DEVELOPMENTS IN THE EVALUATION OF SMALL LAKE WATER QUALITY FROM DIGITAL LANDSAT MSS DATA, KUUSAMO, NORTHEAST FINLAND

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Abstract. The water quality data collected on the ground by the Water District Office in Oulu was subjected to statistical analyses together with Landsat data to display a few interactions and the possibilities of exploiting remote sensing methods in water area surveying. Correlations between the Landsat data statistics and some water quality measurements were identified. The small size of the studied lakes does not allow any clear calibration to be made but there could be possibilities to develop remote sensing methods for the evaluation of environmental variables and the detection of productivity and the eutrophication stage.

The remote sensing procedure could also be useful in portraying temporal variations within lakes as well as relative variations between lakes by classifying each lake on a pixel-by-pixel basis. Although the remote sensing method is not able to supersede ground truth information for lake studies, it has value in regions where many lakes are to be found within a restricted small area. Under these circumstances the collection of information on the ground for a small number of test lakes and the generalization of this data, with the aid of machine-pressing remote sensing, would result in considerably less field work and cost savings.

1. Introduction

Computer-aided Landsat MSS data remote sensing is rapidly developing from a descriptive water area monitoring tool to one which allows quantitative water body quality evaluations to be made simultaneously over large areas. Remote sensing methods for the determination of the trophic state of natural lakes (Strong, 1974; Lindell, 1980; Arkimaa and Raitala, 1981) and of water reservoirs (Lepley *et al.*, 1975; Meinert *et al.*, 1978) have been developed (Blackwell, 1982) to display different biological, physical and chemical properties in water areas.

In this study some investigations concerning the application of Landsat MSS imagery for indicating water quality, and the state of the water body and lake area were carried out over the Kuusamo area in northeastern Finland (Figure 1). The main purpose of this study deals with the mutual correlations between Landsat MSS channel combinations and the analysed water quality values. The second is to demonstrate the influence of environmental factors by Landsat classification.

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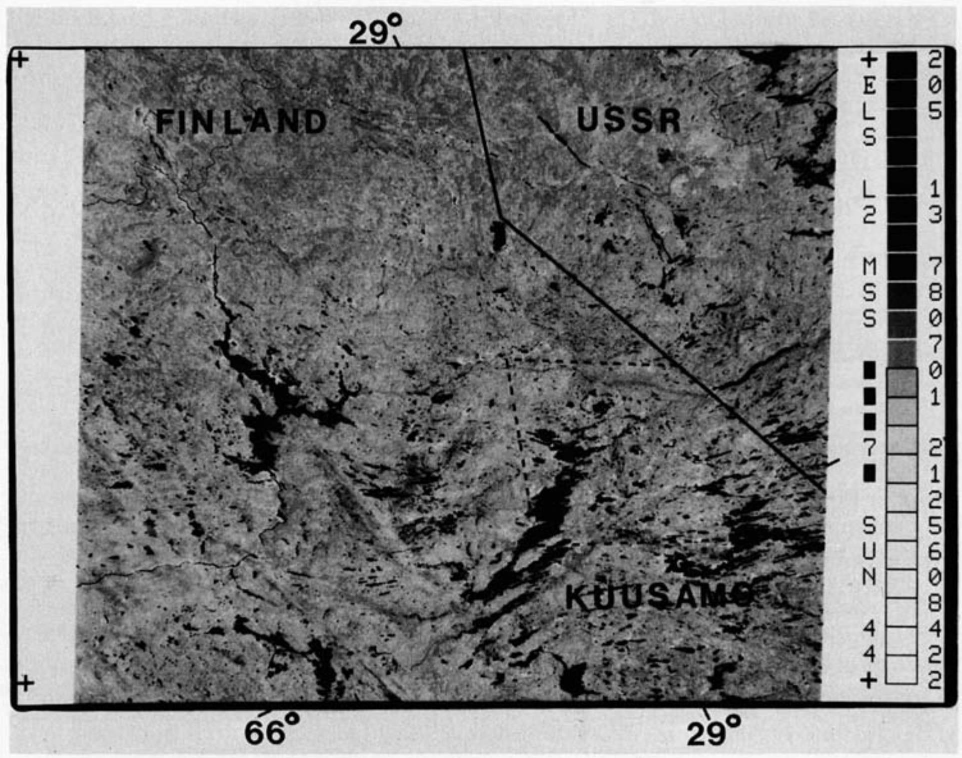


Fig. 1. Landsat MSS scene over the studied area. An area of about 185 × 185 km^2 is covered by the image.

2. The Study Area

The northern Kuusamo lake area (Figure 1) was chosen because of the good quality of the lakes in the region so as to depict the method potential within an area where only minor eutrophication has taken place. Thus it is possible to investigate the lower limit of the method usability and thereby the results would be even more obvious within more eutrophic lake areas.

All the lakes in this study belong to the Koutajoki catchment, which drains towards the east into the White Sea. The geology of the area is described by Simonen (1980) as mainly sedimentogeneous conglomerates, quartzites, slates and mica schists with occasional dolomitic and calcitic limestones. Numerous sills, dikes and intrusions of spilitic rocks and low-grade greenschists are also present. The topography of the area varies with the highest hills rising to a height of about 400 m.

In addition to bedrock tectonics erosion by running water is also an important factor in sculpturing the topography (Aario, 1966). Also drumlins and, in places, eskers may effect the shape of the lake, especially around the upper courses of the rivers Kuusinkijoki and Kitkajoki, where the best-developed chains of lakes and the most regularly shaped

TABLE I

Water quality values of the adopted lakes. N coded lakes are sampled in 1978 and A coded lakes in 1979. All the samples represent July–August water 1 m (in shallow lakes 0, 5 m) below the water surface

Lake		Depth (m)	Secchi disk transparency (m)	O_2 (Sat. %)	Turbidity (FTU)	Conductivity ($m Sm^{-1}$)	Colour ($mg Pt l^{-1}$)	N ($\mu g l^{-1}$)	P ($\mu g l^{-1}$)	Fe ($\mu g l^{-1}$)	Alkalinity ($mmol l^{-1}$)	pH	Chlorophyll a ($\mu g l^{-1}$)	SO_4 ($mg l^{-1}$)
Vasaralampi	7 N	3.5	3.5	109	0.91	8.1	10	605	14	46	0.52	8.5	3.0	8.0
Elijärvi 1.	10 N	6.7	1.0	122	4.9	6.5	35	973	54	348	0.46	8.6	37.9	3.7
Iso-Veska	13 N	4.0	3.3	102	0.53	9.0	30	352	11	77	0.49	7.4	2.3	16.0
Särkilampi	16 N	2.5		103	0.46	10.8	40	244	12	78	0.89	7.8	1.2	4.2
Kesäjärvi	17 N	4.5	2.2	102	1.2	6.4	40	296	25	337	0.46	7.5	5.1	5.1
Pohjoslampi	37 N	11.0	4.6	75	0.78	9.0	20	336	12	144	0.79	7.6	1.6	4.6
Lukkolainen	39 N	18.0	6.9	104	0.41	8.7	10	228	11	82	0.75	7.9	1.35	2.9
Riekamojärvi	47 N	20.0	5.2	102	0.36	7.0	10	74	8	35	0.58	7.7	1.1	2.7
Karhujärvi	50 N	10.0	4.8	97	0.42	7.4	20	506	8	62	0.63	7.7	1.1	3.4
Kalliojärvi	66 N	29.0	6.4	100	0.42	9.3	10	248	7	48	0.64	7.6	0.79	10.0
Kiutajärvi	67 N	23.0	6.1	100	0.33	7.2	10	251	13	91	0.52	7.6	0.81	5.1
Äystönjärvi	74 N	4.8		97	0.95	5.1	25	210	15	84	0.33	7.6		2.7
Iso Ivalampi	75 N	4.4		98	1.2	4.6	60	477	24	370	0.30	7.3		2.5
Ristilampi 2.	97 N	5.0	2.8	103	0.69	5.7	30	300	21	255	0.33	7.4	2.1	2.5
Kotilampi	1 A	1.0			0.89			790	20	270	0.39		0.9	3.8
Nuottilampi	4 A	1.9	0.6	110	0.44	4.9	90	1050	37	360	0.33	7.1	29.3	2.3
Iso Kokkolampi	5 A	1.7		98	0.84	4.1	90	610	9	200	0.27	7.1	2.0	4.0
Pikku Papuluoma	6 A	21.7		99	0.43	3.1	20	340	8	44	0.18	7.1		3.6
Matalalampi	8 A	1.2		94	1.9	3.4	50	540	24	220	0.21	7.0	3.1	2.2
Taivaljärvi	9 A	4.9			1.1	2.9	50	380	10	420	0.17	7.0	1.8	2.1
Pikku-Sorva	10 A	4.8		104	0.71	3.2	50	350	13	220	0.19	6.8	2.5	2.7
Iso-Sorva	11 A	3.0		96	0.86	2.9	60	390	11	350	0.20	6.9	1.8	2.4
Likolampi	12 A	1.0		93	0.95	3.0	50	720	23	360	0.17	6.7	1.5	3.0
Rahkolampi	15 A	1.0		94	1.1	2.6	50	340	11	280	0.18	7.1		2.5
Tiirolampi	16 A	1.5		94	0.84	2.7	50	380	14	260	0.16	7.0	1.9	2.6
Iso Vasaluoma	18 A	1.5		97	1.1	2.4	60	570	12	210	0.13	6.9	3.4	2.6
Pieni Vasaluoma	19 A	1.5		100	1.2	2.8	60	570	16	200	0.17	6.9	6.0	2.6
Kiviperänlampi	20 A	8.3	2.3	88	1.3	5.3	60	505	13	440	0.39	6.6	4.2	
Ali Heikinjärvi	24 A	6.0		93	1.5	3.5	50	244	8	240	0.22	6.7	3.4	
Yli Heikinjärvi	25 A	8.0		91	0.70	3.7	50	288	7	200	0.22	6.7	2.5	
Rytilampi	35 A	1.4		103	1.1	8.3	70	420	22	190	0.70	7.3	2.7	3.9
Hankijärvi	36 A	5.1		92	0.64	8.0	60	(260)	15	210	0.60	7.2	2.3	8.1
Vaimojärvi	40 A	7.0	2.6	100	0.93	8.4	70	370	17	180	0.62	7.3	3.6	7.3
Petäjälampi	46 A	5.4	3.7	106	1.3	12.7	15	330	19	40	1.10	8.4	4.2	
Kalliojärvi	47 A	14.0		70	1.1	7.9	40	300	23	220	0.53	7.3	3.4	
Pikku Porontima	48 A	11.0		79	7.5	4.7	35	620	24	68	0.28	8.5	18.5	
Vansselijärvi	49 A	6.5		91	0.64	6.9	40	130	22	160	0.54	7.0	1.6	
Hivotanjärvi	50 A	7.0		108	2.6	6.1	30	610	27	88	0.48	7.9	22.5	
Kuusijärvi 2.	55 A	12.5		87	0.68	5.4	25	410	8	140	0.43	6.9	1.7	
Ylin-Kiekerölampi	65 A	1.9		98	1.3	6.4	30	270	10	120	0.48	7.2	1.6	
Syvälampi	67 A	18.2		98	0.53	5.8	10	290	10	47	0.46	7.0	2.5	

TABLE II

Mean and standard deviation values of different variables

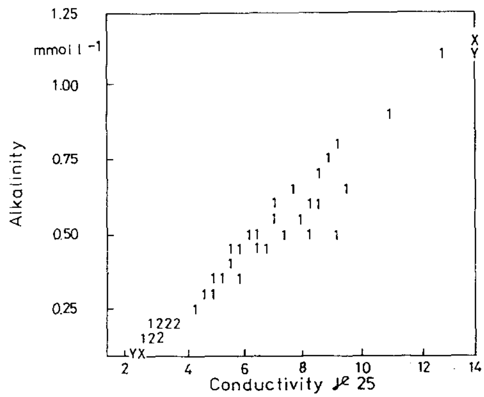
Variable	Mean	St. Dev.
C 4	21.49	2.15
C 5	15.20	2.18
C 6	8.66	2.04
C 7	5.40	0.69
D 4	1.99	0.33
D 5	2.94	0.18
D 6	5.67	0.56
D 7	10.32	1.62
A 4567	50.74	7.05
A 56	23.85	4.75
D 4567	2.30	0.29
D 45 × 10	14.11	1.45
Depth (m)	7.4	6.9
Secchi disk transparency (m)	3.7	1.9
O_2 saturation %	97	9
Turbidity	1.2	1.3
Conductivity (m Sm^{-1})	5.9	2.5
Colour (mg Pt l^{-1})	40	22
Total N ($\mu g\, l^{-1}$)	419	208
Total P ($\mu g\, l^{-1}$)	16	9
Fe ($\mu g\, l^{-1}$)	189	117
Alkalinity (mmol l^{-1})	0.43	0.23
pH	7.3	0.5
Chlorophyll a ($\mu g\, l^{-1}$)	5.06	8.22
SO_4 (mg l^{-1})	4.3	3.0

lakes are to be found (Hänninen, 1915). Near the Oulanka main valley there are a fewer number of lakes than on the surrounding upland plateau.

3. Water Analyses

All the 168 small (50–100 ha) lakes were chosen for sampling during July of 1978 or 1979. Analyses (Table I) of the water samples (Erkomaa and Mäkinen, 1975) were carried out by the Laboratories of the Water District Office of Oulu and the Waterboard of Finland. Several lakes were omitted because of the lack of water samples or because they were too narrow or small when compared to the ground resolution (appr. 0.5 ha) of the Landsat MSS data (cf. Blackwell, 1982). A total of 41 lakes remained for this study.

To test the quality of the Landsat MSS data in displaying the lake ecosystem the values for lake depth, Secchi disk transparency, oxygen saturation percentage, turbidity, conductivity, colour, total nitrogen, total phosphorus, iron, alkalinity, pH, chlorophyll a and SO_4 were chosen for further investigation. Some of these variables strongly display the trophic state of the lake while others were adopted for test purposes (Table II).



N= 40
COR= .9702***

	MEAN	ST.DEV.	REGRESSION LINE
X	5.8975	2.5381	X= 10.807 Y+ 1.2749
Y	.42775	.22787	Y= .08711 X- ,08598

Fig. 2. Conductivity (γ_{25}) vs. alkalinity for 40 lakes.

In this paper some attention has been paid to statistical data between different analysed values. Because the trophic stage of a lake ecosystem indicates the quality which is met by the living substances through the interactions of community and environment, there are evidently no independent factors contributing wholly to the observed phenomena. However, there are some groups of dependant variables which allow some statistical conclusions (Table III) between them to be drawn. The productivity of a lake depends on the nutrient accession from the drainage basin, the physiography of the water body and geographic location, and the sedimentary history of the lake basin. Nutrients (total nitrogen and total phosphorus) are found to correlate with each other (Table III) but because phosphorus is a minor factor controlling production in these oligotrophic lakes it correlates much more prominently with the chlorophyll concentrations than nitrogen does. Turbidity is the degree of opaqueness produced by suspended particles and is also slightly associated with chlorophyll measurements. There is some connection between the Secchi disk transparency and turbidity, colour, iron, nutrients and chlorophyll. The Secchi disk transparency also seems to be influenced by lake depth. There is an extremely good correlation between conductivity (γ_{25}) and alkalinity (Figure 2) and also the moderate correlation coefficients between the pairs: conductivity and pH, and alkalinity and pH which are on a high level of significance. The colour agrees moderately with the iron content.

4. Landsat Data Extraction

The sampled lakes were located on the satellite data print and a test box was positioned in the middle of the open water area for every lake separately. Lakes which were too narrow were omitted to allow the elimination of effects caused by near-shore

TABLE III

Correlations between water quality data and Landsat MSS data for small lakes of the northern Kuusano area in frame 205-13-780701

	Landsat MSS data and derivatives											
	C 4	C 5	C 6	C 7	D 4	D 5	D 6	D 7	A 4567	A 56	D 4567	D 45
C 4		0.883	0.849	0.363	0.026	−0.176	−0.461	0.353	0.938	0.887	−0.003	−0.451
C 5	41		0.917	0.341	0.203	−0.508	−0.639	0.485	0.966	0.985	−0.091	−0.810
C 6	41	41		0.548	0.313	−0.239	−0.829	0.253	0.967	0.972	−0.393	−0.685
C 7	41	41	41		0.366	0.319	−0.476	−0.516	0.503	0.437	−0.744	−0.183
D 4	41	41	41	41		−0.124	−0.499	−0.113	0.215	0.255	−0.549	−0.330
D 5	41	41	41	41	41		0.196	−0.654	−0.293	−0.403	−0.282	0.755
D 6	41	41	41	41	41	41		−0.114	−0.682	−0.734	0.620	0.631
D 7	41	41	41	41	41	41	41		0.323	0.396	0.501	−0.511
A 4567	41	41	41	41	41	41	41	41		0.987	−0.224	−0.676
A 56	41	41	41	41	41	41	41	41	41		−0.223	−0.773
D 4567	41	41	41	41	41	41	41	41	41	41		0.130
D 45	41	41	41	41	41	41	41	41	41	41	41	
Depth	41	41	41	41	41	41	41	41	41	41	41	41
Secchi disk transp.	15	15	15	15	15	15	15	15	15	15	15	15
O_2	39	39	39	39	39	39	39	39	39	39	39	39
Turbidity	41	41	41	41	41	41	41	41	41	41	41	41
Conductivity	40	40	40	40	40	40	40	40	40	40	40	40
Colour	40	40	40	40	40	40	40	40	40	40	40	40
N	41	41	41	41	41	41	41	41	41	41	41	41
P	41	41	41	41	41	41	41	41	41	41	41	41
Fe	41	41	41	41	41	41	41	41	41	41	41	41
Alkalinity	41	41	41	41	41	41	41	41	41	41	41	41
pH	40	40	40	40	40	40	40	40	40	40	40	40
Chlorophyll a	37	37	37	37	37	37	37	37	37	37	37	37
SO_4	30	30	30	30	30	30	30	30	30	30	30	30

Number of lakes

macrovegatation and the adoption of open water characteristics only. The size of the test boxes varied from 15 to 45 picture elements and four channel means for every box were used to display the corresponding lake. The channel 7 (infrared) data was used to eliminate the most obvious non-water effects because these wavelengths are effectively absorbed by water when the chlorophyll (= vegetation) and soil reflectance is high (Hoffer, 1978). In spite of this procedure there are still evidently some vegetation and bottom effects in the Landsat data used and this may slightly deteriorate the results obtained in the case of small lakes.

Twelve Landsat MSS data values and their derivatives were used for every lake: the means of the test boxes for each channel (indicated by C4, C5, C6 and C7) the sum of the channel means (C4 + C5 + C6 + C7 = A4567), this same sum was divided separately by each channel mean

$$\frac{C4 + C5 + C6 + C7}{C4} = D4;$$

Depth	Secchi disk transp.	O_2	Turbi-dity	Conduc-tivity	Colour	N	P	Fe	Alkali-nity	pH	Chloro-phyll a	SO_4
– 0.152	– 0.495	0.488	0.426	0.192	– 0.026	0.514	0.704	0.203	0.181	0.506	0.670	– 0.049
– 0.423	– 0.667	0.391	0.321	– 0.023	0.241	0.578	0.647	0.456	– 0.009	0.199	0.570	– 0.242
– 0.332	– 0.581	0.287	0.378	– 0.081	0.221	0.609	0.681	0.483	– 0.070	0.182	0.603	– 0.220
0.023	– 0.167	0.067	0.266	– 0.168	0.164	0.292	0.427	0.218	– 0.177	0.047	0.335	– 0.158
– 0.192	– 0.118	– 0.167	0.102	– 0.322	0.238	0.162	0.019	0.126	– 0.278	– 0.190	0.120	– 0.326
0.512	0.555	– 0.033	0.092	0.005	– 0.308	– 0.244	– 0.114	– 0.302	– 0.035	0.176	0.000	0.281
0.381	0.535	– 0.019	– 0.192	0.234	– 0.340	– 0.498	– 0.415	– 0.525	0.199	0.147	– 0.348	0.262
– 0.408	– 0.619	0.240	– 0.007	0.083	0.217	0.365	0.250	0.228	0.100	0.068	0.317	– 0.092
– 0.308	– 0.583	0.394	0.393	0.010	0.167	0.591	0.711	0.405	0.014	0.291	0.635	– 0.187
– 0.393	– 0.634	0.355	0.353	– 0.048	0.237	0.603	0.675	0.477	– 0.035	0.196	0.596	– 0.236
– 0.011	0.032	0.266	– 0.160	0.404	– 0.305	– 0.272	– 0.172	– 0.355	0.384	0.260	– 0.131	0.282
0.683	0.801	– 0.138	– 0.072	0.255	– 0.504	– 0.483	– 0.391	– 0.617	0.207	0.211	– 0.243	0.446
	0.825	– 0.499	– 0.094	0.290	– 0.649	– 0.396	– 0.283	– 0.499	0.287	0.203	– 0.110	0.209
15		– 0.336	– 0.522	0.453	– 0.773	– 0.725	– 0.750	– 0.764	0.490	0.141	– 0.686	0.071
39	15		– 0.047	0.133	– 0.013	0.313	0.355	– 0.018	0.111	0.349	0.405	0.053
41	15	39		– 0.118	0.028	0.410	0.531	0.061	– 0.137	0.473	0.636	– 0.154
40	15	39	40		– 0.442	– 0.273	0.041	– 0.515	0.970	0.612	– 0.078	0.593
40	15	39	40	40		0.431	0.232	0.678	– 0.431	– 0.516	0.177	– 0.238
41	15	39	41	40	40		0.643	0.415	– 0.285	0.138	0.691	– 0.175
41	15	39	41	40	40	41		0.383	0.011	0.367	0.828	– 0.178
41	15	39	41	40	40	41	41		– 0.500	– 0.470	0.222	– 0.409
41	15	39	41	40	40	41	41	41		0.577	– 0.090	0.404
40	15	39	40	40	40	40	40	40	40		0.408	0.271
37	15	35	37	36	36	37	37	37	37	36		– 0.135
30	13	28	30	29	29	30	30	30	30	29	26	

Correlations

$$\frac{C4 + C5 + C6 + C7}{C5} = D5;$$

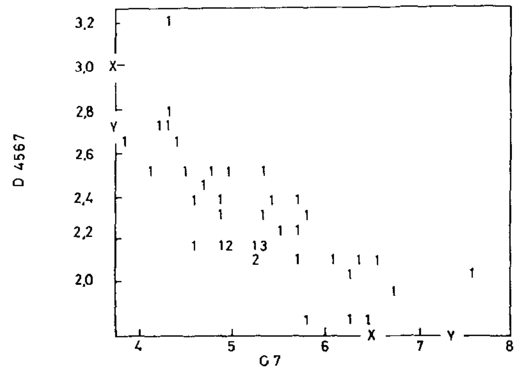
$$\frac{C4 + C5 + C6 + C7}{C6} = D6;$$

$$\frac{C4 + C5 + C6 + C7}{C7} = D7,$$

the sum of channel 5 and 6 means (C5 + C6 = A56), the ratio of channel 4 and 5 means (C4/C5 = D45), and the ratio of the mean sum of the two channel pairs

$$\left(\frac{C4 + C5}{C6 + C7}\right) = D4567 \; .$$

These procedures were adopted in spite of the fact that channels 4 to 6 are quasi-logarithmic, whereas channel 7 is linear. Correlations between different channels and their derivatives are shown in Table III to illustrate that different wavelength bands carry

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N=   41
COR=-.7439***

     MEAN      ST.DEV.     REGRESSION LINE
X    5.3960    .69371   X=-1.7827 Y+ 9.4899
Y    2.2966    .28947   Y=-.31040 X+ 3.9715
```

Fig. 3. C7 vs D4567 Landsat data derivative for 41 lakes in frame 205-13-780701.

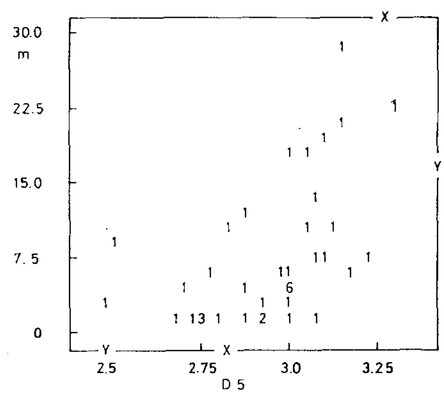
information from clearly different part of the water body and from different phenomena found from within the lakes (Hoffer, 1978). It is worth of noticing that there are only some pairs of Landsat data values with remarkably high correlation coefficients (Figure 3) while other value pairs do not display any significant correlation.

5. The Relationship Between Analyses and Landsat Data

Most of the adopted analyses could be seen as indicating a part of the physiographic, chemical or biological characteristics of the lakes. Because the four channel Landsat MSS imagery also displays some kind of general view, the question arises of how accurately it is possible to evaluate the different analysed values and even get some kind of parametric or multiparametric maps for them. Of course the Landsat satellite cannot directly measure water quality but the provided data allows the detection of phenomena indirectly related to the trophic state (Meinert *et al.*, 1978). Because Landsat data evidently indicates some kind of surface complexes (Raitala *et al.*, 1984) the relative trophic state indication would be the most useful advantage of the digital remote sensing. There is, however, no need to use the nebulous and overlapping categorizations or oligotrophic, mesotrophic and eutrophic terms in this clear-watered area and the relative trophic condition continuum is best indicated by analysed values together with the Landsat data (Tables I and II).

Because the main purpose of this study is to discover some affiliation of different Landsat MSS channels and their derivatives with ground truth data a correlation analysis was performed using the previously obtained values. Correlations which are on a significant level or better are to be seen in Table III. Several correlation coefficients exhibit significant and relatively clear correlations inferring that some kind of relationship does

(A)

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N=   41
COR= .5117***

     MEAN     ST.DEV.     REGRESSION LINE
X    2.9430    .18138   X= .01337 Y+ 2.8434
Y    7.4488   6.9393    Y= 19.576 X- 50.165
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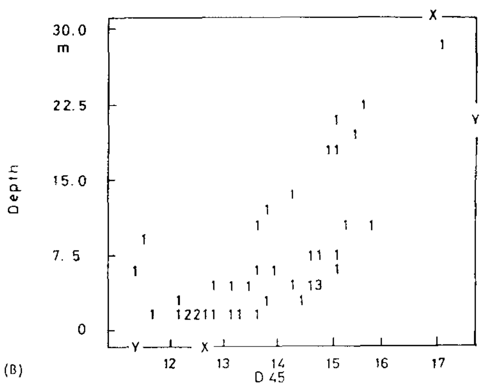
(B)

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N=   41
COR= .6826***

     MEAN     ST.DEV.     REGRESSION LINE
X    14.106   1.4505    X= .14268 Y+ 13.043
Y    7.4488   6.9393    Y= 3.2655 X- 38.614
```

Fig. 4. (a) Landsat derivative D5 vs depth (m) and (b) D45 vs. depth (m) for 41 lakes.

exist between Landsat reflectance values and water quality characteristics although only a linear correlation adjustment was performed between different values in this study.

Some kind of lake depth estimation is evidently gained with the aid of the expressions

$$\frac{C4 + C5 + C6 + C7}{C5} = D5 \text{ and } C4/C5 = D45 \text{ (Figure 4a, b).}$$

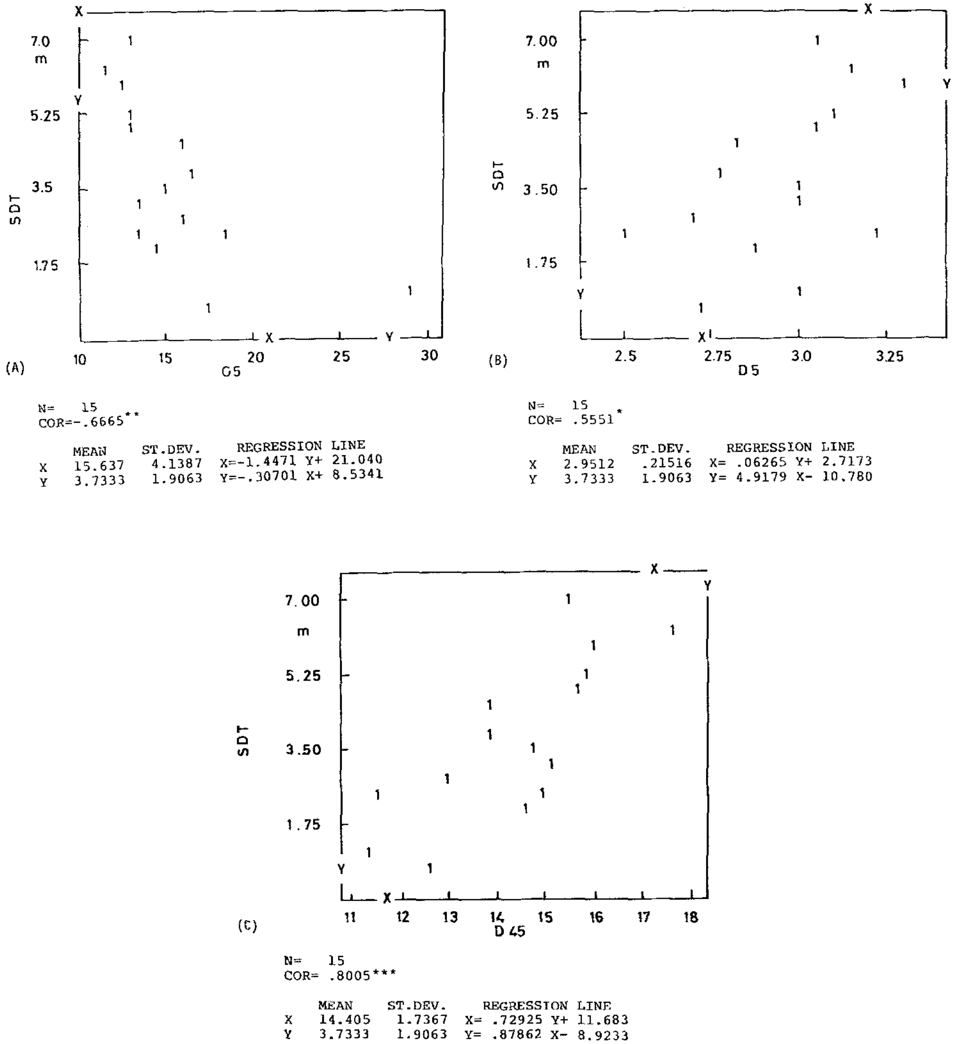


Fig. 5. The Secchi disk transparency values (SDT) can be evaluated by using Landsat MSS formulae (a) C5, (b) D5, and (c) D45.

The latter is also especially suitable in the Secchi disk transparency computation (Figure 5a, b, c) including, however, also simultaneously some information about the inverse values of colour and iron (Figure 6a, b, c, d) which indicate humus substances. The portion of the factors connected with productivity (e.g. nitrogen, phosphorus and chlorophyll) can be approximately estimate by using channels C4, C5 and C6 and the formula C4 + C5 + C6 + C7 = A4567 and C5 + C6 = A56; (Figure 7a, b, c). The total phosphorus is best displayed by the channel 4 data and by the sum of all the channel means

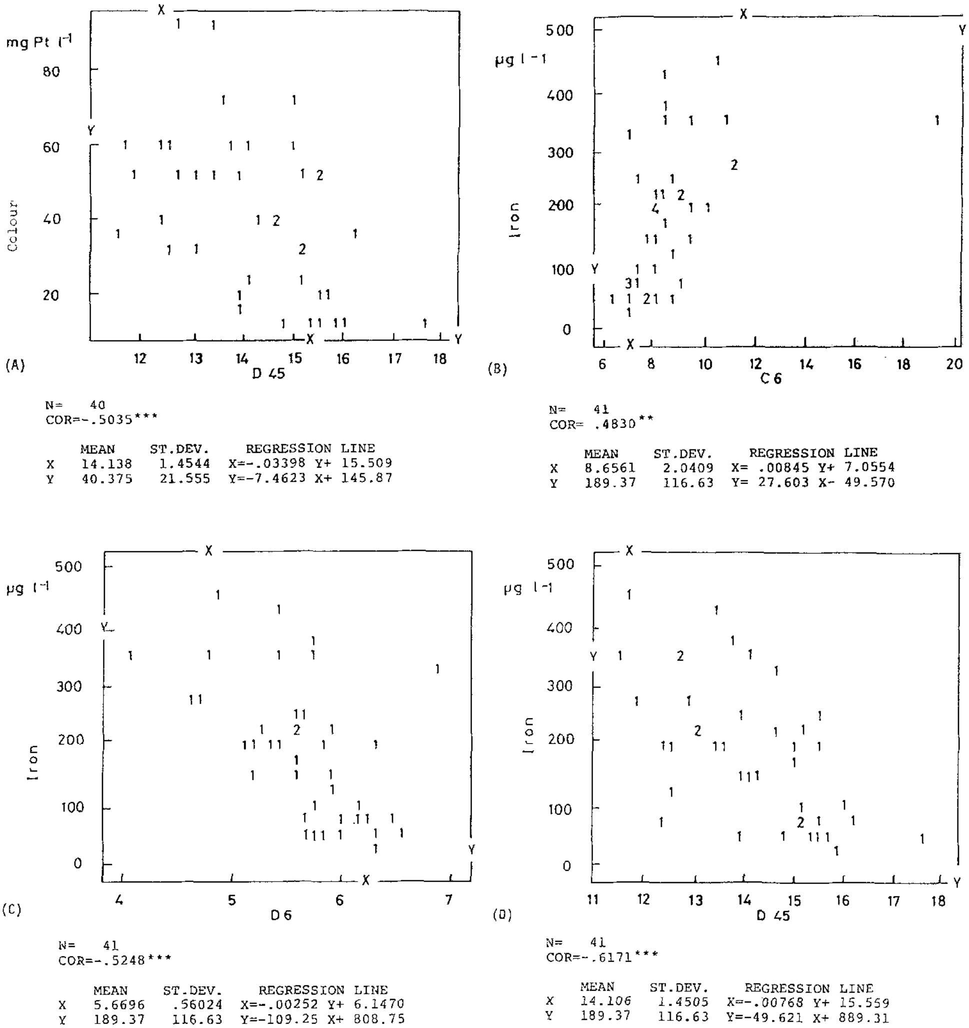


Fig. 6. Landsat MSS data also includes some information about (a) colour and (b), (c), (d) iron.

(Figure 8a, b). The channel 4 mean is also slightly connected with the measured pH values.

6. Thematic Classification

In order to visually represent the relative trophic state of the small lakes, a multispectral pixel-by-pixel classification of the Landsat imagery over the northern Kuusamo area was performed. To make the presentation more economic several small subimage windows,

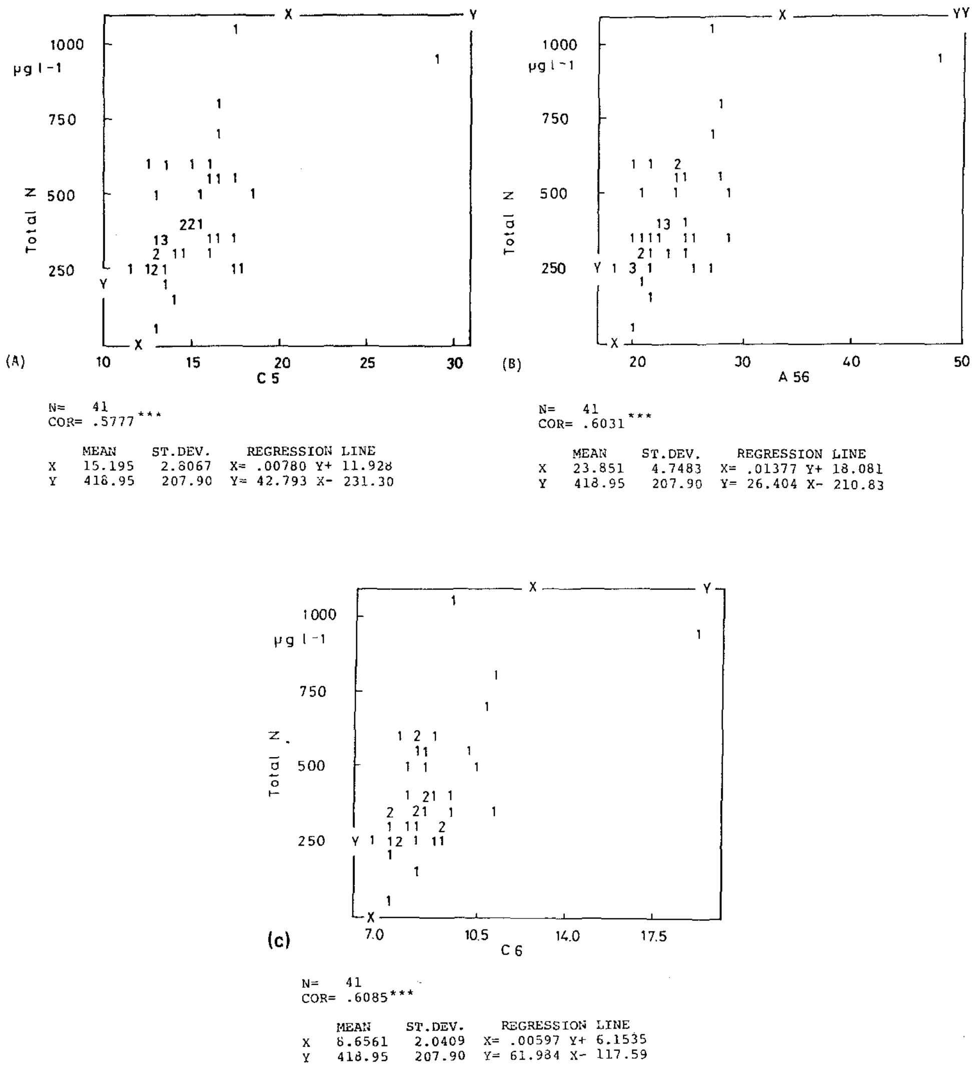
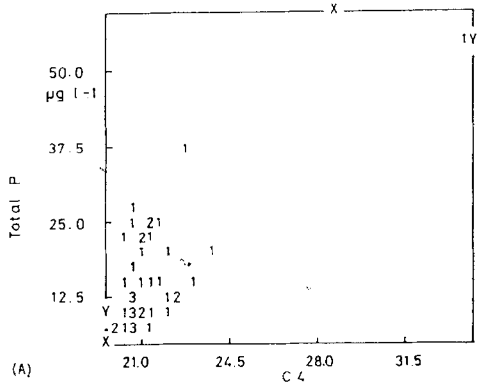


Fig. 7. (a), (b), (c) Three Landsat derivatives vs. total nitrogen for 41 small lakes.

each containing one or more small lakes, were extracted from the Landsat data 205-13-780701 and added together to form a new data base (Figure 9). Processing was carried out with the Univac 1100/22 computer system at the University of Oulu and the XAP and ELLTAB calculation packages (cf. Hayes, 1975; Talvitie *et al.*, 1979).

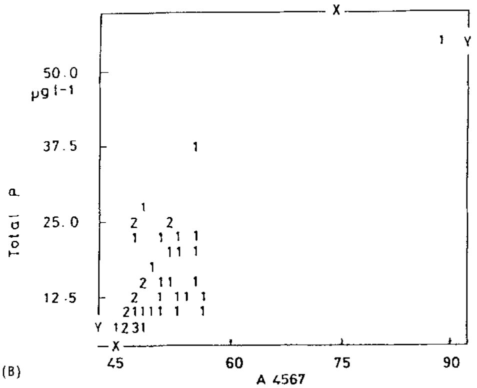
Because the test fields were chosen from within the open water areas of the small lakes, the output primarily indicates only those areas, thereby leaving the nearshore shallows, grounds and effectively vegetated areas mostly unclassified. To avoid the unclassified shore areas a few additional test fields were chosen from them.



(A)

N= 41
COR= .7040***

	MEAN	ST.DEV.	REGRESSION LINE
X	21.485	2.1538	X= .16641 Y+ 18.774
Y	16.293	9.1111	Y= 2.9780 X- 47.691



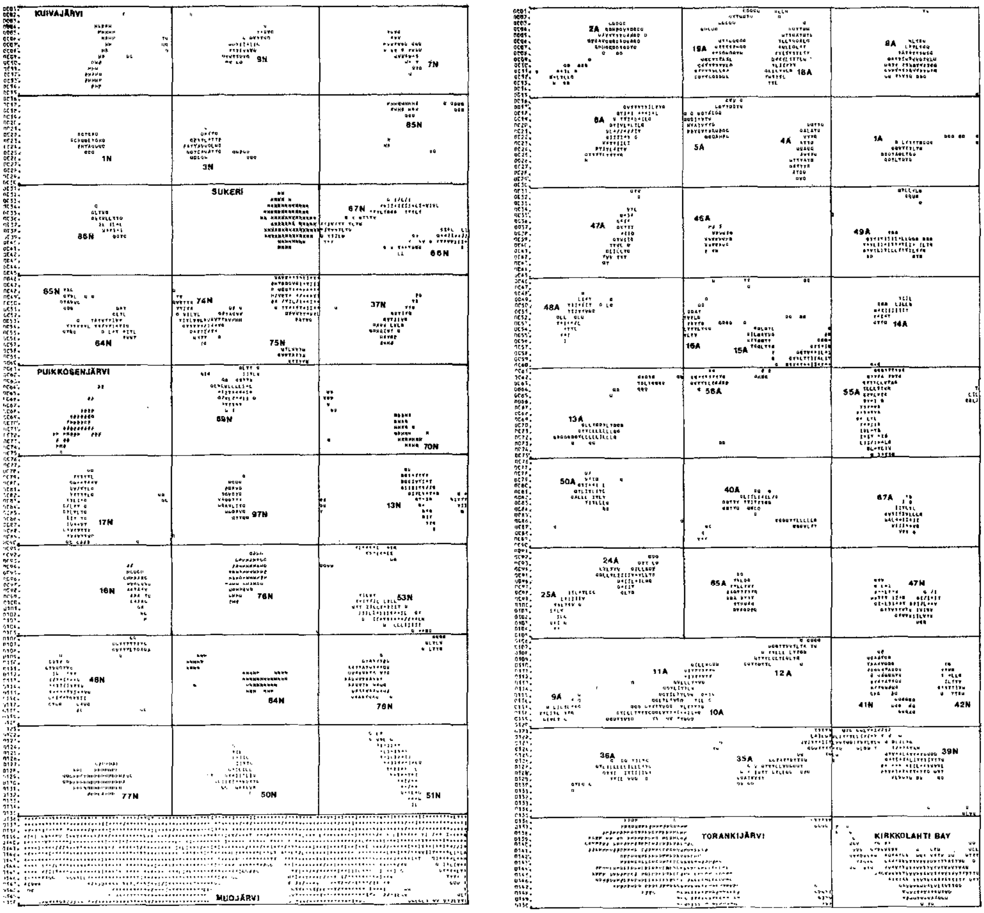
(B)

N= 41
COR= .7111***

	MEAN	ST.DEV.	REGRESSION LINE
X	50.735	7.0530	X= .55049 Y+ 41.766
Y	16.293	9.1111	Y= .91864 X- 30.315

Fig. 8. (a) C4 and (b) A4567 vs total phosphorus for 41 lakes. The statistics are slightly destroyed by the clustering of values in the lower left corner of the figures.

As can be seen in Figure 9, there are variations in the printer symbol within lakes, indicating the step-likeness of the classification and the fact there are possibly several changes in measured values and environmental factors within the lakes. These slight variations in classification may also be caused by the so-called 'sixth-row-effect' which includes nonuniformity in the calibration among detectors on the Landsat satellite. The thematic classification is may be not as unambiguous as the correlation analysis but it might visualize more graphically the involved nature of the lake systems. The reasoning behind adopting additional shore classes remains unclear and under study.



part I

part II

Fig. 9. Printer symbol coded thematic classification of the trophic or environmental status of the selected lakes. The printer symbols are used as follows, enumerated from the clearest to more eutrophic, vegetated and shallow water areas: +, /, I, L, Y, V, A, H, R, M, Q, Z–, N–, N=. The last three symbols consist of two signs printed one on top of the other. For lake identification see Table I. Few more lakes were included as reference fields to get more accurate classification: 1N = Palojärvi, 3N = Lohilampi, 9N = Pikku Hyypiö, 41N = Ahvenjärvi, 42N = Kokkojärvi, 48N = Saarijärvi, 51N = Isojärvi, 53N = Pesosjärvi, 64N = Sorsajärvi, 65N = Lehtojärvi, 69N = Aventolampi, 70N = Isojärvi, 76N = Kuiva Räväjärvi, 77N = Pöytisjärvi, 78N = Porontimajärvi, 84N = Lavajärvi, 85N = Jousilampi, 86N = Toivonjärvi, Puikkosenjärvi, Sukeri, mid Muojärvi open water area, 13A = Kuralampi, 14A = Savolaisenlampi, 56A = Raatelammit (western), 65A = Ylimmäinen Kiekerölampi, Kuivajäarvi, Torankijärvi, and the Kirkkolahti Bay of the L. Kuusamojärvi.

Until field work is complete no significant conclusions can be drawn regarding the classification of vegetated and nearshore areas. Improvements of the study will further be gained after the availability of the new Landsat TM data.

7. Conclusion

At least moderate correlations on a level of high significance between Landsat MSS data and small lake water characteristics have been found. These correlations did not exceed 0.80 but, because this study was not carried out with the best experimental conditions (one half of the ground samples represented the year after the Landsat data scanning and the Landsat data over small lakes also includes information about bottom and vegetation effects in addition to water related phenomena), the observed correlations indicates the validity of this technique even at the very narrow variation band of the oligotrophic end within the trophic state continuum. The utilization of Landsat MSS data can facilitate the surveying and monitoring of a large number of lakes to give up-to-date information repeatedly and in a relatively short processing period.

It has been shown that a generalized classification can be defined to predict lake environmental status from Landsat MSS data. The multispectral classification, when used in conjunction with data obtained on the ground, can be used to characterize water areas. Even unsupervised classification, when interpreted by scientists familiar with a specific water body, can yield estimations on the validity in a cost-effective manner.

Better results in evaluating the water quality could be gained under conditions where the base information recorded by the Landsat MSS system came totally from within the water body itself at a time when differences between different water bodies are at their peak. The most favourable conditions could possibly be offered by a wide and deep open lake or sea with different river discharges, water mixing and production areas (cf. Lindell, 1980). The general applicability of the statistics would also require the use of more and different types of lakes but the data available for this study restricted the inspection to concern only the oligotrophic and small lakes of a large disperse number of all water areas. Due to the relatively small size of these lakes further field work will be arranged especially regarding the effects of nearshore shallows and vegetation on the classification.

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