0.23	262.6	4.9	..	..	..	1	3
60. Kuralampi	0.25	(267)	1.0	2.58	22.48	9.69	1	3
61. Kotilampi	0.18	252.6	1.3	34.03	21.83	5.61	1	2
62. Matalalampi	0.38	(256)	1.2	1.31	9.16	29.01	1	3
63. Savolaisenlampi	0.19	(267)	7.8	1.65	30.90	11.52	1	3
64. Piskalampi	0.12	(258)	6.7	0.72	16.67	16.67	1	2
65. Nuottilampi	0.26	254.7	1.9	8.98	19.82	8.02	1	3
66. Lehtolampi	0.20	(259)	1.5	2.96	22.30	7.09	1	3
67. Iso Kokkolampi	0.31	(258)	1.7	4.53	17.88	7.29	1	3
68. Rahkolampi 2	0.16	256.4	1.0	..	..	..	1	3
69. Jorvanjärvi	0.15	(289)	6.5	25.19	20.96	6.87	1	3
70. Tiirolampi	0.14	256.4	1.5	..	..	..	1	3
71. Pikku Papuluoma	0.48	268.0	21.7	2.83	11.31	16.96	1	3
72. Siikalampi	0.26	(300)	2.3	8.97	24.08	3.01	1	3
73. Kuusijärvi 1	0.42	256.5	1.2	..	..	..	1	3

74. Iso Vasaluoma	0.43	262.7	1.5	1.44	25.00	29.86	1	3
75. Pieni Vasaluoma	0.30	(262)	1.5	4.79	18.79	29.85	1	3
76. Ritalampi	0.12	(305)	1.0	2.37	27.00	5.06	2	3
77. Kiviperänlampi	0.41	(258)	8.3	16.27	24.59	9.90	1	4
78. Molkinlampi	0.12	(265)	2.8	0.68	40.50	17.65	1	3
79. Rytilampi	0.31	(252)	1.4	24.53	18.87	6.11	3	3
80. Markuslampi	0.14	275.7	4.5	0.63	28.50	22.22	1	3
81. Lammaslampi	0.13	(256)	1.7	5.41	15.90	2.40	1	4
82. Haukijärvi	0.26	252.8	5.1	43.14	29.92	3.13	3	2
83. Kurikkalampi	0.14	(252)	1.6	70.86	25.54	3.50	3	2
84. Kivi-Piskamo	0.16	(257)	19.0	21.76	33.59	3.22	3	3
85. Koverinjärvi	0.30	(279)	0.8	18.29	35.16	2.95	3	3
86. Kaarijärvi	0.20	252.3	6.8	25.19	18.66	3.93	3	2
87. Hytölampi	0.14	(257)	0.7	9.65	16.69	2.69	1	3
88. Vaimojärvi	0.20	252.4	7.0	13.48	20.03	3.26	1	2
89. Ali Heikinjärvi	0.29	(284)	6.0	9.08	17.95	8.37	1	3
90. Yli Heikinjärvi	0.22	(285)	8.0	6.53	18.38	7.04	1	3
91. Impo	0.11	299.5	12.8	1.33	16.54	8.27	1	3
92. Sirelampi	0.22	(299)	9.5	2.80	18.21	8.21	1	3
93. Iso Leppilampi	0.21	(318)	5.5	4.70	27.02	4.47	1	3
94. Särkijärvi 1	0.24	(246)	5.7	26.87	14.59	12.69	1	3
95. Suolalampi	0.11	(318)	2.6	3.04	6.58	3.62	3	2
96. Petäjälampi	0.16	296	5.4	1.06	9.43	15.09	1	2
97. Lohilampi	0.14	344	11.0	1.52	12.21	12.87	1	3
98. Ylimm. Kiekerölampi	0.22	272	1.9	10.88	26.93	4.23	2	4
99. Alimm. Kiekerölampi	0.16	270	1.0	16.11	29.05	4.90	2	4
100. Syvälampi	0.24	288	18.2	1.59	15.07	15.07	3	3
101. Kalliojärvi	0.36	261	14.0	50.50	18.02	4.08	3	3
102. Jussinlampi	0.11	(240)	7.0	5.98	16.72	2.17	3	3
103. Pikku Porontimajärvi	0.27	313	11.0	1.00	3.00	27.00	3	2
104. Särkijärvi 2	0.22	212	6.5	31.14	37.44	5.75	1	3
105. Vansselijärvi	0.32	267	7.5	4.55	33.40	9.01	1	3
106. Ylimm. Kuusilampi	0.12	229	17.0	4.92	35.77	4.47	3	3
107. Mustajärvi	0.14	(253)	27.0	0.80	10.00	17.50	2	4
108. Laurinlampi	0.10	(257)	4.8	1.09	33.94	9.17	1	3
109. Keskimm. Kuusilampi	0.11	(229)	15.0	5.65	32.21	5.84	3	3
110. Kuusijärvi 2	0.34	228	12.5	16.28	36.12	7.74	3	3
111. Jelestimänjärvi	0.16	(227)	9.0	17.55	36.92	8.09	3	3
112. Raatelammit länt.	0.13	220.6	2.1	0.59	30.51	22.03	3	3
Drainage area 73.05								
113. Elijärvi 1	0.28	(275)	6.7	1.99	20.13	20.13	3	1
114. Pikku Hyypiö	0.19	278.7	16.8	1.53	7.01	12.40	3	1
115. Naatikkalampi	0.47	(280)	1.7	121.85	26.89	15.76	1	4
116. Särkilampi	0.21	310.1	2.5	5.13	23.66	4.54	1	3
117. Iso-Veska	0.20	(285)	4.0	3.24	28.78	7.56	3	2

Appendix 1. Continued.

2	3	4	5	6	7	8	9	10
118. Äijänlampi	0.14	(310)	14.0	2.54	7.40	6.51	2	2
119. Pohjoislampi	0.17	283.7	0.7	11.39	39.33	6.58	2	4
120. Honkalampi	0.14	(287)	1.0	2.93	42.54	11.42	3	3
121. Kokanlammit (et.)	0.12	288	9.0	1.92	41.85	10.17	3	3
Drainage area 73.06								
122. Iso Ivanlampi	0.15	247	4.4	2.16	27.23	10.78	3	3
123. Äystöjärvi	0.42	245.4	4.8	33.69	16.35	35.25	3	4
124. Ohtajärvi	0.13	(240)	14.5	0.74	3.72	17.57	1	2
125. Mutkalampi	0.10	(245)	1.5	1.62	32.61	8.35	2	4
126. Kutkunlampi	0.19	237	4.5	2.72	51.84	12.13	2	4
127. Halmelampi	0.14	239.7	5.0	1.09	42.86	16.13	1	3
128. Syvälampi	0.11	229.7	6.9	1.14	29.89	10.55	3	3
129. Toivanjärvi	0.17	287.2	7.0	1.18	37.63	14.38	3	3
130. Jousilampi	0.13	240.8	1.0	3.29	55.33	18.57	2	4
131. Ruvanlampi	0.26	237	4.3	2.92	46.40	9.33	2	4