EVALUATION OF WATER-QUALITY IN THE GULF OF FINLAND BY NOAA/AVHRR IMAGE DATA

Filiz SUNAR, Dr.
Technical University of İstanbul
Civil Engineering Faculty, Remote Sensing Department
Maslak 80626 İstanbul/TURKEY

ABSTRACT : *A multi-temporal study of chlorophyll-a concentration and temperature variation has been made by means of 3 sequential NOAA/AVHRR image data in the Gulf of Finland. The relationship between these parameters and satellite data was set up from sea-truth measurements and concurent satellite data obtained on 25, 26 and 27 June 1991. This relation has been applied to images by applying channel calibration procedures. At the end of this study, color-coded maps of chlorophyll-a concentration and temperature variation have also been given.*

0. INTRODUCTION

Satellite remote sensing provides an effective way of evaluating the water-quality data and is of particular significance in areas where conventional methods of hydrological data collection are inadequate or impractical. The efficiency of the remotely sensed data to carry out a multi-temporal study of water-quality depends on the determination of an emprical relation between the parameters examined and the use of this relation to images of other dates. But due to not having any atmospheric reference point specified, the changing effect of the atmosphere hasn't been taken into consideration in this study **[1]**.

1. LOCATION AND THE REGIONAL CHARACTERISTICS OF THE STUDY AREA

The Gulf of Finland which forms the northernmost part of the Baltic Sea is 39 000 km in length, including 73 000 islands and islets. The nutrient-rich easternmost Gulf of Finland affects the study area which is selected as the one of the most heavily loaded area, Kotka-Hamina region, by increasing the basic degree of trophy in the outer archipelago, the sea zone and the open sea (Figure 1). In the report on studies about the water-quality and trophic status in the eastern Gulf of Finland performed by the Finnish National Board of Waters and Environment, it is explained that the high nutrient concentrations in the eastern part of the study area are most probably caused by water originating in the easternmost parts of the Gulf of Finland, i.e., by nutrient discharges from Leningrad and the Neva River, particularly as regards nitrogen. Also it is shown that the water-quality in the nearest to the coast is primarily conditioned by the quality and quantity of the local discharges and the coastal geomorphology in all seasons **[2]**, **[3]**.

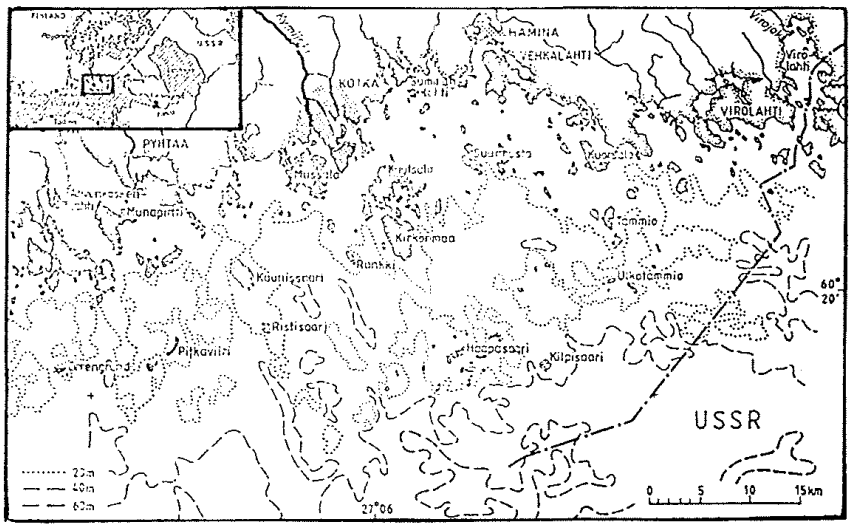

Figure 1 : The Gulf of Finland, the study area and its bottom topography **[3]**.

2. EMPIRICAL RELATION

2.1. Water-quality data

Chlorophyll-a and temperature data used in this study were acquired by the Finnish National Board of Waters and Environment in the campaigns carried out on 25, 26 and 27 June 1991, coincident with the days NOAA images taken. Samples were taken at surface level (0-1 m). The sampling stations and sea-truth measurements are given in Figure 2 and Table 1, respectively. The insufficiency of the numbers of the measurements taken for each day (6 on 25 June, 9 on 26 June and 6 on 27 June) is caused by the inaccesibility of the stations due to many surrounding islands and islets, limited technical staff and sampling boats and high cost of the sampling procedure.

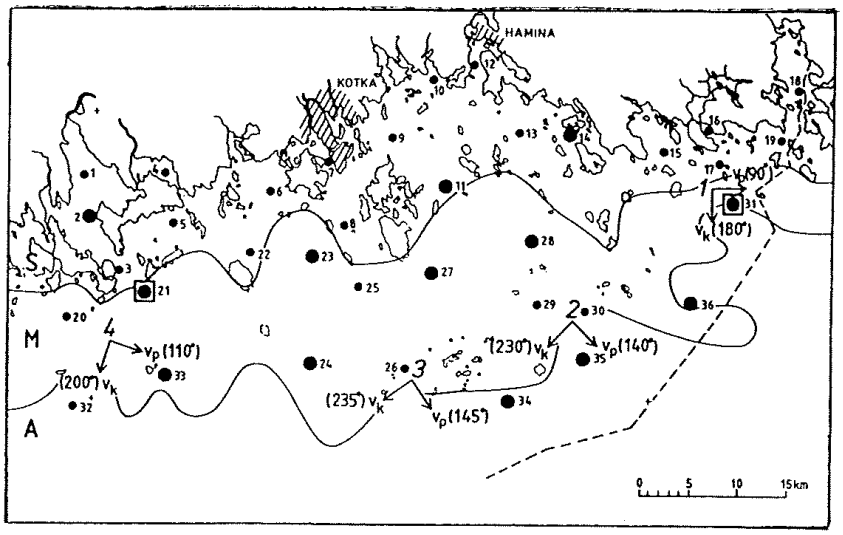

Figure 2 : Sampling stations, current vectors and the directions of current components in the study area (Large dots indicate stations belonging to the routine monitoring programme for the coastal waters) **[3]**.

Table 1 : Chlorophyll-a and temperature measurements done in the study area on June.

Observation Number	Depth (m)	Temperature (°C)	Station no:	Date Day/Month/Year	Chlorophyll-a (mg/m^3)
1	1	18.0	7	25 06 90	7.5000
2	1	18.9	9	25 06 90	4.6000
3	1	17.3	11	25 06 90	7.4000
4	1	17.2	23	25 06 90	6.8000
5	1	17.4	24	25 06 90	6.2000
6	1	17.6	25	25 06 90	6.6000
7	1	19.8	1	26 06 90	....
8	1	19.8	2	26 06 90	13.000
9	1	19.5	3	26 06 90	7.6000
10	1	17.0	8	26 06 90	6.7000
11	1	19.0	21	26 06 90	6.6000
12	1	18.0	26	26 06 90	6.4000
13	1	18.0	27	26 06 90	7.1000
14	1	18.4	34	26 06 90	5.6000
15	1	18.2	36	26 06 90	6.5000
16	1	20.3	4	27 06 90	8.4000
17	1	17.9	5	27 06 90	7.2000
18	1	17.1	6	27 06 90	7.3000
19	1	18.8	18	27 06 90	8.6000
20	1	17.4	19	27 06 90	11.5000
21	1	16.0	29	27 06 90	8.3000

2.2. Satellite data

This study has been carried out using NOAA/AVHRR images corresponding to 25, 26 and 27 June 1991. In order to obtain true sea surface parameters, the raw digital AVHRR data has been processed in the Finnish National Board of Waters and the Environment, Environmental Data Center. After being converted the digital values to the physical values for albedo in case of Band 1 and Band 2 and for sea surface temperature (SST) in case of Band 4 and Band 5 data, the channel calibrated images has been rectified according to control points available in the image and reference map. Representative digital number values corresponding to sea-truth measurements were determined by locating and digitizing the sampling stations on the rectified images.

2.3. Regression analysis

In some of the sampling stations which are too close to the islands or land areas (300-400 m) but having image geometric resolution at 1.1 km, different spectral values have been observed. As an example of this (Figure 3), it can be seen that there is a big difference in the spectral values (3 x 3 pixel neighbouring) of the 7th sampling station. Having the same situation for othersome stations for the other images, these observations haven't been taken into consideration in the linear regression analysis since they could induce errors. Finally, the evaluation of the statistical correlation between the calibrated values and sea-truth has been done with 4 measurements for 25 June, 8 for 26 June and 3 for 27 June. The calibrated values (pixel value and also mean value of the 3 x 3 pixel neighbouring) of these stations are given in Table 2. Linear regression analysis results are given in Table 3.

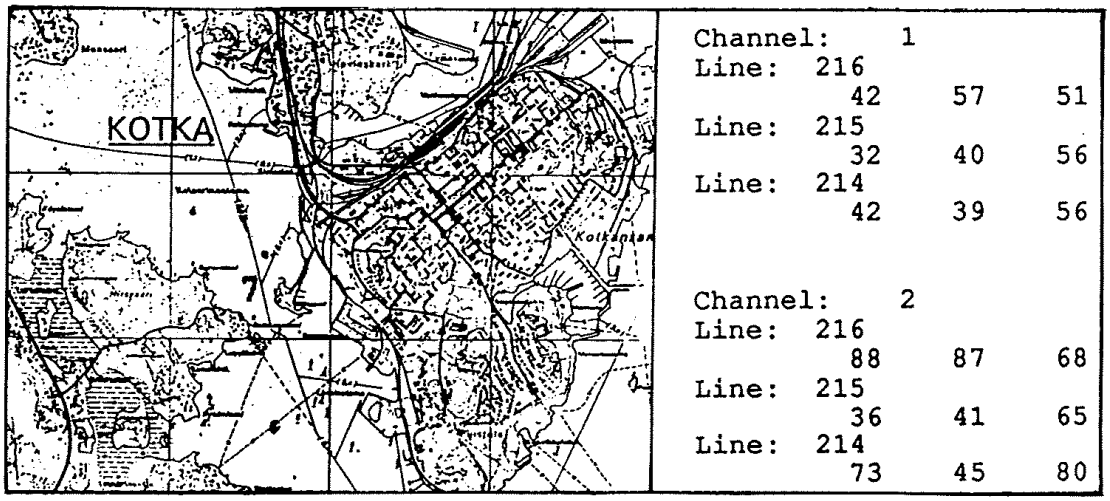

Figure 3 : Location of the 7th sampling stations (1 : 50 000) and spectral values in the 3 x 3 pixel neighbouring.

Table 2 : The calibrated value of the different sampling stations on 25, 26 and 27 June.

Date	Station No:	Band 1 Pixel mean	Band 1 Pixel	Band 2 Pixel mean	Band 2 Pixel	Band 4 (°C) Pixel mean	Band 4 (°C) Pixel	Band 5 (°C) Pixel mean	Band 5 (°C) Pixel
25/6/90	9	53.75	77	39.50	60	14.52	11.73	14.75	12
	23	23	23	9.25	9	15.43	15.46	15	15
	24	22	22	8	8	15.46	15.46	15.22	15
	25	23.5	23	9	9	15.64	15.58	15.50	15
26/6/90	1	32.75	33	19	18	17.19	16.92	17	17
	2	30.75	29	22.75	16	17.53	16.80	17.5	17
	8	28	28	15	15	15.59	15.82	15.5	16
	21	28.25	29	13.5	14	15.61	15.82	15.5	16
	26	26.25	27	12	12	15.61	15.70	15.75	16
	27	26	26	12	12	15.82	15.82	16	16
	34	26	25	12.5	12	15.97	15.94	16	16
	36	24.75	24	11	11	16.13	16.31	16	16
27/6/90	5	31.5	29	18.5	20	15.30	15.45	15	15
	6	32.33	32	26.22	18	15.70	14.83	15.56	15
	29	28	28	15	15	14.68	14.59	14.75	14

Table 3 : Correlation coefficients for the linear relationship between NOAA/AVHRR response and sea-truth measurements.

Date	Band No:	Regression Equation	Correlation Coefficient, R^2 (%)
25 June 1990			
Stations	1(mean)	Y = 7.78 - 0.06 X	97.61
Stations	1(pixel)	Y = 7.18 - 0.03 X	97.21
Stations	2(mean)	Y = 6.95 - 0.06 X	98.41
Stations	2(pixel)	Y = 6.73 - 0.04 X	97.21
Stations	4(mean)	Y = 34.94 - 1.11 X	70.68
Stations	4(pixel)	Y = 22.68 - 0.32 X	84.21
Stations	5(mean)	Y = 32.85 - 0.98 X	21.83
Stations	5(pixel)	Y = 23.85 - 0.41 X	86.47
26 June 1990			
Stations	1(mean)	Y =-19.73 + 1.00 X	64.33
Stations	1(pixel)	Y =-15.03 + 0.84 X	36.49
Stations	2(mean)	Y =- 0.92 + 0.59 X	88.07
Stations	2(pixel)	Y =- 4.87 + 0.93 X	48.39
Stations	4(mean)	Y =-13.51 + 1.92 X	62.94
Stations	4(pixel)	Y =-30.98 + 3.01 X	61.92
Stations	5(mean)	Y =-15.67 + 2.06 X	64.89
Stations	5(pixel)	Y =-31.48 + 3.02 X	58.22
27 June 1990			
Stations	1(mean)	Y = 15.42 - 0.26 X	93.24
Stations	1(pixel)	Y = 13.08 - 0.19 X	40.54
Stations	2(mean)	Y = 9.04 - 0.07 X	45.95
Stations	2(pixel)	Y = 11.66 - 0.23 X	89.19
Stations	4(mean)	Y =- 0.98 - 1.18 X	42.86
Stations	4(pixel)	Y =-13.31 + 2.03 X	90.11
Stations	5(mean)	Y = 3.67 + 0.88 X	14.84
Stations	5(pixel)	Y =- 5.00 + 1.50 X	82.42

In the results (Table 3), it can be seen that these correlation coefficients can not be accepted as stastisticially sufficient because of the observation deficiency, even they are relatively high. In the analysis of multi-date NOAA image data, the correlation became worse than single-day analysis, because of the differences in digital data due to atmospheric characteristics haven't been taken into account (Table 4) **[4]**.

Table 4 : Correlation coefficients for multi-date analysis.

Date	Band No:	Regression Equation	Correlation Coefficient, R^2 (%)
25 + 26 June 1990*			
Stations	1(mean)	Y = 8.00 - 0.04 X	2.65
Stations	2(mean)	Y = 6.76 - 0.01 X	0.11
Stations	4(pixel + mean)	Y = 15.97 + 0.11 X	1.03
Stations	5(pixel + mean)	Y = 15.80 + 0.12 X	1.18
25 + 27 June 1990*			
Stations	1(mean)	Y = 8.53 - 0.06 X	34.34
Stations	2(mean + pixel)	Y = 7.62 - 0.06 X	29.42
Stations	4(pixel)	Y = 21.90 - 0.30 X	20.50
Stations	5(pixel)	Y = 22.18 - 0.32 X	16.53
26 + 27 June 1990*			
Stations	1(mean)	Y = - 3.26 + 0.38 X	22.58
Stations	2(mean + pixel)	Y = 13.62 + 0.40 X	58.14
Stations	4(mean + pixel)	Y = - 3.13 + 1.29 X	49.60
Stations	5(mean + pixel)	Y = - 0.18 + 1.12 X	43.78
25 + 26 + 27 June 1990*			
Stations	1(mean)	Y = 8.11 - 0.04 X	2.29
Stations	2(mean + pixel)	Y = 6.90 - 0.01 X	0.15
Stations	4(mean + pixel)	Y = 14.69 + 0.19 X	2.79
Stations	5(mean + pixel)	Y = 14.25 + 0.21 X	3.68

* In multi-date regression equations, pixel value or neighbouring pixels mean value or a combinations of both have been used according to correlation coefficients obtained in Table 3.

3. COLOR-CODED MAPS OF THE PARAMETERS EXAMINED

To evaluate the water-quality in the calibrated NOAA/AVHRR images, the color-coded maps of the chlorophyll-a concentration and the temperature variation have been prepared by dividing into intervals specified **[5]**. Figure 4 and 5 are geo-referenced, color-coded maps of the entire area depicting spatial distribution of the parameters. Data analysis indicates that the high concentration of chlorophyll-a occurs in the southerneast part of the Gulf towards to northerneast Finnish coast.

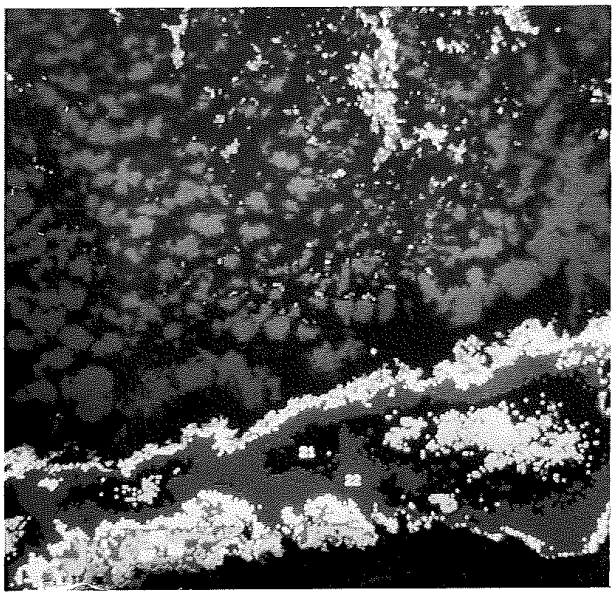

Figure 4 : The color-coded map of the chlorophyll-a concentration of the NOAA images dated on 25 June 1991.

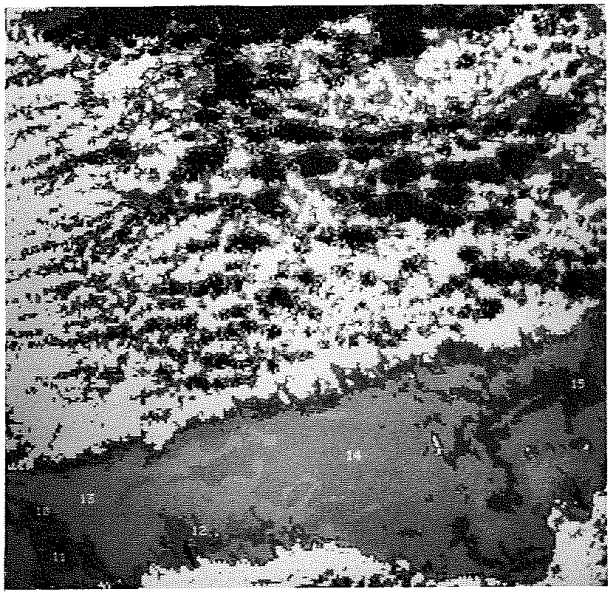

Figure 5 : The color-coded map of the temperature variation of the NOAA images dated on 27 June 1991.

4. CONCLUSION

The purpose of this study was to evaluate the use of 3 sequential NOAA/AVHRR digital spectral data for estimating chlorophyll-a concentration and temperature variation along the Finnish coast of the Gulf of Finland and to determine the relationship between these parameters and *in situ* measurements by linear regression analysis. The high cost of sampling, limited technical staff and boats, and difficulty of the accessibility to the stations due to many islans surrounding, obligated the statistical evaluation with relatively low number of observations than it should be. For the multi-temporal analysis, the correlation coefficients obtained weren't satisfactory due to not knowing the atmospheric parameters required to make atmospheric corrections.

A more reliable database consisting of the satellite data and surface water measurements should be taken into account for the simultaneous evaluation in the future works.

Acknowledgments

I would like to thank to my supervisor Prof.Dr. Cankut Örmeci, Prof.Dr. Einari Kilpelä, Prof.Dr. Risto Kuittinen and also my colleques in Helsinki University of Technology, Institute of Photogrammetry and Remote Sensing, National Board of Survey-Remote Sensing Section, National Board of Waters and the Environment, Environmental Data Center, and Water and Environment Research Office for use of their image processing facilities and their quidiance, support and encouragement during this study.

References

[1] SUNAR, F., The Evaluation of Water-Quality in the Bays by Satellite Images (In Turkish), Ph.D. Thesis, Technical University of İstanbul, October 1991.

[2] PITKÄNEN, H., KANGAS, P., MIETTINEN, V. and EKHOLM, P., The state of the Finnish Coastal Waters in 1979-83 (In English), The National Board of Waters and Environment, Helsinki, 1988.

[3] PITKÄNEN, H., KANGAS, P., SARKKULA, J., LEPISTÖ, L., HÄLLFORS, G. and KAUPPILA, P., Water-Quality and Trophic Status in the Eastern Gulf of Finland, A Report on Studies in 1987-88 (In Finnish), The National Board of Waters and Environment, Helsinki, 1990.

[4] GARCIA L.M.J. and CASELLES. V., A Multi-temporal study of chlorophyll-a concentration in the Albufera lagoon of Valencia, Spain, using Thematic Mapper Data, Int. J. Remote Sensing, 1990, Vol. 11, No. 2, 301-311.

[5] MAKTAV, D. and SUNAR, F., Uzaktan Algılama : Kantitatif Yaklaşım, (Translated from Remote Sensing : A Quantitative Approach by Swain/Davis), İstanbul, 1991.