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Mieczysława GIERCUSZKIEWICZ-BAJTLIK

Water Utilization Department, Research Institute of Environmental Development, Kolektorska 4, 01–692 Warsaw, Poland

THE EFFECT OF INDUSTRIAL POLLUTION ON LAKE EWINGI (MASURIAN LAKELAND) ESTIMATED BY REMOTE SENSING TECHNIQUES

ABSTRACT: Aerial multispectral photographs of Lake Ewingi were taken in August 1979. Lake waters were investigated simultaneously. The results correlated with the map showing the spreading of pollution in lake water made according to multispectral photographs.

KEY WORDS: Lake, pollution sources, phosphorus loading, nitrogen loading, remote sensing techniques, low-altitude multispectral photography.

1. INTRODUCTION

Lake Ewingi lies on the north-western end of Masurian Lakeland in the drainage basin of river Drwęca – the right-bank Vistula tributary. It covers the area of 490.4 ha, mean depth 2 m, maximum depth 4 m. It is a polymictic, flow lake supplied by two streams in the northern part of the lake and by a third one in the southern part. The water flows from the lake by a 2 km navigable channel joining the lake with the system of west Masurian waterways. In the water balance for Lake Ewingi the stream inflow dominates, the coefficient of annual water exchange being 1.8.

The typical agricultural drainage area of Lake Ewingi covers the area of 64.6 km^2 (Fig. 1). The population density on the total drainage area of the lake is not high, 78 $indiv. \cdot km^{-2}$. It is the highest in the direct drainage area at Zalewo (Fig. 1). Domestic sewage and industrial wastes from Zalewo let into the lake after mechanical sewage treatment are dangerous for Lake Ewingi. The tannery wastes, which are the greatest point source of lake pollution, are purified in a mechanical-chemical waste-water treatment plant.

The load of organic compounds and nutrients in the lake is largely due to pollution

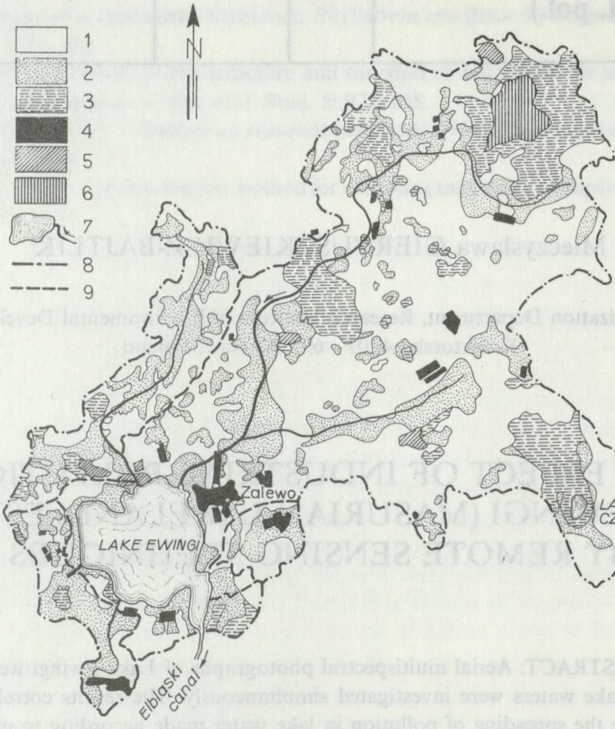

Fig. 1. Land use in the drainage area of Lake Ewingi
1 – arable land, 2 – grasslands, 3 – forests, 4 – compact settlement, 5 – agricultural and breeding plants, 6 – swamps, 7 – lakes and rivers, 8 – the drainage divide of the drainage area, 9 – the drainage divide of the partial drainage area. Elaborated by the Institute of Land-Surveying and Cartography in Warsaw

transport from drainage area by inflowing streams (Table 1). The total, external load of nutrients in Lake Ewingi (Table 1) exceeds the dangerous load determined by Vollenweider (1971) 6 times for nitrogen and 4 times for phosphorus.

Lake Ewingi was investigated by Januszkiewicz (1965) between 1956 and 1958. The lake was determined as a eutrophic one with a great intensity of primary production processes as shown by periodical water blooms. Differences were observed in the chemical composition of water and bottom sediments of lakes and zones in the direct vicinity of inflows and on the area affected by wastes. The studies of the lake between 1976 and 1979 (Giercuszkiewicz-Bajtlik – in press) showed the lake as polytrophic with distinct degradation symptoms (high oxygen deficit in winter 0.6–0.0 mg $O_2 \cdot dm^{-3}$, supersaturation of water in spring and summer due to phytoplankton growth up to the maximum of 17% O_2, chlorophyll-a content 57 mg$\cdot dm^{-3}$, Secchi disc visibility 0.35 m).

High concentrations of indices characteristic of pollution introduced with wastes were observed in lake water in the radius 5, 20 and 50 m from their outlets.

Remote sensing techniques created new possibilities for investigating the aquatic environment, for finding pollution sources, and illustrates their distribution in running

Table 1. External loading of Lake Ewingi in 1976–1979 (Giercuszkiewicz-Bajtlik – in press)

Sources of pollution	Total phosphorus		Total nitrogen		Total organic carbon	
	$g\ P \cdot m^{-2} \cdot year^{-1}$	%	$g\ N \cdot m^{-2} \cdot year^{-1}$	%	$g\ C \cdot m^{-2} \cdot year^{-1}$	%
Spatial* (from the direct drainage area)	0.04	6.35	1.85	12.84	–	–
Point** (industrial wastes, domestic sewage)	0.02	3.17	1.57	10.89	9.40	10.73
Inflows**	0.57	90.48	10.99	76.27	78.20	89.27
Total	0.63	100.00	14.41	100.00	87.60	100.00

* Data estimated acc. to Vollenweider (1971): 10% of nitrogen and 1% of phosphorus from fertilizers utilized on the drainage area. ** Data determined from investigations on concentrations of pollution indices and flow intensity conducted 12 times during a year.

and stagnant water. Interpretation of aerial or satellite multispectral photographs provides information, but requires a comparison with results of ground investigations.

On the basis of Landsat photographs taken on April 6, 1977 in a green belt 500–600 nm Irvin (1978) has confirmed water transparency in lakes Tekapo, Pukaki, Ohau and Alexandrina in New Zealand. Lemoale (1979–1980) has interpreted the multispectral photographs taken by Landsat and correlated them with ground investigations of Lake Tehad in Africa as regards water transparency and its chlorophyll-a content. Curran (1979) has used the multispectral photographs to estimate the pollution of marine waters by wastes from the Somerset (Great Britain) region frequented by tourists, and the spreading of pollution.

The aim of investigations has been to check the sensitivity of the remote sensing techniques and the possibilities of applying them in investigations of the polluted aquatic habitat.

2. METHODS

Aerial photographs of Lake Ewingi were taken on August 18, 1979 between 11^{15} and 11^{45} at a cloudless, sunny weather and weak north-eastern wind. They were taken by a photographic multispectral camera NAC-490 MB, made in Japan, in four spectrum ranges from blue to photographic infrared (400–900 nm) on a scale 1 : 17000. Their interpretation allowed the Institute of Land-Surveying and Cartography to issue a map: "Distribution of pollution in Lake Ewingi on the basis of aerial multispectral photographs" (Fig. 2). Conversions of aerial photography were made

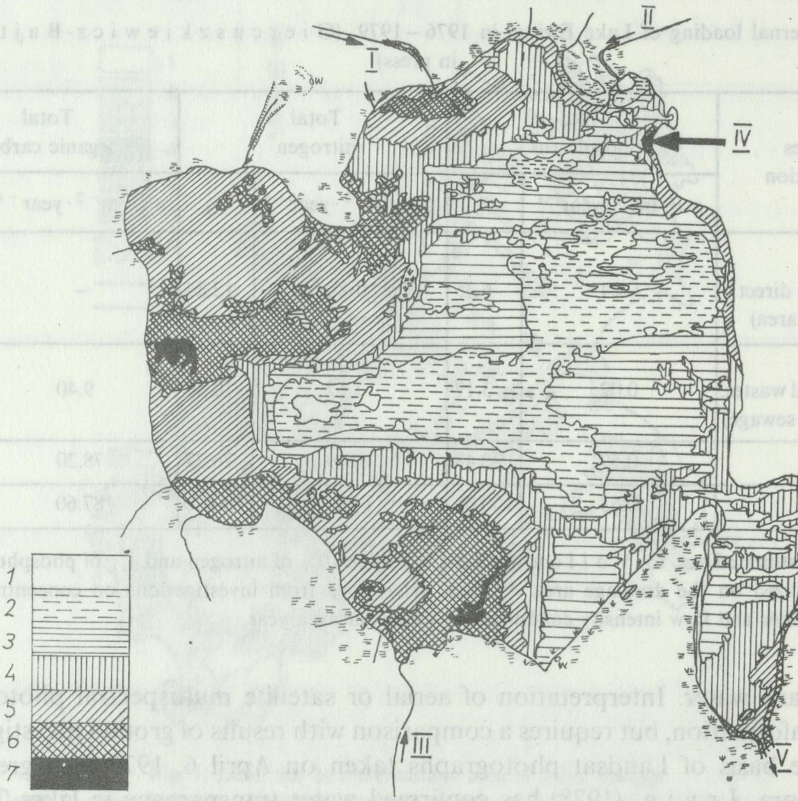

Fig. 2. Distribution of pollution in Lake Ewingi on the basis of multispectral aerial photographs
I, II, III – main river tributaries, IV – inflow of tannery wastes, V – outflow from Elbląski Canal, 1 – 7 – subranges of optical density. Elaborated by the Institute of Land-Surveying and Cartography in Warsaw

using correlations between numerical greyness levels of digitated aerial photograph and results of ground investigations on indices of water quality conducted by the Research Institute of Environmental Development simultaneously with aerial photography.

Water samples were taken at the depth of 0.2 m because of small visibility of Secchi disc being 0.3 m (maximum) on the day of investigations. The lake, its inflows, outflow and sewage brought into the lake were investigated. Physico-chemical and biological analyses of water and physico-chemical analyses of sewage were made for the following indices: Secchi disc visibility, colour, turbidity, water temperature, dissolved oxygen, BOD, COD, TOC, total phosphorus, total nitrogen, total chromium, total suspensions, dry seston weight and chlorophyll-a. The basic physico-chemical analyses were made according to Polish Standards. Organic carbon content in water and sewage was determined by the method of instrumental analysis using the Beckman TOC analyser, model 915. Dry seston weight was determined by Whatman GF/C filter.

Meteorological and hydrological conditions of the lake drainage area during investigations were characterized on the basis of data of the Institute of Meteorology and Water Management.

3. RESULTS

Multispectral aerial photographs of Lake Ewingi were made during summer stagnation – the period of abundant appearance of algae. The balance of nutrients inflowing and outflowing from the lake on the day photographs were taken showed that the transport of pollution from the draingae area by streams was the main input (Table 2).

Ground investigations showed a considerable pollution of the lake (Table 3).

Interpretation of multispectral aerial photographs on a spectral negative $\lambda =$ $= 650$ nm allowed to distinguish seven subranges of optical density. A significant correlation was also observed between the subranges of optical density and indices of lake water pollution: Secchi disc visibility ($r = -0.928$), total suspensions ($r = 0.849$), dry seston weight ($r = 0.748$), total phosphorus ($r = 0.710$), COD ($r = 0.946$) and total organic carbon ($r = 0.767$).

Thus elaborated map (Fig. 2) is a pictorial image of surface distribution of concentration of pollution indices in Lake Ewingi. Table 4 is the legend of the map.

Striking is the great sensitivity of the photo-interpretation method showing concentrations of lake water pollution which are greatly differentiated (Fig. 2, Table 4). The distinguished subranges of optical density correspond to the range of determined Secchi disc visibility – 0.04 m, of total suspensions – 4.0 $mg \cdot dm^{-3}$, COD – 10.0 mg $O_2 \cdot dm^{-3}$, and TOC – 1.0 $mg \cdot dm^{-3}$.

The interpretation of the map (Fig. 2) gives profound information on aquatic environment of Lake Ewingi. The map illustrates first of all the surface distribution of water pollution in the entire lake.

A distinct influence of tannery wastes on surface lake waters (north-eastern end) was observed only 50 m from their outlet.

Table 2. Balance of nutrients and organic matter in Lake Ewingi on August 18, 1979

Pollution indices		Inflow: direct drainage area – spatial sources	Inflow: direct drainage area – point sources	Inflow: indirect drainage area inflows	Inflow: total	Outflow	Cumulation in lake
Total nitrogen	$kg \cdot day^{-1}$	33.1	15.2	42.5	90.8	62.8	28.0
	%	36.46	16.74	46.80	100.00	69.16	30.84
Total phosphorus	$kg \cdot day^{-1}$	0.5	0.3	7.2	8.0	5.2	2.8
	%	6.25	3.75	90.00	100.00	65.00	35.00
Total organic carbon	$kg \cdot day^{-1}$	–	92.0	680.0	772.0	702.0	70.0
	%	–	11.92	88.08	100.00	90.93	9.07

Table 3. Results of physico-chemical and biological ground investigations on water of Lake Ewingi conducted on August 18, 1979 simultaneously with taking multispectral aerial photographs of the lake (range of indices examined at particular stations and mean values)

Index		Research site					
		in pelagial zone			at sewage outlet		
		min.	max.	mean	min.	max.	mean
Secchi disc visibility	m	0.30	0.35	0.33	0.10	0.30	0.22
Colour	mg Pt · dm^{-3}	40	50	48	45	55	50
Turbidity	mg · dm^{-3}	30	50	40	30	50	40
Temperature	°C	20.1	22.0	20.9	21.2	21.0	21.0
Dissolved oxygen	mg O_2 · dm^{-3}	10.1	12.0	10.9	8.2	11.4	10.0
Oxygen saturation	%	112.0	133.0	124.4	102.0	113.5	109.7
BOD	mg O_2 · dm^{-3}	8.8	15.4	11.2	13.1*	32.4*	22.0*
COD	mg O_2 · dm^{-3}	76.0	97.6	87.3	91.2	132.8	112.0
TOC	mg C · dm^{-3}	30.2	33.3	31.6	33.6	36.9	34.8
Total phosphorus	mg P · dm^{-3}	0.56	0.91	0.77	0.71	1.31	1.02
Total nitrogen	mg N · dm^{-3}	1.68	3.36	2.59	1.95	6.64	4.31
Total chromium	mg Cr · dm^{-3}	0.005	0.015	0.009	0.007	0.350	0.107
Total suspension	mg · dm^{-3}	32.1	39.0	36.6	39.8	53.8	46.7
Dry seston weight	mg · dm^{-3}	32.7	40.5	37.8	35.0	50.5	45.0
Chlorophyll-a	mg · dm^{-3}	51.06	57.07	55.23	79.09	84.10	81.09

* Because of higher concentration of total chromium in water of this lake zone the BOD results are considered as unreliable.

Table 4. Indices of lake water pollution from ground investigations corresponding to subranges of optical density determined on the photograph of Lake Ewingi (Fig. 2)

Secchi disc visibility	Dry seston weight	Total phosphorus	Total organic carbon	Chemical oxygen demand	Total suspensions	Subranges of optical
m	mg · dm^{-3}	mg PO_4 · dm^{-3}	mg C · dm^{-3}	mg O_2 · dm^{-3}	mg · dm^{-3}	density
>0.43	<31	<0.50	<30	<69	<30	1 2
0.43 – 0.39	31 – 35	0.50 – 0.70	30 – 31	69 – 80	30.0 – 34.0	3
0.39 – 0.35	35 – 39	0.70 – 0.85	31 – 32	80 – 91	34.0 – 38.0	4*
0.35 – 0.32	39 – 43	0.85 – 1.05	32 – 33	91 – 102	38.0 – 42.0	5*
0.32 – 0.28	43 – 47	1.05 – 1.20	33 – 34	102 – 113	42.0 – 46.0	6
<0.28	>47	>1.20	>34	>113	>46	7

* Significant subranges.

Sources of pollution (out of control) at the west and south lake shore with farm buildings were identified (Fig. 1).

The inflows were found to affect significantly the pollution concentration in lake water, i.e., inflow I receiving mechanically treated wastes from machinery centre before it reaches the lake and inflow III running through a big settlement on the drainage area of the lake (Figs. 1, 2).

The drainage ditches reaching the western shore of lake had also a negative effect on lake pollution (Fig. 2).

The diluting effect of inflow II on lake water is quite interesting (Fig. 2).

Underground well-heads, already mentioned by Januszkiewicz (1965), were identified on the western part of lake photograph. On the eastern end of the lake (Fig. 2), in the littoral zone, the erosion effect of the shore freshly cleaned of sediment can be observed from the sewage outlet towards the south, whereas the southern bay, near the outflow of Elbląski Canal, shows a distinct influence of the cemetary on the lake shore zone.

The interpretation of the map "Distribution of pollution in Lake Ewingi on the basis of aerial multispectral photographs" allowed to determine the range and sensitivity of this remote-sensing technique.

4. DISCUSSION

The remote-sensing technique, interpretation of multispectral aerial or satellite photographs, allowed to study qualitatively and quantitatively the aquatic environment. The remote-sensing technique in investigations of Lake Ewingi allowed to determine effectively the significant sources of pollution of surface waters.

Davis and Fosbury (1973) have used the same technique to carry similar investigations as on Lake Ewingi on the effect of Hauston channel on Golveston bay during three successive flights correlated with ground investigations. They determined BOD, COD, TOC, total inorganic carbon, Secchi disc visibility, chlorophyll-a, temperature, content of dissolved oxygen and turbidity, obtaining a significant correlation between the optical density and Secchi disc visibility in water ($r = 0.88$), total organic carbon ($r = -0.59$), turbidity ($r = -0.63$), COD ($r = -0.39$), chlorophyll-a ($r = -0.87$). In Lake Ewingi a significant correlation was not found between subranges of optical density on the lake photography and the chlorophyll-a concentration determined in investigations.

Alföldi and Jaques (1979) have interpreted the multispectral photographs from Landsat from the point of water quality. The data processed provide information on water colour and suspension quantity. Compared with results of four years of ground investigations they showed a significant correlation ($r = 0.97$). The colour index of Lake Ewingi did not show any correlation with subranges of optical density.

The final report (R o g e r s 1977) on the usefulness of data recorded by Landsat satellite for controlling the degree of eutrophication of Great American Lakes provides a map of water quality of Saginaw Bay on Lake Huron, elaborated on the basis of optical density of lake water recorded on July 31, 1975. These data were correlated with the following indices of water pollution: Secchi disc visibility ($r = 0.73$), chlorides ($r = 0.92$), electrolytic conductivity ($r = 0.93$), Kjeldahl total nitrogen ($r = 0.94$), total phosphorus ($r = 0.94$), chlorophyll-a ($r = 0.90$), total suspensions ($r = 0.94$) and dry residue (r = 0.79), determined at the same time as by the ground laboratories.

In this case the range of investigations and of correlations obtained is much broader than for Lake Ewingi. Striking is the correlation with indices having a high index of solubility as chlorides or electrolytic conductivity.

Despite the broad range of investigations on Lake Ewingi, when taking photographs of the lake (Table 4), no significant correlations were obtained between optical density ranges and water pollution indices: temperature, turbidity, dissolved oxygen, BOD and total chromium.

5. SUMMARY

Interpretation of multispectral aerial photographs of Lake Ewingi taken on August 18, 1979 and simultaneous ground investigations of lake surface water (Table 3) allowed to elaborate a map of surface distribution of pollution concentrations in lake water (Fig. 2). A significant correlation was observed between the subranges of optical density and the determined in ground investigations indices of lake water pollution: Secchi disc visibility ($r = -0.928$), total suspensions ($r = 0.849$), dry seston weight ($r = 0.748$), total phosphorus ($r = 0.710$) and total organic carbon ($r = 0.767$).

This map (Fig. 2) provided information on the qualitative and quantitative pollution of the entire aquatic environment at the moment of investigations and on main sources of lake pollution. The sensitivity of the method for particular water pollution indices was determined (Table 4).

6. POLISH SUMMARY

Wyniki interpretacji wielospektralnych zdjęć lotniczych jeziora Ewingi wykonanych w dn. 18 VIII 1979 r. i równolegle przeprowadzonych badań naziemnych wód jeziora (tab. 3) pozwoliły na opracowanie mapy powierzchniowego rozkładu stężeń zanieczyszczeń w wodzie jeziora (rys. 2). Wykazano bowiem istotną korelację między podzakresami gęstości optycznej, a określonymi – w wyniku badań naziemnych – wskaźnikami zanieczyszczenia wody jeziora: widzialnością krążka Secchiego ($r = -0{,}928$), zawiesinami ogólnymi ($r = 0{,}849$), suchą masą sestonu ($r = 0{,}748$), fosforem całkowitym ($r = 0{,}710$) i ogólnym węglem organicznym ($r = 0{,}767$).

Opracowana mapa (rys. 2) stworzyła możliwość poznania jakościowego i ilościowego stanu zanieczyszczenia całej powierzchni środowiska wodnego jeziora w momencie wykonywania badań. Pozwoliła na poznanie głównych źródeł zanieczyszczenia jeziora. Wyznaczono czułość metody dla poszczególnych wskaźników zanieczyszczenia wody (tab. 4).

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