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VISUAL WATER CLARITY AND LIGHT PENETRATION IN SOME RECREATIONALLY USED LAKES (WESTERN POLAND)*

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Key words: recreation, water clarity, swimming zone, PAR, physical features, turbidity, opalescence.

Abstract

A characteristic of apparent and true depth of illuminated zone in 12 recreationally used lakes of western Poland during the summer was conducted. Depth of photic zone derived from using underwater spherical quantum sensor of photosynthetically active radiation (PAR). The effects of dissolved and suspended optically active substances (chlorophyll *a*, turbidity, total suspended sediment, dissolved substances) on light conditions in the trophic types of lakes were analyzed. Lakes were divided into three trophic states: mesotrophic, eutrophic, and hypereutrophic. Additionally, the content of some optical features of water in zone of swimming versus to lake were analyzed. Turbidity of water was mainly related to the TSS, especially in swimming zone. The large differentiation the depth of illuminated zone within the meso- and eutrophic lakes was noted. The mesotrophic lakes were characterized by greater depth of PAR than lakes of higher trophy. In hypereutrophic lakes with high content of chlorophyll and turbidity in the sub-surface layer the disappearance of light was rapidly below the surface.

PRZEZROCZYSTOŚĆ WODY A GŁĘBOKOŚĆ PRZENIKANIA ŚWIATŁA W WYBRANYCH JEZIORACH UŻYTKOWANYCH REKREACYJNIE (POLSKA ZACHODNIA)

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Słowa kluczowe: rekreacja, przezroczystość wody, kąpielisko, promieniowanie słoneczne, właściwości fizyczne, mętność, opalizacja.

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Abstrakt

Przedmiotem badań była ocena pozornego i rzeczywistego zasięgu strefy prześwietlonej w 12 jeziorach Polski zachodniej wykorzystywanych rekreacyjnie. Badania prowadzono w okresie letnim. Pozorny zasięg światła określano za pomocą krążka Secchiego, a rzeczywisty oraz miąższość strefy fotycznej miernikiem kwantowym (LI-1400, LI-COR) z czujnikiem kulistym (LI-193SA). W obrębie typów troficznych jezior (mezotroficzne, eutroficzne, hypereutroficzne) badano wpływ na warunki świetlne substancji optycznie aktywnych rozpuszczonych i zawieszonych w toni wodnej (chlorofil, mętność, zawiesina, materia organiczna). Dodatkowo analizowano zróżnicowanie przestrzenne właściwości optycznych wody w strefach kąpielisk *versus* pelagial jeziora. W obrębie kąpielisk stwierdzono ścisły związek mętności wody z koncentracją zawiesin. W jeziorach mezotroficznych i eutroficznych odnotowano znaczne zróżnicowanie zasięgu strefy prześwietlonej. Rzeczywisty zasięg światła w jeziorach mezotroficznych był zwykle mniejszy, a w eutroficznych większy w porównaniu z pozornym zasięgiem światła obliczanym na podstawie przezroczystości wody. W jeziorach silnie zanieczyszczonych, gdzie obserwowano często masowe zakwity fitoplanktonu, szarozieloną barwę wody, silną mętność i opalizację, zanik światła następował dość płytko pod powierzchnią wody. W takich warunkach rzeczywisty zasięg światła był zdecydowanie większy od pozornego.

Introduction

The behavior of light in water, particularly its attenuation in subsurface layer, has important ecological implication and shape our perception of water quality. This phenomenon is regulated by the composition and concentration of various attenuating constituents, which include water itself, gelbstoff, tripton, phytoplankton (KIRK 1994) and many others substances named formally as turbidity. The assessment of water transparency and cleanliness by persons enjoying recreation on lakes is frequently ambiguous. Some of us easily identify clean water, but in the case of turbid water, the assessment of its cleanliness is varied, often not reflecting the actual degree of pollution of the lake. The observer only sees water in the coastal zone, where its condition is usually very different from that occurring at a larger distance from the shore. Similar problems with organoleptic assessment of water are encountered by state services specifying its usefulness for bathing. The occurrence in one lake of water zones strongly diversified in physical and chemical terms is related to a number of factors, and concerns both lakes (BAJKIEWICZ-GRABOWSKA 1981, PEŁECHATY 2006), and small waterbodies (JONIAK et al. 2007, JONIAK nad KUCZYŃSKA-KIPPEN 2008). The reasons include among others the resuspension of bottom sediments in shallows and shallow lakes (JAMES et al. 2004), the degradation of the shores, and surface runoff (SMAL et al. 2005, FURGAŁA-SELEZNIOW et al. 2012) as well as excessive human pressure, including recreation (KUCZYŃSKA-KIPPEN et al. 2004, SOBCZYŃSKI and JONIAK 2009).

Lakes, as a place for people the psychophysical power regeneration, are thought to be one of the main determinants of nature's attractiveness for man. Human activities can adversely affect both water quality and the shoreline.

Recreational opportunities are a primary reason people choose to live by or visit lakes, and the demand on our water resources is always increasing. That increasing demand also increases the potential for damage to water quality. Assessing and improving leisure-time activities will help preserve water quality for all hydrobionts as well as for our own recreational purposes. Poor water quality can affect recreation in and on the water, degrade natural habitat, and pose a health risk for water contact recreation (DOREVITCH et al. 2012).

As a result of eutrophication and the connected degradation of lake waters the natural optic features of water change, which leads to numerous changes in the environment. A key consequence of this is an acceleration of the primary production and as an effect there is a considerable decrease of penetration the solar radiation, which is mostly absorbed in the shallow sub-surface layer (JONIAK 2009). Water clarity and depth of light penetration have significant effects on recreational water use. Both features are closely related. Suspended particles and algae have the main influence on light penetration in polluted and eutrophicated waters. The use of Secchi depth (SD) to measure water clarity is a very valuable tool in surface water research. SD offers us readings that are directly related to key ecological variables and human perceptions of water quality (BRUVOLD et al. 1975, STEDMAN and HAMMER 2006). However, many authors pointed out that white disk image attenuation does not only depend on water quality but also changes with the nature of the ambient light field. Therefore, Secchi depth is referred to as an apparent optical property (AOP) (TYLER and PREISENDORFER 1962) and might not be an ideal parameter for modeling water clarity. Alternatively, they suggested using inherent optical properties (IOP), such as the beam attenuation coefficient, which describes the extinction of light due to the processes of absorption and scattering (PFANKUCHE et al. 2000). The aim of study was to characterize the influence of turbidity, total suspended solids, optically active substances and algae biomass as chlorophyll *a* affecting of summer water clarity and depth of solar light penetration in recreationally used lakes of western Poland.

Material and Methods

In the Wielkopolska region, approximately 80 lakes and reservoirs are admitted for swimming in the summer season. The study concerned 12 lakes with bathing sites controlled by the State Sanitary Inspection, and those not subject to control, located at recreation resorts. The study lakes were located in the macroregion of the Wielkopolska Lake District (KONDRACKI 2001), in which a thick net of rivers, lakes of various sizes and post-glacial water bodies appear. The research was carried out in the summer season of 2009 and 2010 in lakes on the Poznańskie Lakeland, Gnieźnieńskie Lakeland and Lubuskie Lakeland. The area of the lakes are different between 9.0 ha to 348.0 ha, and a maximal depth between 6.8 m and 35.2 m (Table 1). Most of the lakes were closed units in the hydrological sense besides throughflow Łódzko-Dymaczewskie Lake (on Samica Stęszewska River), Biezdruchowskie Lake (on Główna River), and Przedwieśnie Lake (on Sadowicka Struga).

Table 1

Morphometrically characteristics of lakes

Lake	Parameter			Lakeland
	area [ha]	max depth [m]	mean depth [m]	
Lipno	9.0	9.5	5.5	Poznańskie
Dębno	25.1	12.0	6.8	
Strzeszyńskie	33.5	17.8	8.4	
Łódzko-Dymaczewskie	119.6	12.0	5.3	
Chrzypskie	304.3	15.0	6.1	
Strykowskie	305.3	7.7	4.5	
Przedwieśnie	13.4	18.3	6.5	Gnieźnieńskie
Biezdruchowskie	48.8	17.7	5.7	
Budzisławskie	153.5	36.7	11.1	
Wilczyńskie	199.3	24.9	7.8	
Lednica	348.0	15.1	7.0	
Solecko	87.5	6.8	4.1	Lubuskie

Both *in situ* and laboratory measurements were made. Sampling and field measurements were conducted in each lake once during summer (June/July) 2009 or 2010 at a pelagic station. Due to the diurnal dynamics of solar height above the horizon the research was undertaken in between 12 a.m. – 2 p.m. The effects of optically active substances on light conditions in the trophic types of lakes were analyzed. For comparing of some physical features of water the samples from watering places were collected (in triplicate). Apparent water transparency use the Secchi disk was analyzed (white, diameter 30 cm). The apparent thickness of the illuminated zone (ATIZ) was calculated after formulae $SD \cdot 2$.

Vertical profiles of photosynthetically active radiation PAR (400–700 nm) were measured with a spherical quantum sensor LI-193SA with LI-1400 Datalogger (LI-COR Corporation, Lincoln, Nebraska, USA). The spherical sensor expands the range of underwater study of light as it enables the measurement of total PAR. The bottom limit of the euphotic zone (Z_{eu}) is the depth reached by 1.0% of light penetrating the water surface, and dysphotic zone by 0.1%. True depth of illuminated zone (sum of euphotic and dysphotic zone) for photosynthetically active radiation ($TDIZ_{PAR}$) was determined *in situ*. A vertical attenuation coefficient of PAR (K_d) was calculated by regressing log-transformed light with depth (KIRK 1994) for the euphotic zone (K_{dZeu}). Measurements of light were conducted at the weather stable in terms of insolation (cloudless). When cloudiness occurred during the study, the actual PAR value on the water surface was additionally measured (sensor LI-190SA).

Four measurements were made routinely to characterize the features of optical regime: turbidity NTU (nephelometrically, Eutech Instr. TN-100), total suspended solids TSS (after filtration through GF/F filter, gravimetrical method), optically active substances OAS (characterized by beam attenuation coefficient of membrane 0.45 μm filtered water at 380 nm using a Cadas 200 UV-VIS (Dr Lange) spectrophotometer with a 5 cm glass cell against deionised water (SIPELGAS et al. 2003), and chlorophyll *a* concentrations (ISO 10260). Total phosphorus was measured by acid digestion with persulfate (APHA 1998). Lakes were divided into three trophic states (mesotrophic, eutrophic, hypereutrophic) based on total phosphorus, Secchi depth and chlorophyll *a* measurements using the guidelines of CARLSON (1977) and trophy state index (TSI) ranges value of CARLSON and SIMPSON (1996). Statistic calculations (Carlson coefficient correlations) were made with Statistica 8.0 software.

Results and Discussion

The lakes studied were distinguished by moderate trophic status. This was reflected by values of TSI indices, categorising 6 lakes as the mesotrophic (TSI ≤50). Three of the remaining lakes were eutrophic (TSI >50–70), and three were hypereutrophic (TSI >70). The trophic status was mainly influenced by phosphorus, and to a somewhat lesser degree by chlorophyll (Figure 1). According to the suggestion by Carlson (1977), the index based on chlorophyll is dominant, while the remaining ones are auxiliary. The statistical analysis revealed significant influence of chlorophyll on water transparency (r=-0.61, p<0.033, n=12). The lack of correlation the chlorophyll and total phosphorus was also stated, which suggest excess of this nutrient in lakes and lack of limiting effect on phytoplankton biomass (KAJAK 2001).

Apparent water transparency ranged from 0.50 m in hypereutrophic Łódzko-Dymaczewskie Lake to maximal 8.60 m in mesotrophic Budzisławskie Lake. *In situ* measured euphotic zone depth (Z_{eu}) ranged from 1.0 m to 12.4 m, respectively (Table 2). An examination of the photon stream penetration PAR in the water column showed that it was strongly absorbed in the shallow

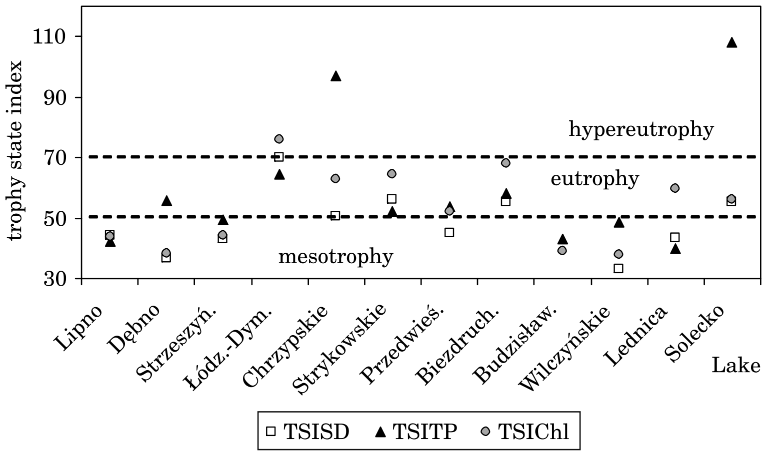

Fig. 1. Trophy state of researched lakes on base of transparency (TSISD), phosphorus (TSITP) and chlorophyll index (TSIChl)

Table 2

Apparent transparency (SD), apparent thickness of illuminated zone (ATIZ), depth of euphotic zone (Z_{eu}), true depth of illuminated zone (TDIZ) and diffuse attenuation coefficients for scalar irradiance in euphotic zone (K_{dZeu}) of study lakes

Lake	Parameter				
	SD [m]	ATIZ [m]	Z_{eu} [m]	TDIZ [m]	K_{dZeu} [m^{-1}]
Lipno	2.95	5.9	4.4	4.5	0.74
Dębno	5.05	10.1	6.5	6.8	0.61
Strzeszyńskie	3.20	6.4	8.0	10.5	0.52
Łódzko-Dymaczewskie	0.50	1.0	1.0	1.6	4.65
Chrzypskie	1.90	3.8	3.4	4.8	1.36
Strykowskie	1.30	2.6	2.2	3.4	1.91
Przedwieśnie	2.80	5.6	5.3	7.0	0.80
Biezdruchowskie	1.40	2.8	3.5	4.7	1.29
Budzisławskie	8.60	17.2	12.4	18.0	0.40
Wilczyńskie	6.35	12.7	9.8	12.7	0.42
Lednica	3.15	6.3	7.4	9.2	0.68
Solecko	1.40	2.8	3.8	4.4	1.12

surface layer of hypereutrophic and eutrophic lakes. This resulted from high water turbidity and algae biomass concentration, and consequently strong light scattering and absorption. The illuminated layer was shallow. In lakes with a lower trophy, the light conditions were clearly better, and TDIZ much higher (Fig. 2). Significant differentiation of the quality of waters in lakes with a lower and higher trophic status was reflected in K_{dZeu} values (Table 2).

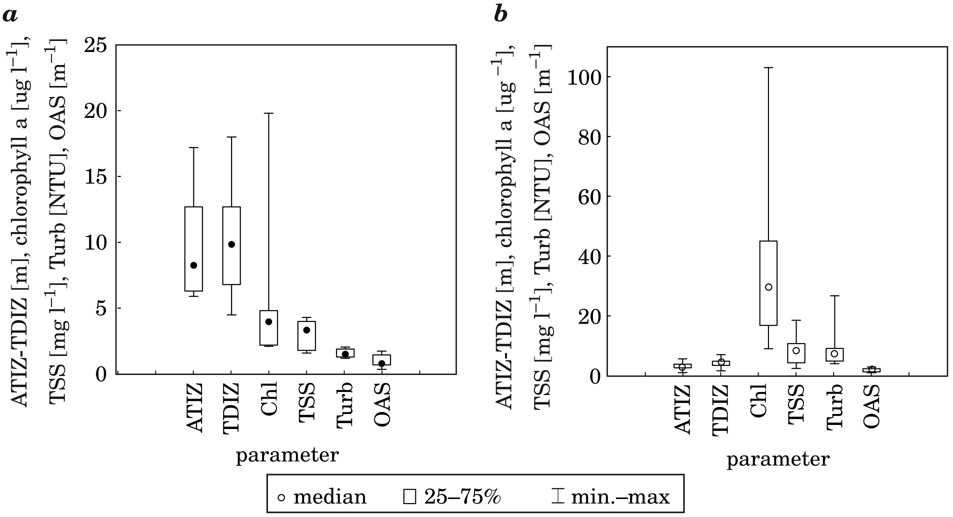

Fig. 2. Apparent and true range of photic zone in relation to concentrations of chlorophyll, TSS, turbidity and optically active substances (median values) in mesotrophic lakes (*a*), and eu- and hypereutrophic lakes (*b*)

In mesotrophic lakes K_{dZeu} showed a low variation (mean 0.56 m^{-1}, std. dev. 0.14 m^{-1}) than in lakes of higher trophy (1.97 m^{-1} and 1.41 m^{-1}, respectively).

Differentiation of the ATIZ and TDIZ in lakes with a high trophy state revealed the underestimation of the true range of the photic zone. The range of light was mean 1.2 m higher than that estimated on basis the Secchi disk visibility. In mesotrophic lakes, the relation was not so unequivocal. In 4 lakes, TDIZ was higher or equal to ATIZ and in lakes Dębno and Lipno it was much lower (Table 2). The feature distinguishing the lakes was the occurrence of shallow-layer turbidity in the zone of limited Secchi visibility, where the turbidity was 4–5 times higher than that in the shallow waters. This type of turbidity results from the accumulation of (mainly dissolved) organic substances (REINART et al. 2003) as well as picoplankton and microorganisms. The barrier limiting light availability in this case are bacterial colloid suspensions or gels released in abundance by plankton and bacteria, frequently forming layers of varied thickness (JONIAK 2009). The excess of organic substances results in the opalescence of water similar to that observed in the deoxygenated near-bottom waters rich in hydrogen sulphide (JONIAK et al. 2010). This type of transformations of physico-chemical conditions of the lake environment directly affects the light conditions, suggesting unfavourable changes in the ecosystem.

The comparison of the content of physical components in the surface water (0–0.5 m) of the pelagial zones and bathing sites revealed much higher concentrations of suspensions and turbidity (Figure 3). Water turbidity at bathing sites was determined by TSS (r^2=0.92, p<0.000), and to a lesser extent by OAS (r^2=0.64, p<0.002). These relations were also dependent by the character of the material forming the bottom within the bathing site. Mineral coarse-grained sand generated higher suspension concentrations, and fine-grained (till) or organic material – higher OAS values. According to DAVIES-COLLEY and SMITH (2001) suspended particles are the dominant influence on light penetration in most natural waters, except of highly colored waters. In the pelagial, turbidity was exclusively correlated with TSS (r^2=0.87, p<0.000), mainly constituted by chlorophyll (r^2=0.95, p<0.000). This type of relationships with algae biomass is typical for the pelagial of deep non--through-flow lakes with high trophy, where the abioseston occurs in minimum

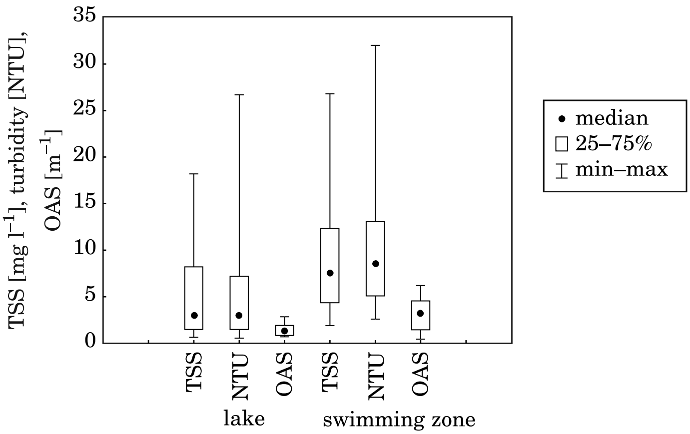

Fig. 3. Differentiation of the concentration of total suspended sediments (TSS), turbidity (NTU) and dissolved optically active substances (OAS) in water of sub-surface layer in pelagial and swimming zone of researched lakes

quantities or not at all. Under low or zero-flow conditions, the finer particles (as phytoplankton) tend to occupy the surface zone of the waterbody, whilst the coarser particles tend to occupy the deeper zone of the waterbody (BILOTTA and BRAZIER 2008). It is worth attention that high correlation of parameters occurred *) in the group of lakes representing varied level of trophic status and **) in the shallow near-surface level considered as an area dangerous for phytoplankton (algae suspended in the water column) due to the penetration by harmful short-wave UV radiation (HÄDER et al. 2007). The occurrence of chlorophyll *a* in the strongly illuminated water layer suggested lack of the harmful influence of UV resulting from absorption by dissolved organic substances (JONIAK 2007). Although, the reduction in light penetration through the water column restricts the periphyton and submersed macrophytes assimilating of energy through photosynthesis this mechanism is not so important for the planktonic species including surface phytoplankton (GONÇALVES et al. 2011).

High turbidity within bathing sites was mainly generated by suspended solids. The composition of suspension was not analysed. Designing such analyses should consider external factors such as wind which can change both the concentration and composition of suspensions in the daily cycle. If wind blows towards the bathing site, it develops breakers exceeding the impression of turbidity by pushing high amounts of phytoplankton towards the shore and elevating abioseston from the bottom (JAMES et al. 2004). In such conditions, the concentration of suspensions at the shore is unnaturally high, and can have a significant deleterious impact on the physical, chemical, and biological properties of the waterbody (BILOTTA and BRAZIER 2008). The water has a form of a mixture of suspensions, and our impression of water cleanliness is very bad. The organoleptic assessment of the usefulness of water for bathing conducted in such conditions (according to the guidelines of the Minister of Health) often results in closing a bathing site, even in a clean lake, until the moment of explaining whether the visible suspension is a mass cyanobacterial bloom or harmless tripton.

Conclusions

1. Lakes used for recreation include those representing a wide range of water quality – from clean to highly polluted. This results in a high scale of differentiation of optical features of the water and light conditions.

2. Using lakes with phytoplankton blooms, in our climatic conditions usually developed by toxic cyanobacteria, for recreational purposes is potentially dangerous for the health of humans, and particularly children. The concentration of phytoplankton biomass in the shallow surface layer of a lake results in the grey-green colour of water, and its opalescence and turbidity. The true range of PAR in such conditions, however, is higher than that estimated based on Secchi visibility.

3. At bathing sites water turbidity is higher than in the pelagial mainly due to the occurrence of suspensions. The composition of suspensions is not only determined by the migration of matter from the pelagial (horizontal pushing the algae by wind), but mainly by the properties of sediments deposited at the bottom of the bathing site. Fine-grained mineral and organic sediments, natural for majority of lakes, usually increase the impression of water turbidity of people using the lakes and is unreasonably assesed as the effect of water pollution by sewage.

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