The Investigation of Correlation Functions Between Water Quality Parameters and Uprising radiation

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The results of research carried out in the southern water area of the Saimaa lake to establish correlation between water quality parameters and the characteristics of the uprising radiation are given. The possibilities for the remote measurement of characteristics both directly influencing the amount of uprising radiation, such as turbidity, coloration and those indirectly connected with the optically active components were studied. A correlation between spectral brightness coefficients combinations and the content of oxygen, general phosphate, nitrogen and sodium was established. Regression equations for the restoration of these water quality parameters upon the remote sensing data was obtained.

Keywords: Remote sensing, natural waters, reflectance spectrum, spectral brightness, optically active components, correlation

1. INTRODUCTION

Spectrophotometry of natural waters from airplanes and satellites takes place for a long time. Considerable data bank on it's spectral characteristics has formed by now. But in most cases these researches had resulted in qualitative estimation of nature waters condition. Whereas for ecological monitoring a quantitative data about physical and chemical condition of nature waters is necessary. Obtaining such a data can be realized by determining correlation dependences between optical characteristics of reflected radiation and nature waters composition. Quality of Saimaa Lake waters was the object of this research. The lake is situated in Finland and is affected by polluting waters of pulp and paper plants.

An aim of the research was to construct a water quality parameters restoration model which could allow determining of specified components concentration in water by reflected sun radiation spectrum. To construct such a model it is necessary to determine a correlation between spectral brightness coefficients and optically active content of nature waters. Some earlier researches [1, 2] shows within certain conditions a possibility of estimating parameters that doesn't affect at reflected radiation directly. Primary condition of such estimation is a stability of hydrodynamic processes which defines movement and transformation of chemical and biological components in lake while polluting sources are stationary.

2. OBJECT OF RESEARCH

Southern Saimaa is a part of a large lake system called the Greater Saimaa and it's territory is about 620 km^2. The hydrological mode of the western part of Southern Saimaa called the Western Small Saimaa where there are main sources of pollution is defined by the Vehkataipole alluvial showed in Fig. 1.

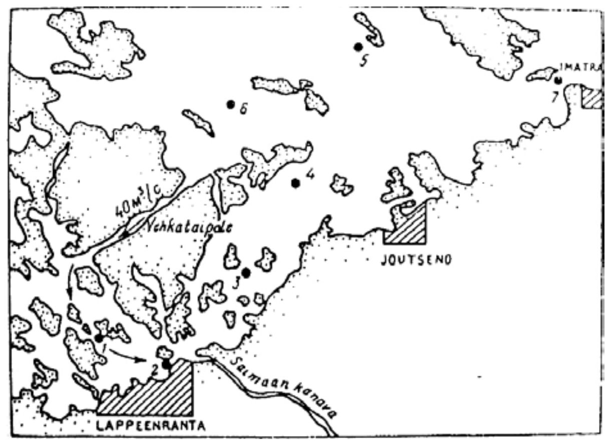

Figure 1. Southern Saimaa main currents and points of measurements.

This station pumps over water from the Greater Saimaa in Small with productivity 40 m^3/s, increasing natural current along southern coast to the east. Industrial sewage extend from pulp and paper plants "Kaukas" in Lappeenranta and "Joutseno Pulp" in a direction to r.Vuoksa. To these waters sewage of enterprises in Imatra are added. Natural water in Southern Saimaa is transparent, oligotrophic and slightly painted with humus.

3. TECHNIQUE OF RESEARCHES

Joint researches of ascending radiation with simultaneous sampling water for laboratory researches have been begun for the first time on August, 20th, 1991. Measurements were made from a boat at seven points which arrangement is shown on Fig. 1, arrows specify the main currents. On August, 20th, 1993 it has been carried out repeated research at five points (points 1-5). In both cases radiation measurements were performed with spectrograph HSS-3 [3]. Calculation of spectral brightness coefficients (SBC) was made in a range of 406-690 nanometers by a technique stated in [4]. Conditions of carrying out of measurements in 1991 and 1993 г were approximately identical: mainly overcast and roughness no more than 1-2 points.

Laboratory researches of water included definition of following quality parameters: chromaticity, turbidity, general phosphorus, general nitrogen, sodium, dissolved oxygen, chemical oxygen consumption, conductivity, pH.

Results of measurements in 1991 have been used in finding of the regress equations for water quality parameters restoration by remote sensing, and results of 1993 - for check of effectiveness of the regress equations received [5].

In the spring of 2003 there were unforeseen dumps of sewage from a "Kaukas" pulp and paper plant. It has led to deterioration of the lake's ecological condition. With a view to control the restoration of waters quality, it has been decided to continue spectrophotometric researches. In this connection one more experiment has been lead in August, 2003 by the same technique. Measurements of ascending radiation and samples from different depths were performed at the same points of lake, as in previous researches, at stations 2 - 5. The analysis of water samples in which the parameters specified above have been determined, was made in Saimaa Lake chemical Laboratory of waters protection.

Spectrums of water surface reflected radiation were registered at angle of 45 degrees to a water surface and at angle of 45, 90 and 135 degrees relative to a solar vertical plane from one and the other board, and also at nadir. For reception of statistically significant measurements ten spectrums were recorded in each direction.

For realization of researches the photoelectric spectrometer HSS-3M on the basis of existing Hand-driven Satellite Spectrograph HSS-3 has been developed and made. The device measures spectral distribution of radiation in the range 420-720 nanometers with the spacing of 8 nanometers. The ruler of photo diodes is used as a receiver of radiation.

4. DATA ANALYSIS

Equivalent spectral measurement data was combined to get more statistically effective results. Thus waters condition at each point evaluated through analysis of three average spectrums, recorded in directions 45º, 90º and 135º relative to a solar vertical plane. Fig. 2 – 4 demonstrates spectral brightness coefficients (SBC) dependences from wavelength on different stations where each curve corresponds to 20 measurings.

Correlation method was used for data analysis aimed to establish correlation between water components concentration and SBC at all stations. SBC for each wavelength evaluated as

$$R(\lambda) = (I_{\mathrm{ref}} - I_{\mathrm{dark}}) / (I_{\mathrm{fall}} - I_{\mathrm{dark}}) \qquad (1)$$

where λ = wavelength
$R(\lambda)$ = spectral brightness coefficient (SBC)
I_{ref} = device indications when measuring reflected radiation flux
I_{dark} = device indications with closed lens
I_{fall} = device indications when measuring falling radiation flux (with frosted glass filter)

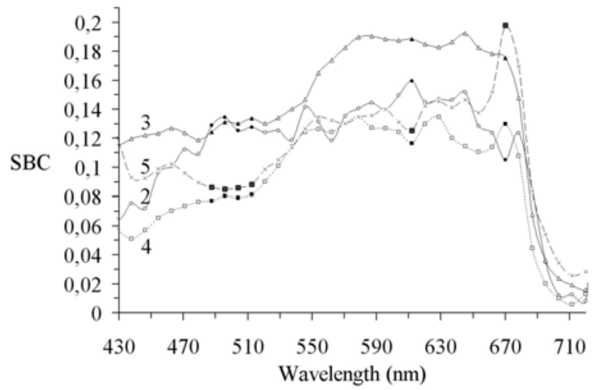

Figure 2. SBC Spectral distribution recorded at 45º in four points

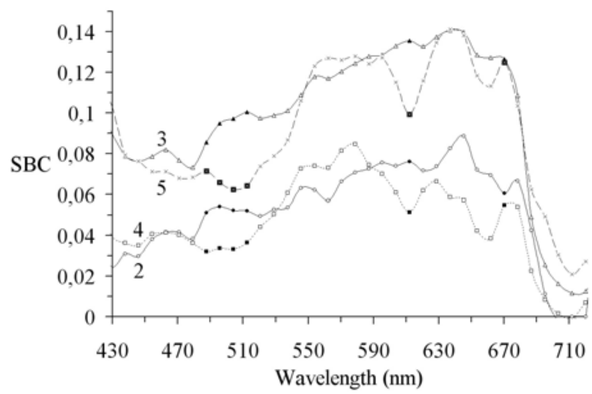

Figure 3. SBC Spectral distribution recorded at 90º in four points

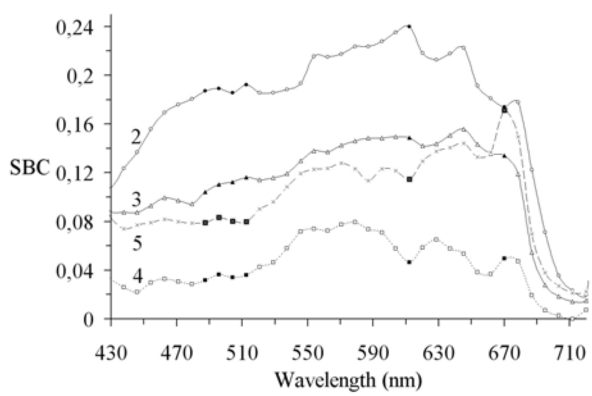

Figure 4. SBC Spectral distribution recorded at 135º in four points

Correlation analysis at single wavelength hasn't given satisfactory results. Therefore we concentrated attention at correlation analysis of all possible SBC combinations $R(\lambda_1) / R(\lambda_2)$ alike. Every direction of record (45º, 90º, 135º) and every wavelength used in measurements were taken into account.

In the correlation analysis the main criterion of an estimation was the correlation coefficient of a sample (ρ) evaluating by the equation

$$\rho_{x,y} = cov(x,y) / (\sigma_x \sigma_y) \quad (2)$$

$$\sigma_x^2 = \Sigma(x_i - \mu_x)^2 / n$$

$$\sigma_y^2 = \Sigma(y_i - \mu_y)^2 / n,$$

where x_i, y_i = data set x, y
$cov(x,y)$ = covariation of x and y
σ_x , σ_y = standard deviations of x and y
μ_x , μ_y = an arithmetic average of data sets x, y
n = number of points in data set

During the analysis combinations which correlation with water parameters at all directions of shooting was more than 0,95 have been chosen. Laboratory tests results of water parameters are presented in Table 1.

For correlation analysis first four parameters - oxygen (O_2), nitrogen (N_2), phosphorus (P) and sodium (Na) have been chosen. Results of the analysis are shown in Table 2 in the form of the ratio of wavelengths on which the greatest correlation ($\rho > 0{,}95$).

Table 1. Laboratory tests of water

Point	O_2, mg/l	N_2, µg/l	P, µg/l	Na, mg/l	t, ºC	Turbidity, FTU	Conductivity, mS/m	pH	CODMn, mg/l
2	4,9	530	38	21	18,7	2,8	16	7	12
3	8,6	470	37	16	17,3	2,3	13,7	7,4	11
4	9,2	390	21	9,6	17,1	1,7	9,4	7,5	8,1
5	9,9	300	7	5,7	14,2	0,49	6,8	7,3	6,8

Table 2. Wavelengths ratios of greatest correlation

	λ_1, nm / λ_2, nm ($\rho > 0{,}95$)								
O_2	488/670								
N_2				612/670	670/612	670/512	670/504	670/496	
P					670/612				
Na		504/670	512/670	612/670					670/488

From the table it is obvious, that SBC on λ = 670 nm are present in every chosen combination either as numerator or as a denominator, and high correlation is kept at all angles of record. Such statistics shows self-descriptiveness of radiation on this wavelength. The second often meeting wavelength is λ = 612 nanometers. For three of four elements combination $R(612) / R(670)$ or $R(670) / R(612)$ is well correlating with concentration of a substance containing in water. Oxygen is not included into their number, correlating with combination $R(487) / R(670)$, that most likely is connected with being of λ = 487 nm in a strip of absorption of a chlorophyll and organic substances on which basically concentration of oxygen in water depends.

If to decrease correlation criterion to 0,91 it is possible to determine concentration of oxygen on combination $R(612)$ / $R(670)$. It is possible to describe dependence of concentration of substance y from SBC combinations $x = R(\lambda_1) / R(\lambda_2)$ with different reliability of approximation r^2 by linear $y = a \cdot x + b$ or parabolic $y = c \cdot x^2 + d \cdot x + e$ functions.

Value r^2, also called a square of the mixed correlation, is a number from 0 up to 1 which reflects affinity of values of function to the actual values. Values of function most correspond to the validity when r^2 is close to 1.

Coefficients of such equations together with reliability of approximation and coefficients of correlation are listed in Tables 3 – 6 for oxygen, nitrogen, phosphorus and sodium accordingly.

Table 3. Oxygen ($R(487) / R(670)$)

	ρ	a	b	r^2	c	d	e	r^2
45º	-0,996	-6,49	12,95	0,991	-3	-1,34	11,05	1
90º	-0,983	-17,43	19,84	0,965	-39,56	38,86	0,35	0,987
135º	-0,960	-8,25	14,24	0,922	-12,25	10,82	7,46	0,996

Table 4. Nitrogen ($R(670)$ / $R(612)$)

	ρ	*a*	*b*	r^2	*c*	*d*	*e*	r^2
45º	-0,989	-254,29	695,12	0,978	64,79	-401,72	771,4	0,983
90º	-0,998	-506,24	935,25	0,996	-5,86	-494,17	929,2	0,996
135º	-0,983	-298,34	734,56	0,966	219,94	-794,76	995,34	0,992

Table 5. Phosphorus ($R(670)$ / $R(612)$)

	ρ	*a*	*b*	r^2	*c*	*d*	*e*	r^2
45º	-0,956	-36,29	64,66	0,914	-10,92	-11,46	51,81	0,921
90º	-0,965	-72,21	98,88	0,93	-83,25	99,26	13	0,955
135º	-0,966	-43,29	71,03	0,934	3,83	-51,92	75,56	0,934

Table 6. Sodium ($R(612)$ / $R(670)$)

	ρ	*a*	*b*	r^2	*c*	*d*	*e*	r^2
45º	0,976	17,79	-5,24	0,952	-7,4	33,93	-13,25	0,965
90º	0,993	34,22	-21,68	0,985	-6	46,57	-27,86	0,986
135º	0,986	22,46	-9,94	0,972	4,91	12,42	-5,12	0,975

For an estimation of concentration of chemical components in water of lake it is convenient to use linear dependence for what it is enough to measure a spectrum of reflection and in parallel to make the chemical analysis only in two points of lake. On these data it is possible to define coefficients of the linear equations for the components. After that by spectral measurements of reflected radiation at any point of lake one may define concentration of the components using the equations. If the raised accuracy is necessary, it is possible to use the equation of a parabola, defining thus coefficients at three points. But in most cases a parabola doesn't give appreciable difference from linear dependence. Therefore it is more convenient to use a linear dependence.

As a result of the analysis it is established that generally the greatest correlation with SBC combinations is reached when measurings are made in a direction 90º in relation to a solar vertical plane. Though for separate substance in each direction there are some combinations with correlation more than 0,99 and on the average 50 combinations with correlation more than 0,95. The combinations chosen are differing by the fact of using SBC on λ = 670 nm and in the majority SBC on λ = 612 nm that reduces number of wavelengths to make measurements on and can be convenient in certain cases. At the same time, as it is already mentioned, in case of need there is wide enough choice of shooting directions that can be used for linear dependence.

5. CONCLUSION

Carried out research has shown an opportunity of creation a model for natural waters quality parameters restoration by reflected sun radiation spectrum. Combinations of spectral brightness coefficients having greatest correlation with concentration of chemical components in water are found. Received linear and parabolic equations of concentration dependences from these combinations allow remote control with sufficient accuracy to supervise distribution of the concentration of chemical elements in water.

A large number of SBC combinations highly correlating with concentration gives very many variants of choice. Results of the analysis shows that for each substance there is a range of the best angles of shooting, but generally they are from 45º up to 90º to a solar vertical plane.

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