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EVALUATION OF THE STATUS OF WARMIAN-MASURIAN LAKES IN POLAND DUE TO EUTROPHICATION PROCESS

The article is devoted to the study the origins and consequences of the eutrophication problem of Warmian-Masurian lakes of Voivodeship in Poland and to find the possible ways of its solution. Eutrophication, also known as hypertrophication is a process of enrichment of water bodies with nutrients, especially nitrogen and phosphorous that leads to algae and plants growth and results in inadequate supply of oxygen and loss of water quantity. Nowadays, the problem of eutrophication concerns not only Baltic countries, but also countries in the West Europe, the same as in whole world. The eutrophication problem also influences local landscape changes, because it is strictly associated with terrestrialization process, which is well-seen in the area of Warmian-Masurian Voivodeship. The aim of the work is to find the relationship between the eutrophication process and the environmental problems caused by them, as well as to find potential solutions and review the currently done ones, base on comparison of observations and literature sources. The work was mainly based on field observation, publications of researches, and the program of "lakes cleaning" in Szczytno and literature study, which confirmed the negative changes in structure of local associated with eutrophication and terrestrialization processes. To see the structural changes in the lakes as a result of the terrestrialization process, we compared their current state with old photographs of the area. Visible changes were found in the coastline, which was overgrown mainly with reeds and typhus, as well as former beaches, which were replaced by flora. To point out possible ways of solution, the program of "lakes cleaning" in Szczytno was used. The project was running for 3 years (from 2010 to 2013) and consisted of introducing of 71 tons of a polyaluminium coagulant under surveillance of scientists from the University of Warmia and Mazury. It was concluded that the changes of water bodies in the Warmian-Masurian Voivodeship are strongly associated with eutrophication process. To avoid and withdraw that processes there are many solutions, starting with the simplest to advanced ones what is well-seen in Szczytno Warmian-Masurian Voivodeship, where polyaluminium coagulant was used to "clean" the lake. Further research may focus on finding a variety of substances that can be used to mitigate and eliminate eutrophication without side effects, both for the environment and for humans.

Key words: *eutrophication, lakes, cyanotoxins, terrestrialization, algal bloom, Warmian-Masurian Voivodeship.*

Introduction. Eutrophication is a natural process of aging of water bodies that lasts for centuries. In water bodies that are subject to anthropogenic impact, the processes are rapidly accelerating: significantly change the physicochemical properties of the aquatic environment, increases the content of nutrients and organic matter, reduces the level of oxygen saturation, anaerobic zones are formed in the bottom layers, turbidity increases and water transparency decreases . Eutrophication indicates a violation of the ecological balance and subsequently leads to the degradation of water ecosystems. The natural ability of rivers to self-purify, self-regulate, form biotic bonds, water quality parameters is disturbed, the state of their ecosystems deteriorates [6,8].

Base on different sources it is possible to find following definitions of eutrophication: "*Eutrophication is an enrichment of water by nutrient salts that causes structural changes to the ecosystem such as: increased production of algae and aquatic plants, depletion of fish species, general deterioration of water quality and other effects that reduce and preclude use* [1].

Since the last decades there were negative changes associated with the eutrophication process observed on these grounds. Consequently, periodically the water (because of algal bloom) is almost unable to be used, among others, for touristic, recreational, bathing and fishing reasons. Every year there are cases of cyanotoxin poisoning and allergic reaction reported, what

constitutes that the problem of eutrophication can have huge influence on human and animal health.

Lakes provide many crucial functions in different regions of the world that include: supplying of drinking water and providing environment for aquatic habitats and being integral component of local landscape, fishery place or area of recreation and tourism development.

Intensive agricultural production around water bodies – excessive fertilization, industrialization, urbanization, development of tourism and, lack of methods of lakes protection have an influence on an excessive load of phosphorus and nitrogen compounds in water. An excessive amount of nutrients in lakes is mainly a consequence of the progressive eutrophication. In overfertilized lakes, the usefulness of water for recreation, municipal, industrial and fishing purposes decrease, which results in specific economic consequences (increase in the cost of water treatment, losses in fish population, tourism, recreation). It is recognized that phosphorus is a limiting factor in primary production in the vast majority of inland water reservoirs. Currently, it is considered that eutrophication is the biggest danger to biodiversity of freshwater habitats [14].

Warmian-Masurian Voivodeship includes area, which is known as “Masurian Lake District”. It consists of more than 3000 lakes, including 2000 lakes greater than 1 ha. Negative changes associated with the eutrophication process were observed in this area since the last decades. As a consequence the water is periodically (because of algal bloom) almost unsuitable for touristic, recreational, bathing and fishing reasons [7, 12].

It is known that eutrophication process cauces macro- and microchanges in a waterbody. These macrochanges can be seen with the naked eye every year as algal bloom, when water of some of lakes becomes green, turbid and unwell, because carries risks of allergy or cyanotoxin intoxication. The microchanges can be confirmed by water tests which show a presence of different types of bacteria including cyanobacteria group. Unfortunately, the process can negatively influence health of human and animals. It is known that algal bloom often includes also cyanotoxin development. The toxins, depending on the route of contamination, can cause fatal consequences to health and life [1].

The local landscape changes represent one of the offshoots associated with terrestrialization process (transforming of aquatic environment into land). It can be observed in the changes of the structure and appearance of the Warmian-Masurian lakes [10].

The simple methods of problem solution include: reduction in usage of natural and artificial fertilisers, removing sources of waste water discharge, as well as raising awareness about proper usage of water bodies (no use of detergents and other chemicals and no discharge of waste water from households and farms) and establishment of proper legislation. The advanced methods were introduced relatively recently and will be shown using the example of lakes in Szczytno.

The aim of the paper is to find relationships between eutrophication process and factors influencing the process (such as overfertilization of fields, animal husbandry, sewage outflow to waterbodies), to point out the hazards for humans and animals getting in contact with waterbodies containing cyanotoxins, as well as to find potential solutions and review the measures already taken.

Materials and methods. The work was mainly based on field observation, publications of researches, and the program of “lakes cleaning” in Szczytno and literature study, which confirmed the negative changes in structure of local associated with eutrophication and terrestrialization processes. To see these structural changes of lakes – terrestrialization – we compared the present state with old photos of the area and observed visible changes of coastline that became overgrown mainly by canes and typhas and former beaches that were replaced by plant life. To address the influence of that problem on human and animal health examples of allergic reactions caused by different kinds of bacteria through the contact with water, noticed by local people were shown and subsequently literature study confirmed that eutrophication can have an influence on human and animal health.

To point out possible ways of solution, the program of ‘lakes cleaning’ in Szczytno was used. The project was running for 3 years (from 2010 to 2013) and consisted of introducing of 71 tons of a polyaluminium coagulant under surveillance of scientists from the University of Warmia and Mazury. The observations and description of the process was used in this work as well. [15, 3, 4].

Results and discussion. Base on the literature resources and observation comparison it is possible to answer, which factors influence eutrophication in lakes in Szczytno (Poland) and what is their genesis?

One of the factors which have an influence on the eutrophication process is agriculture and more precisely using of excessive amounts of fertilizers (both organic and inorganic). As we know, farmers use protective agents as pesticides, fungicides, etc. to improve the harvest and protect plants. Agricultural fields in the Warmian-Masurian region are often localized near the waterbodies, including lakes. Then nitrogen and phosphorus compounds reach the water through soil retention [20] determined that almost all fertilizers reach natural waterbodies. They calculated and explained annual losses of components of fertilizers by the example of the water catchment area of the rivers reaching the sea. In the case of nitrogen, 1, 00 – 3,00kg $NNH4_{+NO2}$ ha^{-1} and in case of phosphorus, 0,20 kg P_2O_2 ha^{-1}. Durkowski (1998) determined that in the case of intensive-fertilized lands 4% of the compounds reach the water (annually 5,5 kg Nha^{-1} and 0,6 kg Pha^{-1}). Lessow (1995) reported that 1-5% of phosphorus and 10-20% of nitrogen are rinsed to the local waterbodies [14, 18, 21].

The animal husbandry has also an influence on eutrophication process. It is known that manures and slurries are also rich in nitrogen and phosphorus. Organic fertilizers are in the Warmian-Masurian area. Animal husbandry leads to deposition of animal faeces, which are used to produce fertilizers. And whether that phosphorous and nitrogen compounds are included in artificial (mineral) (Tab.1) or natural (for example: manure) reach water through the soil [15, 18].

Table 1. **Mineral nutrient content in the manure (kg/t)**

Nutrient	Animal species			
	Cattle	Pigs	Horses	Sheep
N	4,7	5,1	5,4	7,5
P_2O_2	2,8	4,4	2,9	3,8

The next factor, which has an influence on increased level of phosphorus and nitrogen in water, is the sewage. According to Voivodship Fund for Environmental Protection and Water Management in Olsztyn [9] waterbodies in Szczytno were contaminated by waste water from local dairy, linum-processing factory, brewery and state auricular farm in Kamionek. There was a time when the pollution reached the water directly. Although a lot of industrial plants do not exist right now, the water for a long time was unsuitable for swimming. Fortunately, in recent years the sewage-management has changed in Poland and EU. On the one hand, it is reported that these changes improved the water state. But on another hand, inappropriate sewage-management leads to eutrophication process.

It is known that eutrophication leads to excessive load of phosphorus and nitrogen in water. Algal blooms which can be harmful for human and animal life are called HAB (harmful algal blooms) [11]. The process of algal bloom formation is complex. The planktonic bloom is the result of phytoplankton development (for example cyanobacteria, diatoms, green algae, flagellates). The result of their accumulation in the waterbody leads to sunlight inflow limitation to deep layers of water, which causes limitation of photosynthesis. These changes result in oxygen deficiency in water, phytoplankton decomposition what may be toxic and decreasing of water quantity as well as its smell and taste. The limited oxygenation has unfavourable effect on aquatic animals, what could be confirmed by observation of dead fish in lakes affected by algal bloom.

Starting from the eighteenth, but mainly in the nineteenth and twentieth centuries, there was an intensification of terrestrialization process, which significantly contributed to the acceleration of the lakes disappearance, as well as to the increasing rate of their eutrophication [19].

This manifested itself clearly in the areas that were predisposed to the development of agriculture, including the Masurian Lake District. In the 20th century, the area of most lakes in Poland decreased by about 44% [13]. The rate of such disappearance of water reservoirs has been recorded for about 160 years, growing every year. Small lakes and water reservoirs are

particularly susceptible to disappearing, transforming into swamps and then drying completely (Tab.2) [7].

Table 2. **Changes in the area and number of lakes in Poland**

Research area	Directory of Polish lakes [1954]		Directory of Polish lakes [2006]		
	Number of lakes	Area of lakes [ha]	Number of lakes	Area of lakes [ha]	Disappearance of lakes area [%]
Masurian like district	2704	144946,7	2061	130481,0	9,89
Poland	9296	316614,1	7081	280977,0	11,26

It can be concluded that the factors influencing accelerated eutrophication include industrial and agricultural activities, which causes a very intensive growth of algae and aquatic vegetation. As a result of excessive fertilization, surpluses of phosphorus and nitrogen compounds are washed out of the soil and are transported through underground and surface runoff to lake waters [18, 21].

Every year cases of cyanotoxin poisoning and allergic reaction are reported, what means that eutrophication can have huge influence on human and animal health? The first publication was written by George Francis (1878) [10, 17], who described the case of domestic and wild animals' death, watered from the shallow, offshore lake in Alexandrina in South Australia. Hepatotoxic cyanobacterium Nodularia *spumigena* had developed in the lake. The deaths of several hundred animals' horses, sheep, dogs and, pigs - occurred within 1-15 hours of consumption of the contaminated water or "sheepskin coats" [19].

Many cases of animal poisoning caused by contact with cyanobacteria have been reported. Death of domestic animals (e.g. dogs, ducks and young cattle) associated with blooms of *N. spumigena* was also recorded in the Baltic Sea region: in Sweden, Denmark, Germany and Finland. In Finland in 2004, cyanotoxin poisoning occured within a few hours after the contact with it and included vomiting and diarrhoea. Some of the animals died as a result of circulatory disorders caused by excessive influx of blood to the liver. According to the World Wide Fund (2011) to the at-risk group practicing water sports such as swimming, sailing, surfing or water skiing belong. Occurrence of accidental digestion of the contaminated water or inhalation of aerosol containing cyanobacteria or their toxins is very often. It is confirmed that this way of transmission is more toxic than others. Also, potential risk can include the consumption of products, which can be contaminated by algae such as fish and seafood. It was proved that swallowing of just few millilitres of "blue-green algae soup" is associated with a real threat. Over 10 years ago in Brazil, many poisonings after drinking water covered by cyanobacterial blooms (*Microcystis* and *Anabaena*) were reported. About 2,000 patients felt different types of the digestive system iscomfort; and 88 of them died. Examples of human exposure to cyanotoxins during recreation, were reported from Canada (13 people), Great Britain (20 people) and Australia (852 people) [19].

In the Baltic region, in spite of intense blooms of toxic cyanobacteria, cases of poisoning are less documented than in the northern Poland (Barlewice Lake, Bertolt, Benecke). Mass death of birds, fish and farm animals, as well as cases of skin irritation of people who had contact with lake water were recorded already in 1884 [19].

It is known that cyanotoxins may have many properties, depending of cyanobacteria genera. Contact with cyanobacteria may result in skin irrigations to nerve synapses damage.

Many repercussions associated with eutrophication forced people to find solutions to protect waterbodies. EU introduced proper legislation to regulate the sewage-management and financial fines for polluting lakes. For example, the law of 2001 on environmental protection in Poland regulates sewage outflows and its purifying [2, 16]. Also law, which regulates the proper doses of fertilizers has to control usage of fertilizers to protect environment from harmful effect of

overdosages of its components. There are also methods and solutions to reserve the effect of eutrophication and improve general state of the lakes, which was introduced relatively recently. The project realized in lakes in Szczytno is a good examples of that, where 71 tons of a polyaluminium coagulant was applied during 3 years from 2010 under surveillance of scientists from the University of Warmia and Mazury. The effect is well-seen, what is confirmed by reopening of the town beach after many years and, increased level of lake usage by local inhabitants, as well as tourists. There has been some scepticism from fishermen who claim that after introducing of the substance the fish population decreased. The lack of oxygen caused by the coagulant layer on the lake bottom lead to, decreased population of *Chironomidae* larvae that, is the main fish nourishment.

Conclusions. It can be concluded that the changes of water bodies in the, Warmian-Masurian Voivodeship are strongly associated with eutrophication process. The genesis of problem can include different factors such as over-usage of fertilizers, discharge of waste-water into waterbodies as well as reduction of self purification capacity. The eutrophication process has negative influence on human and animal. It was established that the main risk factor in this case are cyanotoxins, which can cause different complications. The results of comparing of observation and literature sources showed that the eutrophication is also associated with terrestrialization process. To avoid and withdraw that processes there are many solutions, starting with the simplest to advanced ones what is well-seen in Szczytno, where polyaluminium coagulant was used to 'clean' the lake. It lead to decrease of algal bloom, reduction in development of different types of bacteria, as well as to increase in the use of the lakes for recreational purposes.

Prospects for further research. Nowadays, the possible ways of genesis of eutrophication process are well-known and cyanotoxins peculiarities as well. The technological progress allowed people to find substances which can effectively treat the problem. The further research can be focused on finding different substances, which can be used to mitigate and eliminate eutrophication without side effects.

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Оцінка стану Вармінсько-Мазурських озер у Польщі внаслідок процесу евтрофікації

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Стаття присвячена дослідженню причин та наслідків проблеми евтрофікації Вармінсько-Мазурських озер однойменного Воєводства в Польщі та пошуку можливих шляхів її вирішення. Евтрофікація, також відома як гіпертрофіка, - це процес збагачення водойм поживними речовинами, особливо азотом і фосфором, що призводить до росту водоростей і водних рослин, наслідком чого є недостатнє постачання кисню і погіршення якості води. Сьогодні проблема евтрофікації стосується не лише країн Балтії, а й країн Західної Європи, як й усього світу загалом. Проблема евтрофікації також впливає на локальні ландшафтні зміни, оскільки вона тісно пов'язана з процесом терестриалізації, що прослідковується на території Вармінсько-Мазурського воєводства. Метою роботи є пошук взамозв'язку між процесами евтрофікації, спричиненими ними екологічними проблемами, пошук потенційних рішень для вирішення проблеми, а також огляд зроблених на основі порівняння та спостережень літературних джерел. Робота базувалася на польових спостереженнях, публікаціях досліджень, спеціальній програмі «очищення озер» у Щитному та вивченні літератури, що підтвердило негативні зміни в структурі місцевого населення, пов'язані з процесами евтрофікації та терестріалізації. Щоб побачити структурні зміни озер внаслідок процесу терестріалізації, нами було порівняно їхній сучасний стан зі старими фотографіями місцевості. Було виявлено видимі зміни берегової лінії, яка заросла переважно очеретами та тифами, а також колишні пляжі, які були замінені рослинним світом. Щоб вказати можливі шляхи вирішення погіршення стану водойм було використано програму «очищення озер» у Щитному. Проект тривав 3 роки (з 2010 по 2013 рр.) і полягав у введенні 71 тонни поліалюмінієвого коагулянта під наглядом вчених з Вармінсько-Мазурського університету. Зроблено висновок, що зміни водних об'єктів у Вармінсько-Мазурському воєводстві тісно пов'язані з процесом евтрофікації. Для того, щоб уникнути та зменшити ці процеси є чимало рішень, починаючи від найпростіших і закінчуючи складними, що добре видно в Щитно Вармінсько-Мазурського воєводства, де за допомогою поліалюмінієвого коагулянта «очищали» озеро. Подальші дослідження можуть бути зосереджені на пошуку різноманітних речовин, які можна використовувати для пом'якшення та усунення процесу евтрофікації без побічних ефектів, як для навколишнього середовища, так і для людей.

Ключові слова: *евтрофікація, озера, ціанотоксини, терестріалізація, цвітіння водоростей, Вармінсько-Мазурське воєводство.*

Оценка состояния Варминско-Мазурских озер в Польше в связи с процессом эвтрофикации

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Статья посвящена исследованию причин и последствий проблемы евтрофикации Варминско-Мазурских озер одноименного воеводства в Польше и поиска возможных путей ее решения. Эвтрофикация, также известна как гипертрофика, – это процесс обогащения водоемов питательными веществами, особенно азотом и фосфором, что приводит к росту водорослей и водных растений, следствием чего является недостаточное снабжение кислородом и ухудшение качества воды. Сегодня проблема эвтрофикации касается не только стран Балтии, но и стран Западной Европы, как и всего мира в целом. Проблема эвтрофирования также влияет на локальные ландшафтные изменения, поскольку тесно связана с процессом терестриализации, что прослеживается на территории Варминско-Мазурского воеводства. Целью работы является поиск взаимосвязи между процессами эвтрофикации, вызванными ими экологическими проблемами, поиск потенциальных постановлений для решения проблемы, а также обзор сделанных на основе сравнения и наблюдений литературных источников. Работа базировалась на полевых наблюдениях, публикациях исследований, специальной программе очистки озер в Щитном и изучении литературы, что подтвердило негативные изменения в структуре местного населения, связанные с процессами эвтрофикации и терестриализации. Чтобы увидеть структурные изменения озер в результате процесса терестриализации, нами было сравнено их современное состояние со старыми фотографиями местности. Были обнаружены видимые изменения береговой линии, заросшей преимущественно камышами и тифами, а также бывшие пляжи, замененные растительным миром. Чтобы указать возможные пути решения ухудшения состояния водоемов, была использована программа «очистка

озер» в Щитном. Проект длился 3 года (с 2010 по 2013 гг.) и заключался во введении 71 тонны полиалюминиевого коагулянта под наблюдением ученых из Варминско-Мазурского университета. Заключено, что изменения водных объектов в Варминско-Мазурском воеводстве тесно связаны с процессом эвтрофикации. Для того, чтобы избежать и уменьшить эти процессы, есть немало решений, начиная от простейших и заканчивая сложными, что хорошо видно в Щитно Варминско-Мазурского воеводства, где с помощью полиалюминиевого коагулянта «очищали» озеро. Дальнейшие исследования могут быть сосредоточены на поиске различных веществ, которые можно использовать для смягчения и устранения процесса эвтрофикации без побочных эффектов как для окружающей среды, так и для людей.

Ключевые слова: *эвтрофикация, озера, цианотоксины, терестриализация, цветение водорослей, Варминско-Мазурское воеводство.*

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