DOCTORAL (PhD) DISSERTATION

Doctoral School of Chemical Engineering and Material Sciences

Institute of Environmental Engineering

University of Pannonia

DOI:10.18136/PE.2023.839

ADVANCED COMPREHENSIVE WATER QUALITY ASSESSMENT

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Veszprém, Hungary

2023

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propose acceptance (yes / no) ………………………………………….
(Supervisor/s)

As reviewer, I propose acceptance of the thesis:

Name of Reviewer: Dr. ------------------, PhD yes / no……………………….
(Reviewer)

Name of Reviewer: Dr. -----------------, PhD yes / no ……………………….
(Reviewer)

The PhD-candidate has achieved …..........% at the public discussion.

Veszprém/Hungary, Február, 2023 ……………………...
(Chairman of the. Committee)

The grade of the PhD Diploma …...................................... (……. %)
Veszprém/Hungary, Február, 2023

……………………….
(Chairman of UDHC)

ABSTRACT

In order to maintain a good environmental status of surface waters, an assessment of water quality carried out at specific intervals to monitor the changes of water quality in function of time. Human knowledge and experience are currently focused on using assessment methods, especially the integration of multiple constraining factors and considering them in conjugation with the correct decision-making process concerning the environment. When surface water is highly exposed to human activities, either from recreational or economic activity, the degree of vulnerability is high, and the quality of surface water is highly compromised. Heavy metals cause deleterious effects on human health and drastically alter the biogeochemical cycles within freshwater habitats. Lake Nasser is one of the largest man-made lakes on earth. It has a vital importance to Egypt for several decades because it safe water supply of the country. In case of Lake Balaton, there are many activities that can disrupt water dynamics. Therefore, the water quality of the lakes must be profoundly investigated, water parameter changes should be continuously monitored and assessed. The first goal of this study is to determine the location of the least and most polluted sites around the lakes. The processing of data was carried out by using multi-criteria decision techniques and environmental impact assessment method based on physicochemical parameters and heavy metals as special chemicals parameters in comparison with the limiting parameters as defined in Water Framework Directive and pertaining legal regulations. Additionally, effects of heavy metals bioaccumulation in aquatic ecosystem, via water, sediments and fish organs were investigated. This work covers a novel approach to comparing methods based on sum of ranking differences, whereas many method comparison studies suffer from ambiguity or from comparisons not being quite fair. This problem can be avoided if there are differences between ideal and actual rankings. The main purpose of the PhD work is to devise a quantitative type of water quality assessment method which could provide rapid, accurate, and reliable information on quality of surface waters using water parameters. The algorithm was devised at University of Pannonia, Hungary, for evaluation of water quality. In light of the tremendous demand for safe and healthy water supply in Egypt, Hungary and international requirements, water quality assessment is a very important tool for providing reliable information on water quality. The protocol for water quality assessment could significantly contribute to the provision of high-quality water supply in Egypt and Hungary. In conclusion, it can be stated that the parameters under investigation in different regions of Lake Nasser and Lake Balaton fall within the permissible ranges and the water of the lakes have good quality according to Egyptian and Hungarian standards; however, according to European specifications, there are steps to be accomplished for future water quality improvement.

Keywords Water quality assessment; Physicochemical parameters; heavy metals; Bioaccumulation; Aquatic environmental index; SRD; MPI; Lake Nasser; Lake Balaton

الملخص العربي

من أجل الحفاظ على حالةٍ بيئيةٍ جيدةٍ للمياهِ السـطحية، فـــــ إنه قد تم إجراء تقييم لنوعية المياه على فترات زمنية متقطعة، وذلك لرصــــدِ التغييرات في جودةِ المياهِ تماشـــيًا مع الفوارق الزمنية. وبما أنه تتركّز المعرفة والخبرة البشرية في الوقت الحالي على استخدام طرق التقييم، لا سيما من خلال دمج العوامل المُقيّدة المتعددة والنظر فيها مُقترنةً مع عملية صنع القرارات الصحيحة المتعلقة بالبيئة. فـــ عندما تتعرض المياه السطحية للعديد من الأنشطة البشــريةِ ســواءً الترفيهية أو الاقتصــادية؛ فإنّ ذلك يتســبّب في إحداث تلوث بدرجة كبيرةٍ لها، وتتعرّض جودتها للخطر بشكل كبير. على الجانبِ الآخر نجد أنّ المعادن الثقيلة تُمثِّل ضــررًا كبيرًا يُهدّد صــحةَ الإنسـان ويُغير من الدورات الجيوكيميائية في المياه العذبة، فبحيرة ناصر، والتي تُعَدّ واحدة من أكبر البحيرات التي صنعها الإنسان على مســـتوى أنحاء العالم، والتي تلعب دورا مهمًا لجمهورية مصـــر العربية على مدار عقودٍ من خلال توفير مصـدرٍ آمنٍ للمياه العذبة، وكذلك بحيرة بالاتون بدولة المجر والتي تحدث بها العديد من الأنشـطة البيولوجية التي قد تُمثِّل تهديدًا مباشـــرًا لديناميكية حيوية هذه المياه، مما يدفعنا إلى الاتجاه نحو حتمية فحص جودة هذا النوع من المياه بشكل كبير، ومراقبة وتقييم التغيرات التي تحدث بها بشـكل مستمر. وعلى ما سبق، فإنّ الهدف الأول من إجراء هذه الدراسـة كان تحديد المواقع الأكثر والأقل تلوثًا حول هذه البحيرات. تم تنفيذ معالجة البيانات باسـتخدام تقنيات اتخاذ القرار متعددة المعايير وطريقة تقييم الأثر البيئي بناءً على المعلمات الفيزيائية والكيميائية واسـتخدام المعادن الثقيلة كمُعلِّمات كيميائية خاصــــة، وذلك بالمقارنة مع المُعلِّمات المحدّدَة على النحو المُعترَف به في "الإطار التوجيهي الخاص بالمياه واللوائح القانونية ذات الصـــلة". بالإضـــافة إلى ذلك ، تم دراســـة آثار التراكم الأحيائي للمعادن الثقيلة في النظام الإيكولوجي المائي، وذلك عن طريق دراســـة الماء، الرواســـب، وهياكل (أعضاء) الأسماك. يُتيح هذا العمل نهجًا جديدًا لمقارنة الأساليب بناءً على مجموعة من الاختلافات الترتيبية، في حين أن العديد من دراسـات مقارنة الطرق تعاني من الغموض أو من المقارنات غير المُتحيّزة، في حين أنه يمكن تجنب هذه المشكلة إذا كانت هناك اختلافات بين التصنيفات المثالية والفعلية. الغرض الرئيسي من عمل الدكتوراه هو ابتكار نوع كمي لطريقة تقييم جودة المياه والتي يمكن أن توفر معلومات ســـريعة ودقيقة وموثوقة حول جودة المياه الســـطحية باســـتخدام معايير المياه. تم ابتكار الخوارزمية في جامعة بانونيا، المجر، لتقييم جودة المياه. في ضــوء الطلب الهائل على إمدادات المياه الآمنة والصـحية في مصــر والمجر والمتطلبات الدولية، يعد تقييم جودة المياه أداة مهمة للغاية لتوفير معلومات موثوقة حول جودة المياه. يمكن لبروتوكول تقييم جودة المياه أن يســـاهم بشكل كبير في توفير إمدادات مياه عالية الجودة في مصر والمجر. وأخيرًا، يمكن القول أن المعايير قيد البحث في مناطق مختلفة من بحيرة ناصــر وبحيرة بالاتون تقع ضــمن النطاق المســموح به وأن مياه البحيرات ذات نوعية جيدة وفقًا للمعايير المصـرية والمجرية، ومع ذلك، فإنه وفقًا للمواصفات الأوروبية، هناك خطوات يجب القيام بها لتحسين جودة المياه في المستقبل.

الكلت الدالة:

تقييم جودة المياه؛ المُعلِّمات الفيزيائية الكيميائية؛ معادن ثقيلة؛ تراكم بيولوجي؛ مؤشر البيئة المائية؛ بحيرة ناصر بحيرة بالاتون؛ SRD؛ MPI.

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Declaration

Undersigned ***"Roquia* Ibrahim Saad Rizk*"*** PhD student, declare that the thesis was made at University of Pannonia, Doctoral School of Chemical Engineering and Material Sciences, in order to obtain Doctor of Philosophy degree in Bio, Environmental and Chemical Engineering.

I hereby declare upon my honour that the present thesis is entirely my intellectual property based on my own original ideas and I used only the sources which are listed in the bibliography. I have not submitted this thesis for any other thesis purpose before.

Date: Veszprém, Hungary:

Signature

The undersigned "**Professor Dr. Rédey Ákos† and Professor Dr. Hashem Mohamed Shafik Ahmed**", as supervisors, declare that the thesis was made at University of Pannonia, research Centre for Biochemical, Environmental and Chemical Engineering, Research Group of Sustainability Solutions, in order to obtain Doctor of Philosophy degree in Bio-Environmental and Chemical Engineering.

I declare that I authorize the PhD thesis.

Date: Veszprém, Hungary:

Signature

LIST OF SYMBOLS

CM_n	concentration of n_{th} metal in the tissue sample	mg/kg dry wt
QDi	deviation of measured water chemistry parameter i from legal limit value	%
C_{Lvi}	limit value of water chemistry parameter i	-
CMi	measured value of water chemistry parameter i.	mg/L
R^2	Value of the liner regression	-
V	Volume of solution	L
DO	Dissolved oxygen	mg/L
WI	Weights indices	-
QC_i	Quality class for water chemistry parameter i	-
Chl-*a*	Chlorophyll-*a*	μg/L
COD	Chemical oxygen demand	mg/L
BOD_5	Biological oxygen demand	mg/L
TOC	Total organic carbon	mg/L
TU	Turbidity	-
pH	potential of hydrogen	-
EC	Electric conductivity	μS/cm
OS	Oxygen saturation	%
TP	Total phosphate	mg/L

LIST OF ABBREVIATIONS AND ACRONYMS

AEA	Aquatic environmental assessment
MSZ	Magyar Szabványügyi Testület (Hungarian Standards Board)
WFD	Water frame work directive
MCDM	Multi-criteria decision-making techniques
GD	Governmental Decree
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
SAW	Simple Additive Weighting
APHA	American Public Health Association
AAS	Atomic absorption spectroscopy
USEPA	United States Environmental Protection Agency
GF	Graphite furnace
DORM 4	Dogfish protein certified reference material for trace metals
DOLT 5	Dogfish Liver Certified Reference Material for Trace Metals
ANOVA	Analysis of variance
CORR	Pearson correlation coefficient
AEI	Aquatic environment index
SRD	Sum of Ranking Differences
EQS	Environmental Quality Standards
UESEPA	United States Environmental Protection Agency
CCME	Canadian Council of Ministers of the Environment For the Protection of Aquatic Life
SQG	Sediment quality guideline
TEC	Threshold effect concentration
PEL	Probable effect level for dry weight
SEL	Severe effect level for dry weight
TET	Toxic effect threshold for dry weight
PEC	Probable effect concentration
EC	European Community
FAO	Food and Agriculture Organization
WHO	World Health Organization
MAFF	Ministry of Agriculture, Fisheries and Food
ROS	Reactive Oxygen Species
CIS	Common implementation strategy for water framework directive

Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful. All thanks and praise are to Allah, the all-wise, the all-knowing, the creator of this wonderful world. All praises to Allah SWT for his greatness and blessing for giving me the strength and courage to complete this thesis. I thank Allah for all the opportunities, trials, and strength that have been showered on me to finish writing the thesis. I experienced so much during this process, not only from the academic aspect but also from the aspect of personality. My humblest gratitude to the holy Prophet Muhammad (Peace be upon him) whose way of life has been continuous guidance for me.

This work is carried out as a part of the research activities in Sustainability Solutions Research Lab, Research Centre for Biochemical, Environmental and Chemical Engineering. First and foremost,I would like to express and sorrily convey my deepest thankfulness to the soul of my previous supervisor (Prof. Dr. Ákos Rédey†) and my supervisor Prof. Dr. Hesham Shafik, all which I achieve is belong to them, for entrusting me with this subject, as well as for their encouragement, invaluable advice, motivation and regular monitoring. Thank you for all the time you have given me, your guidance and your encouragement during this period.

I owe special thanks to Dr. Tatjána Juzsakova, director of laboratory which I worked in for her kindness, availability, and support. I owe also a debt of gratitude to Prof. Dr. Anna Farkas, Balaton Limnological Research Institute, Tihany, Hungary, for her support, help and approachability. Additionally, I would like to thank Dr. Endre Domokos, head of Research Centre for Biochemical, Environmental and Chemical Engineering, for his help and support.

My deepest gratitude goes to all my family members. It would not be possible to write this thesis without their support. I would sincerely like to thank my dearest husband Mohamed Ali and my beloved girls, who gives me happiness and optimism in my life. Special deep appreciation is given to my late father, my mother, and my sister. Thank you all for your unwavering support and for reminding me to take breaks and have fun when I've been stressed out.

1. INTRODUCTION

Environmental impact assessment (EIA) is an effective tool for conducting an assessment of the environmental impacts of various actions, projects, and investments [1]. It is the systematic evaluation of the impacts of human activities on the environment [2]. The environmental impact assessment supports the procedures to improve the environmental quality and provides technical support to prevent and eliminate the future environmental damages [3].

In light of the international requirements defined by Water Framework Directive (hereafter WFD) and the huge world demand for pure and potable water supply, the water quality assessment is a very important tool to follow the variations in water quality of Lakes. The aquatic environmental assessment method, water quality assessment technique, and outcome of the assessment could significantly contribute to provision of high-quality water from Lake Nasser and Lake Balaton and to monitor the water supply lines in Egypt and Hungary. Therefore, the aim of this research work was study and determine the water quality of Lake Nasser and Lake Balaton by applying the aquatic environmental assessment (AEA) method according to Egyptian Governmental Decree No. 92/2013 [4] in Lake Nasser and Hungarian National Water Framework Directive according to the Decree No. "10/2010 (VIII.18.) of VM" [5] in order to make recommendations for water quality improvement on the basis of conclusions of the study.

Methodology, which is deployed here in this study, uses 2010 version of Hungarian Decree and 2013 of Egyptian Decree and all threshold values are according to WFD 2010 standard. EIA studies comprise the mechanisms employed to assess the relation between human activities and their impact on environment, which aims the environmental protection, future improvement sand sustainable development [6]. EIA represents a package of the well-defined procedures, which requires a thorough discussion. Normally, it comprises the following major points: the project screening, scoping, consideration of alternatives, project actions, description of baseline conditions, impact identification, prediction of impacts, evaluation of significance, public consultation and negotiations with authorities [7] as well as review actions, recommendations on mitigation measures, decision-making and monitoring [8] . The aquatic environmental index (hereafter AEI) can provide excellent and quick information on the quality status of any given surface water body through analyzing and producing a quantity index (hereafter QI) of several water quality parameters as a single metric. Hence, AEI has a vital role in management and operations of measures to be taken, until the surface water quality of given water body reaches a good ecological status. Moreover, the quality of the aquatic environments has been incessantly deteriorating worldwide [9] requiring a continuous need for operational analysis and assessment of the methodological development, covering also the economic feasibility and the technological advancements, in order to keep the ecological status sustainably in good conditions [10]. AEI methodology was developed for calculating the environmental impact index by employing only physicochemical parameters of surface waters. AEI methodology is considered a quantitative EIA method, since the basic development procedures follow the weighting, standardization and congruence of water chemistry parameters [6]. Given the increasing pressure to quantitatively express the environmental impacts, the methods used were considered to be beneficial because they can compare different project alternatives. The multi-criteria decision-making method and Technique for Order Preference by Similarity Systems (TOPSIS) [11] can be further employed, as well as to support decision-making process. The application of various assessment techniques helps interpretation of complex data matrices to better understand water quality and ecological status of the studied systems. This allows identification of potential factors that influence aquatic environment systems and represents a valuable tool for a further reliable management of water resources [12]. The benefits of combining different methods are maximization of the advantages of these methods and avoidance of the inherent the differences between methods, by promoting the Sum of ranking differences (hereafter SRD), a novel statistical method that is rapidly becoming popular in various fields of applied science, such as analytical chemistry [13]. The SRD evaluation method was also used to explore the pharmacokinetic properties in pharmacology [14]. Using the SRD in the multi-objective analysis, the process of decision-making by scientists becomes the optimum solution in various fields of engineering [15].

Hence, the need for appropriate monitoring techniques to be implemented in order to check water quality on a regular basis is of primary importance. Among various types of pollutants, heavy metals are of major concern, given not only the wide array of compounds with multifaceted effects on lake ecosystems, but equally their various input pathways, such as the bedrock weathering, hydrodynamic processes and atmospheric deposition. The government administration of Aswan region (Aswan

Governorate) restricted severely use of agricultural fertilizers, discharge of household and industrial wastewater [16].

Heavy metals in aqueous solution do not always exhibit direct toxic effects on the environment; instead, they tend to bioaccumulate and to persist in the environment.

Moreover, these compounds are not biodegradable and cause detrimental effects on the environment and human health [17]. Several techniques were developed in time to assess heavy metal effects bound to sediments, such as the geological accumulation index [18], sediment enrichment agent, contamination factor and degree of contamination. Historically, the worldwide fish consumption increased directly with the interest in its nutritional value, mainly as a source of valuable proteins. Dietary guidelines in the United Kingdom recommend the consumption of fish and fish-based products at least twice a week to meet the daily requirements of polyunsaturated fatty acids [19]. Given that fish fill upper positions within aquatic food webs, the heavy metals can bioaccumulate in their biomass via food, water and sediments in significant amounts [20], with direct toxic effects to humans [21]. The human contamination with heavy metals via fish consumption leads sometimes to liver and kidney failures and cardiovascular diseases, to name just a few of the induced detrimental health effects. This led to the implementation of numerous international screening approaches with the aim of estimating the quality of fish meat, as well as to survey health of aquatic ecosystems [22]. Essential metals, such as zinc and copper fulfill important physiologic roles; however, their bioaccumulation beyond certain thresholds becomes highly toxic for humans. Non-essential metals, such as lead, cadmium and mercury are nonetheless extremely dangerous for both humans and environment [23]. These non-essential metals bioaccumulate in any given organism, leading to tissue damages, followed by a wide series of disorders and significant toxic effects along food webs. Heavy metals are non-biodegradable and once released in aquatic habitats, they are absorbed into sediment or accumulate in biota. Usually, the fish are more prone to accumulate significant amounts of heavy metals from water and food in various tissues [24]. Moreover, they absorb significant concentrations of heavy metals even when their amount in aqueous form is below the detection limit of routine chemical analyses [18]. Therefore, various fish organs represent important targets for properly assessing the health of the aquatic environment from this perspective. Accumulation rate of heavy metals such as lead, zinc, copper and cadmium in several tissues of the iconic fish Nile Tilapia (Oreochromis niloticus) from Lake Nasser was previously investigated [25] and

Bream (*Abramis brama* L.) from Lake Balaton which previously investigated [26]. The main findings of these studies were that these heavy metals are cycled within the lake ecosystem along with the energy and nutrients flows through food webs. However, most of these studies rather focused on one compound at a time, therefore precluding their synergic interactions within both the lake ecosystem and within fish tissues, despite a general acknowledgment of this information gap. Therefore, in the current study, we tried to fulfill this knowledge gap through a holistic investigation of the distribution of these heavy metals in water, sediment, and fish in Lake Nasser and Lake Balaton, as well as through assessing their accumulation rates in various fish organs. To understand the ecological risk related to heavy metal contamination, metal pollution index (MPI) has been calculated. MPI provides comprehensive information about the metal toxicity in a particular sample and offers an understanding of the quality of aquatic environment. The current study comprises a continuation of previous ecotoxicological investigations carried in Lake Nasser [27].

1.1 Scope and Aim

The purpose of the PhD work is to devise a quantitative type of water quality assessment method which could provide rapid, accurate, and reliable information on surface waters quality by using water parameters. The method is to be illustrated on Lake Balaton in Hungary and Lake Nasser in Egypt with special focus on physico-chemical parameters and heavy metals as special chemicals which defined by WFD. The goal of this work is to elaborate a method for the comprehensive evaluation of water parameters and to illustrate its usability on Lake Balaton and Lake Nasser. Therefore, the main aims of this thesis are as follows:

- The first goal of this study aimed to determine the location of the least and most polluted sites around the lakes and monitoring the water supply lines both in Egypt and in Hungary with special focus on Lake Nasser and Lake Balaton.
- Main objective in Lake Nasser with focus on physico-chemical parameters and heavy metals as special chemicals which defined by WFD.
- The second goal is to compare water quality indices of lake Nasser and Lake Balaton and to make recommendations how to further improve water quality.
- To investigate the effects of heavy metals bioaccumulation in aquatic ecosystem, via water, sediments and fish organs.

2. REVIEW OF LITERATURE

2.1 Characterization of Water Bodies

Water bodies can be described by the three main components: hydrology, physical chemistry, and biology. A complete assessment of water quality depends on appropriate monitoring of these components [28].

2.1.1 Hydrodynamic features

All freshwater bodies are interconnected through the hydrological cycle, from the atmosphere to the sea. The water thus forms a continuum of different phases ranging from rain water to marine salt water. It focuses on freshwater, which take place in rivers, lakes, or groundwater. These are closely related and can affect each other directly as well as indirectly. Each of these three main types of water body has different hydrodynamic properties.

Rivers have a unidirectional current with a relatively high average flow velocity of 0.1 to 1 m/sec. River flow varies greatly over time, depending on the climatic condition and drainage pattern. Generally, extensive and continuous vertical mixing is achieved in rivers due to the prevailing currents and turbulence. Lateral mixing may only occur at large distances downstream of major confluences.

Lakes are characterized by a low, average current velocity of 0.001 to 0.01 m/sec (surface values). Therefore, water or element residence times, ranging from one month to several hundreds of years, are often used to quantify mass movements of material. Currents within lakes are multi-directional. Many lakes have alternating periods of stratification and vertical mixing; the periodicity of which is regulated by climatic conditions and lake depth. Groundwaters are characterized by a rather steady flow pattern in terms of direction and velocity. The average flow velocities commonly found in aquifers range from 10^{-10} to 10^{-3} m/sec and are largely governed by the porosity and permeability of the geological material.

Reservoirs are characterized by intermediate features between rivers and lakes. They can range from large-sized reservoirs, such as Lake Nasser, to small dam rivers with a seasonal pattern of operation and fluctuations in water level closely related to river discharge, to fully constructed bodies of water with pumped inflows and outflows. The hydrodynamics of reservoirs is greatly influenced by their operational management system. Flood plains form an intermediate state between rivers and lakes with a distinct seasonal pattern of fluctuation. However, its hydrodynamics is determined by the river's flow regime. Marshes are characterized by the dual features of lakes and phreatic aquifers. Their hydrodynamics are relatively complex.

The hydrodynamic characteristics of each type of water body are highly dependent on the size of the water body and on the climatic conditions in the drainage basin. The governing factor for rivers is their hydrological regime, i.e. their discharge variability. Lakes are classified by their water residence time and their thermal regime resulting in varying stratification patterns. Although some reservoirs share many features in common with lakes, others have characteristics which are specific to the origin of the reservoir. One feature common to most reservoirs is the deliberate management of the inputs and/or outputs of water for specific purposes. Ground waters greatly depend upon their recharge regime, i.e. infiltration through the unsaturated aquifer zone, which allows for the renewal of the ground-water body.

2.1.2 Physical and chemical properties

Each freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer. Summary characteristics, such as total dissolved solids, conductivity and redox potential; provide a general classification of water bodies of a similar nature. Mineral content, determined by the total dissolved solids present, is an essential feature of the quality of any water body resulting from the balance between dissolution and precipitation. Oxygen content is another vital feature of any water body because it greatly influences the solubility of metals and is essential for all forms of biological life.

2.1.3 Biological characteristics

The development of biota (flora and fauna) in surface waters is governed by a variety of environmental conditions which determine the selection of species as well as the physiological performance of individual organisms. The primary production of organic matter, in the form of phytoplankton and macrophytes, is most intensive in lakes and reservoirs and usually more limited in rivers. The degradation of organic substances and the associated bacterial production can be a long-term process which can be important in groundwaters and deep lake waters which are not directly exposed to sunlight. In contrast to the chemical quality of water bodies, which can be measured by suitable analytical methods, the description of the biological quality of a water body is a combination of qualitative and quantitative characterization.

Biological monitoring can generally be carried out at two different levels: 1- the response of individual species to changes in their environment or, 2- the response of biological communities to changes in their environment. Water quality classification systems based upon biological characteristics have been developed for various water bodies. The chemical analysis of selected species (e.g. mussels and aquatic mosses) and/or selected body tissues (e.g. muscle or liver) for contaminants can be considered as a combination of chemical and biological monitoring. Biological quality, including the chemical analysis of biota, has a much longer time dimension than the chemical quality of the water since biota can be affected by chemical, and/or hydro-logical, events that may have lasted only a few days, some months or even years before the monitoring was carried out.

2.2 Water Framework Directive

European Water Framework Directive (2000/60/EC) aims at integrated water policy [29]. In 2000, it came into effect and is supposed to ensure consistent and clear water policy in the European member states by combining various earlier directives in the field of water (For instance, the Directive on the Required Quality of Surface Waters Prepared for the abstraction of Drinking Water in Member States (75/440/EEC) or the Directive on the Quality of Freshwaters Needing Protection or Improvement in order to Support the Life of Fish [30].

2.2.1 Introduction of the EU Water Framework Directive 2000/60/EC

The introduction of the WFD guidance was intended to facilitate the transition from these fragmented policies into a comprehensive approach that integrates all parts of the broader ecosystem [31]. With the advent of integrated watershed management in many countries around the world, the growing recognition of the multiple - often competing - uses of water, and the growing awareness of the interrelationships of water systems with other physical, socio-economic systems [32] formed the WFD's systemic intent.

WFD aims to usher in a new era of European water management, with an emphasis on understanding and integrating all aspects of the aquatic environment to be efficient and sustainable [33]. The Directive offers an integrated and coordinated approach to water management in Europe based on the river basin planning concept [34]. Recognizing that watersheds differ from each other in terms of both socio-political and natural conditions [35] it signified a shift toward watershed management and systems thinking. Consistent with systems theory that focuses on interactions and interdependence within a system that constitutes an efficient whole [36], it has required an understanding of the relationship between land and water under different socio-economic drivers in water resource management [37]. Furthermore, the Directive's requirements for public participation in its planning process address the inherent complexity of water resource management and create momentum for integrating multiple perspectives and skills for decentralized policy-making in freshwater management [38]. Through WFD Joint Implementation Strategy (CIS), an iterative process of interim goal setting and review based on learning [39], WFD has introduced an empirical approach to water management, providing much greater flexibility than previous guidance, and continuous opportunities for policy learning and adjustment [40] which leaves many options open to member states [41]. Unlike any other environmental directive that sets specific goals, it is clear that WFD is not goal-based legislation, the only notable exception being the WFD's explicit commitment not to subject water to class-to-class state deterioration [31]. Rather, it defines specific operational and technical implementation obligations for the EU member states that may lead to legal action being taken against them by EU Court of Justice [42]. Generally, WFD was regarded as the first European directive to focus on environmental sustainability [43] and it was seen as a potential model for future environmental regulation because of the introduction and innovations it created [44]. Within the first WFD cycle, which ran from 2009 to 2015, the number of water bodies in 'good' condition increased by only 10% [45]. With many reviews pointing out more flaws and weaknesses, the Directive has been a very effective policy tool [46].

2.2.2 The purpose of EU Water Framework Directive

European Water Framework Directive (2000/60/EC) was legislated to create a framework for the European water policy. Other important features are transnational management of river basins based on management plans, emission reduction of priority substances, degradation requirement in water bodies, extensive water control and cost recovery approach for all water services [47].

The purpose of the Directive was to establish a framework for the preservation of European waters in order for Member States to reach "good status" objectives for water bodies throughout EU.

The general objective of water bodies, both surface and ground water is to achieve a good status [47]. For surface water bodies, at least good environmental condition (or good ecological potential for artificial or highly modified bodies of water, respectively) must be achieved, and good status must be determined using reference conditions [48]. Inter-calibration procedures will ensure consistent requirements across all EU Member States [48], inter-calibration is planned among others to environmental quality standards For priority assets or reference extensions.

These efforts are based on a six-year cycle, whereby WFD environmental objectives provided that no deadline extension or exception was invoked. It had to be implemented by the EU member states into their national law [42].

The directive was adopted for success and to replace traditional management practices based on the command and control model, which considered stresses in isolation and reduction of ecosystems to their constituent elements when setting specific water targets. Under this approach, specific parameters at the point of discharge were monitored to control emissions of individual pollutants beyond established limits [49].

2.2.3 The combined approach

The combined approach in Water Framework Directive requires the member states to reduce pollution from point and diffuse sources by applying emission limits on the basis of best available techniques or best available controls.

For this purpose, each member state must specify significant impacts and pressures on water bodies [50]. WFD has developed a list of priority substances (2455/2001/EC), which are pollutants particularly hazardous to the environment and therefore more stringent of emission limits must be considered. Therefore, environmental quality standards must be intended by the member states of the European Union [51].

WFD includes the combined approach, meaning that emissions standards and environmental quality standards are valid and more stringently applied [52]. If the pollution reduction from emission limits is not sufficient to protect the specified receiving water (ie if the specified quality target or specified quality standards for the specified receiving water are exceeded) more stringent emission controls should be established. The combined approach of WFD does not allow for wastewater treatment requirements to be reduced below emissions limits even if the receiving water can handle the pollution. However, it should be noted that the EU Water Framework Directive is not European law but rather a guideline that member states have to adapt. Therefore, national water law may deviate [52].

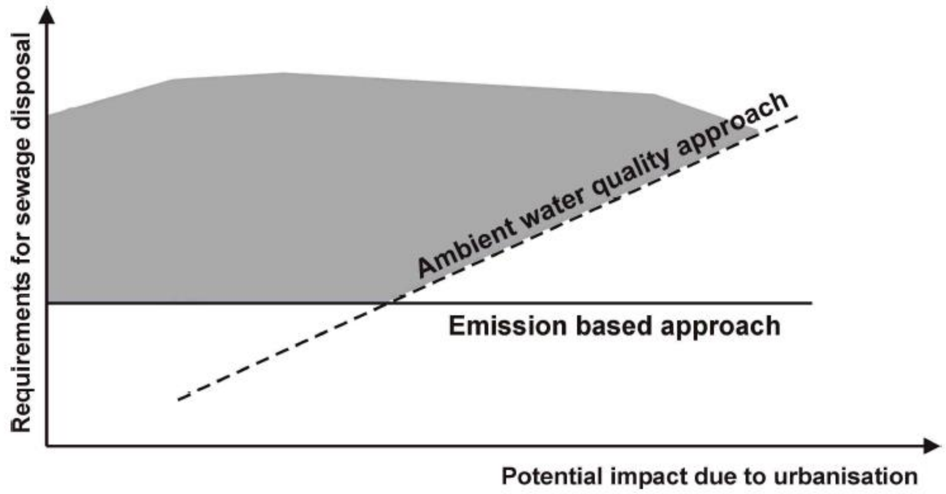


Fig.1. Illustration of the combined approach [52]

2.3 Classification of Surface Waters According to WFD

Characterization includes biological, hydromorphological, physico-chemical and chemical compounds related to biology and other chemical elements (Fig. 2). Based on biological quality elements and related hydromorphological and physico-chemical elements, the water body must be classified into five quality classes. Based on chemical elements (priority substances) the water body must be classified into two classes; it gives the chemical status [53]. The chemical and biological status together gives the status of the water body [54] [55].

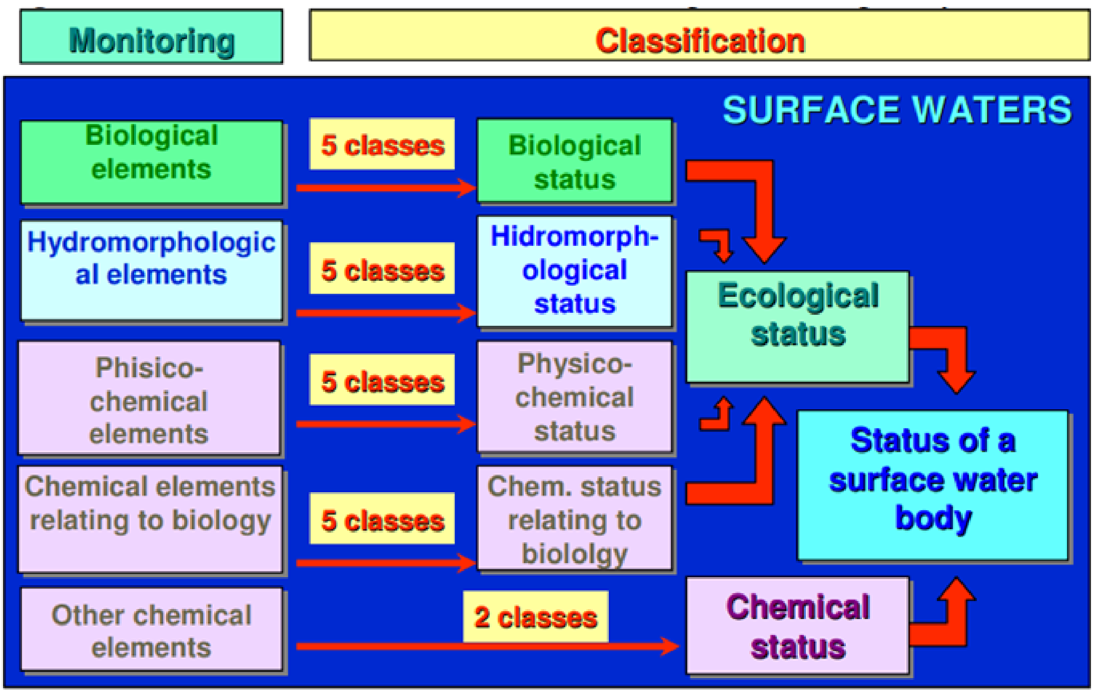


Fig.2. Classification of surface waters according to WFD [56]

The classification is based on Environmental Quality Ratio (EQR) values. The EQR is calculated by dividing the measured value by the type-specific reference value. It results a number between 0 and 1, where 1 shows excellent quality, 0 means bad quality (Fig. 3) [56]. Width of the five EQR classes can be either equal or different depending on how the given parameter influences the change in water quality. Terminology and colour coding [34].

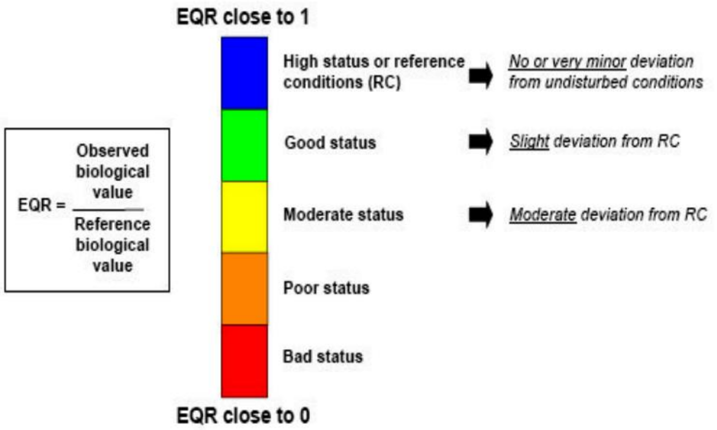


Fig. 3. Principle of classification of ecological status based on ecological quality and its visualization [56]

2.3.1 Ecological protection

For this reason, a general requirement for ecological protection, and a general minimum chemical standard, was introduced to cover all surface waters. These are the two elements "good ecological status" and "good chemical status". Good ecological status is of the Water Framework Proposal, in terms of the quality of the biological community, the hydrological characteristics and the chemical characteristics (fig. 4). As no absolute standards for biological quality can be set which apply across the Community, because of ecological variability, the controls are specified as allowing only a slight departure from the biological community which would be expected in conditions of minimal anthropogenic impact. A set of procedures for identifying that point for a given body of water, and establishing particular chemical or hydromorphological standards to achieve it, is provided, together with a system for ensuring that each Member State interprets the procedure in a consistent way (to ensure comparability). The system is somewhat complicated, but this is inevitable given the extent of ecological variability, and the large number of parameters, which must be dealt with.

2.3.2 Chemical protection

Good chemical status is defined in terms of compliance with all the quality standards established for chemical substances at European level. The Directive also provides a mechanism for renewing these standards and establishing new ones by means of a prioritisation mechanism for hazardous chemicals. This will ensure at least a minimum chemical quality, particularly in relation to very toxic substances, everywhere in the Community. Good chemical status means that no concentrations of priority substances exceed the relevant EQS established in the Environmental Quality Standards Directive (EQS)- 2008/105/EC.

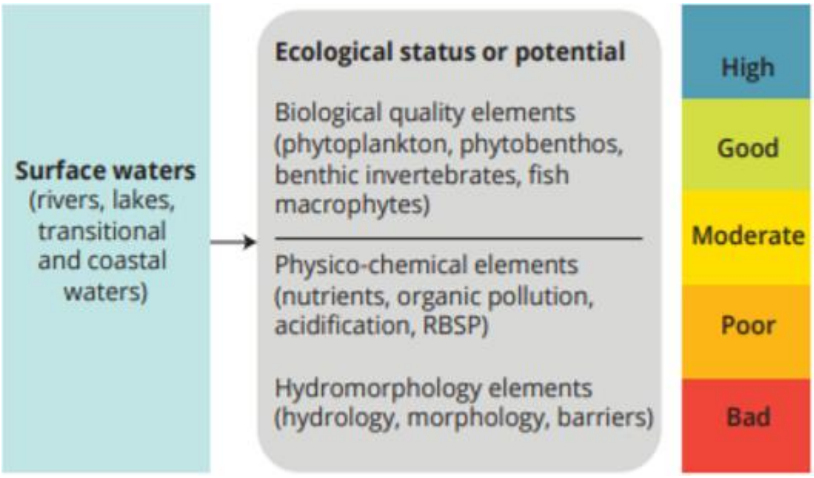


Fig. 4 Ecological status of surface water [57]

2.4 Water Quality Assessment Process

Water quality assessment is the overall process of evaluation of the physical, chemical and biological nature of the water, whereas water quality monitoring is the collection of the relevant information.

2.4.1. Monitoring, survey and surveillance

The usual aim of a water quality management program is to maintain water quality such that none of the designated uses are adversely affected in the short and long term [58]. The main reason for the assessment of the quality of the aquatic environment has been, traditionally, the need to verify whether the observed water quality is suitable for intended uses. The use of monitoring has also evolved to help determine trends in the quality of the aquatic environment and how that quality is affected by the release of contaminants, other anthropogenic activities, and/or by waste treatment operations (impact monitoring). More recently monitoring has been carried out to estimate nutrient

or pollutant fluxes discharged by rivers or groundwaters to lakes and oceans, or across international boundaries [59]. Monitoring to determine the background quality of the aquatic environment is also now widely carried out, as it provides a means of comparison with impact monitoring. It is also used simply to check whether any unexpected change is occurring in otherwise pristine conditions, for example, through the long range transport of atmospheric pollutants (note, however, that natural water quality is very variable depending on local conditions).
This implies that water quality assessment has: (a) a planning function (systems understanding); (b) a regulatory function (surveillance monitoring program). The planning function requires an understanding of the water system to be managed. This will include what is to be protected, system variability, determination of the consequences of various types and intensities of use (cause-effect). Planning should also be predictive in that the information gained allows the anticipation of potential problems. The regulatory function or surveillance monitoring is used to correct errors in predictions and is reactive in the sense that action can be taken if management objectives, strategies or standards are not being met. To gain the information to fulfill these roles water quality assessment programs usually take the form of surveys, surveillance or monitoring [60] as the following phases: (1) monitoring; measurement and observation of the aquatic environment in order to define status and trends, (2) Survey; an intensive program to measure and observe the quality of the aquatic environment for a specific purpose within a short period of time and (3) surveillance; continuous, specific measurement and observation program for the purpose of water quality management and operational activities [61].

Monitoring, survey and surveillance are all based on data collection. Data are principally collected at given geographical locations in the water. Water quality variables are often described by the longitude and latitude of the sampling or measurement site (x and y co-ordinates) and further characterized by the depth at which the sample is taken (vertical coordinate z). Monitoring data must also be characterized and recorded with regard to the time (t) at which the sample is taken or the in situ measurement made. Thus any physical, chemical or biological variable will be measured as a concentration (c), or number, which is a function of the above parameters: $c = f(x,y,z,t)$. In rivers, the flux determination and the data interpretation also require the knowledge of water discharge Q, thus: $c = f(x,y,z,t,Q)$. Monitoring data must, therefore, provide a clear determination of these parameters in order to be used for data interpretation and water quality assessments [62]. System understanding programs will have broad objectives. Bioindicators may be used to gain an understanding of the structure and function of communities to establish what needs to be protected, and to determine the fate, or action, of potentially hazardous substances. Toxicity testing is used to evaluate the potential effects of discharges on ecosystems and to set standards, or criteria. Usually monitoring has narrowly defined or limited objectives with bioindicators used to warn of pollutant impact, to measure the bio-available portion of an input over time or to detect an intermittent pollutant input. t is essential that planners of assessment programs using bioindicators realize that the objectives of survey, surveillance and monitoring listed above are separate from each other. Bioindicators can be used to achieve each of these objectives but the design of the assessment program will be different for each of the study types [63].

2.4.2 Objectives of water quality assessment

Each level of the WFD's three-level monitoring system serves a different aim. The aim of surveillance monitoring is to characterize the water bodies, validate risk assessments and registration of long-term ecological changes of water bodies. In the operation of surveillance monitoring, all water bodies must be investigated at least in every six years, over one year observation period for the given components. The aim of investigative monitoring is to clarify the unknown reasons of water quality degradation of water bodies, and to study the impact of accidental pollution. Operational monitoring serves to determine magnitude of impacts and control the effect of quality improving programs in water bodies identified as being at risk of failing to meet environmental objectives [64].

2.5 Water Framework Monitoring System

The WFD prescribes the minimum measuring frequency of quality elements, whereas prescribes, that the classification must be based on the typical status of water body and the reliability of classification [65]. Monitoring programmes are required to establish a coherent and comprehensive overview of water status.

2.6 Water Pollution Control Programs

The Department’s approach and associated programs designed to protect, maintain, enhance, and restore water quality and to ensure the protection of ecological and public health in all waters of the States. This overarching goal serves as the foundation for the Department's water quality management programs.

2.7. Description of the Studied Lakes

2.7.1 Lake Nasser

Lake Nasser is one of the largest man-made lakes on earth. It has a vital importance to Egypt for several decades because of the safe water supply of the country [27]. Lake Nasser was generated by the construction of Aswan High Dam between January 1964 and June 1968 [66]. The area of the lake is about 5000 km^2 [67]. The lake has a high-water storage capacity of 150–165 km^3 providing a maximum water flow of 11,000 m^3 /s. The mean depth of Lake Nasser is 90 m [68] [69] and the maximum width of the lake is about 60 km [70]. Eastern Desert is the east border of the lake, which contains many precious mineral resources including metals and is bordered on the west by the Western Desert, which contains deposits, limestone, agricultural lands, and archeological sites [71] [72].

2.7.2 Lake Balaton

Lake Balaton (northern latitude 46˚ 71´ and 47˚ 01´ and the eastern longitudes 17◦ 24´ and 18˚ 16´, 104.84 m altitude) is the largest shallow lake in Central Europe. It is connected to Danube River via Sió channel and is situated in the western part of Hungary [73], covers a surface of 596 km^2, a volume of 1.9 x109 m^3, has an average depth of 3.25 m [74] and represents one of the main touristic attractions and recreational spa [75]; [76]. For the ease of national surface water management, the Hungarian government has divided four main watershed regions that are River Danube, River Drava, River Tisza, and Lake Balaton. The Hungarian National Water Framework Directive recognises 16 different types of water bodies; Lake Balaton belongs to the Typology 16 according to the Decree No. ''10/2010 (VIII.18.) of VM" [77].

3. MATERIALS AND METHODS

3.1 Physicochemical Parameters

Water parameters were measured according to the stipulations of American Public Health Association [78],[79] and [80] based on standards of Hungary [77], which is in harmony with Water Framework Directive of European Union [54]. Water samples were analyzed for the following water chemistry parameters at site: turbidity (NTU), pH measurements, electrical conductivity, and dissolved oxygen content. Measuring device of pH was a glass electrode pH meter (Orion model 601/digital ion analyzer); electrical conductivity (EC) was measured using Amber Science Inc., San Diego, conductivity meter, model 1062; and dissolved oxygen content (DO) was determined by Winkler titration method [79]. Water samples (3 L from each site) were taken and transferred directly into an ice box, and a predefined volume of water was filtered through glass microfiber filter (GF/F, 0.45-μm membrane), and the samples were refrigerated till further analyses. The following water chemistry parameters were measured at the laboratory according to APHA standard methods [78][79] and [80], BOD_5 [80], COD was determined by potassium dichromate open reflex method [80]. Ammonium-nitrogen content was measured according to [81]. Nitrate and phosphate content [82], total suspended solids [83]. Fecal coliform (FC) following the Standard Procedures for Water Analysis sections 9221B and 9221E [84]. Three parallel samples were taken from each measuring point for all parameters. The average values of the parallel measurements were used for the evaluation.

3.1.1 Sampling strategy

3.1.1.1 Lake Nasser

Water samples of Lake Nasser were taken by a 1.5 dm^3 Ruttner sampler. The measurements within the present study were conducted at nine measuring points alongside the Lake (Fig. 5). Fourteen water chemical parameters were measured (Table 1).

The measurements were carried out in April–May, 2018, and water samples were taken from 1m depth along the main channel of Lake Nasser (Fig.5). The exclusive water source of the lake is River Nile inflow from the south, with water yield 70 km^3/year [85].

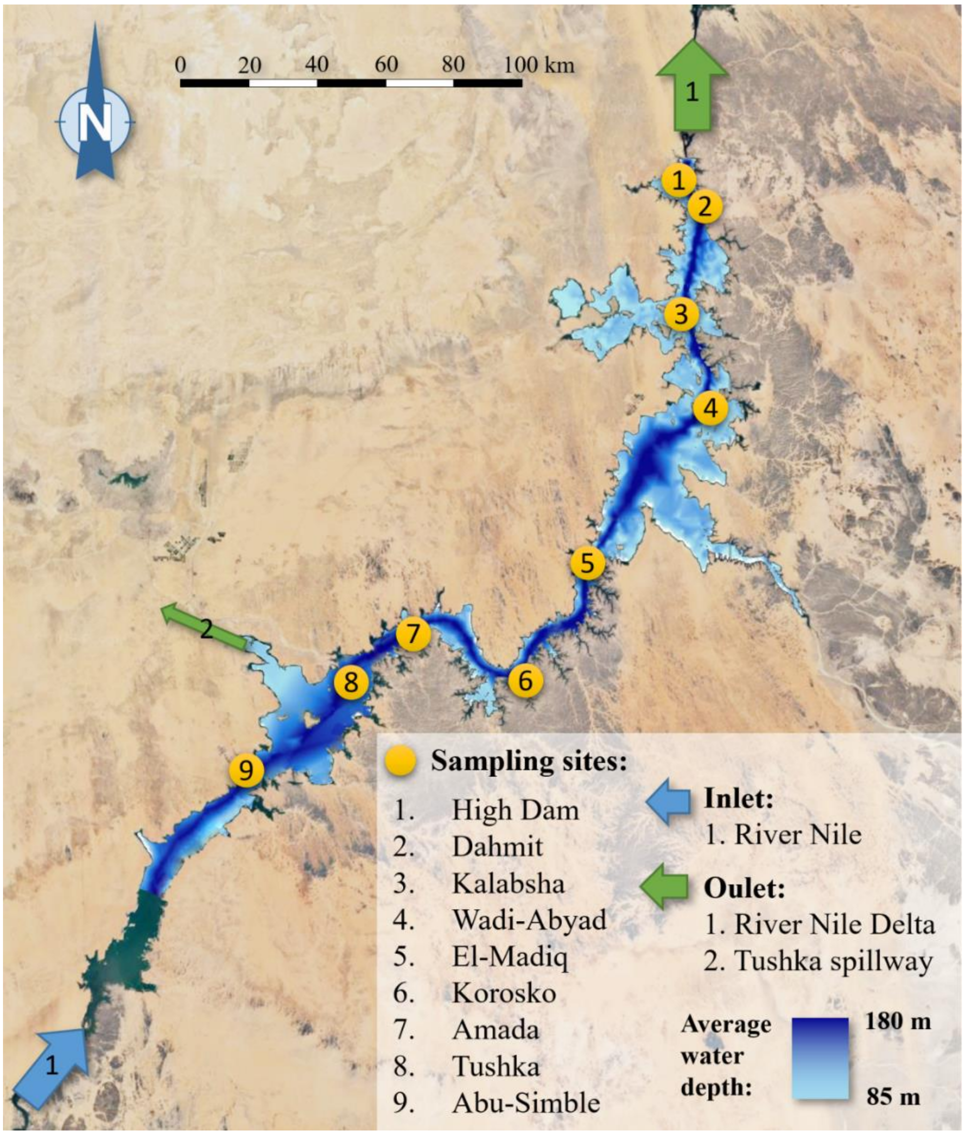


Fig. 5 Sampling sites and main water supplies/inlets and discharge/outlet points of Lake Nasser

3.1.1.2 Lake Balaton

There are 25 rivers and 17 stagnant water types in Hungary. Lake Balaton is characterized as open water surface of large area having moderate depth of 3.25 m and lime-water type. Water samples were from 15 sites taken along Lake Balaton, in September 2018 (Fig. 6). Water samples were taken at a depth of half a meter and 70 m distance from shores, excepting those that did not had access from beach and required the use of an engine boat.

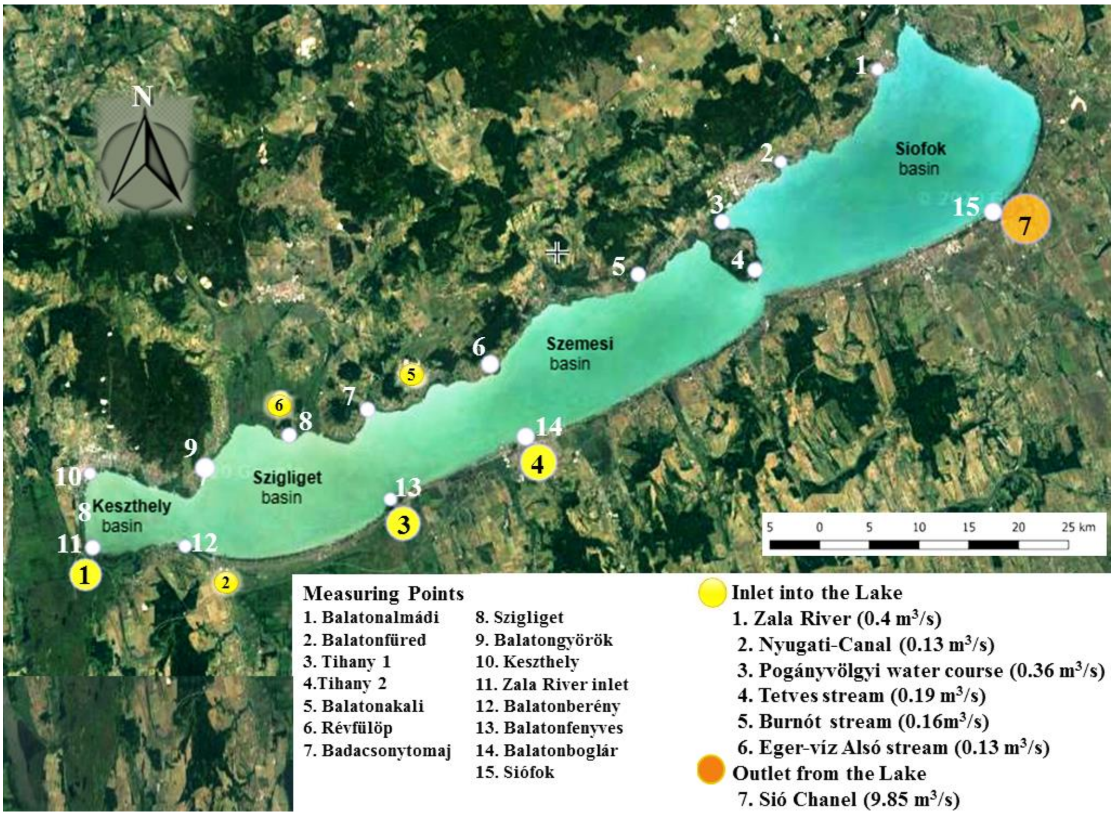


Fig. 6 Measuring points and main water supplies/inlets and discharge/outlet points of Lake Balaton

3.1.2 Methodology

3.1.2.1 Aquatic environmental index

Five water quality classes and categories were used during the assessment of AEI. The legal limit values for water parameters were determined from the pertaining specifications used for the quality categorization of water parameters according to Egyptian Governmental Decree No. 92/2013 [4] and Lake Balaton which belongs to the Typology 16 according to the Decree No. ‘‘10/2010 (VIII.18.) of VM” [77]. The methodology, which is deployed in Lake Balaton, uses the 2010 version of Hungarian Decree and the entire threshold values are according to 2010 standard which is in harmony with Water Framework Directive of European Union [54].

3.1.2.2 Technique for Order Preference by Similarity to Ideal Solution Method

TOPSIS method used in several cases and it is one of multiple criteria decision-making methods (MCDM). TOPSIS procedure is based on an initiative and simple idea that maximize the benefit. TOPSIS is a classical technique developed by [86]. In TOPSIS technique, basic solution method is defining positive and negative ideal (non-ideal) solutions [87]. The positive ideal solution includes the best available value of parameters, while the non-ideal one is made of the worst available value of parameters. Finally, the best answer has both the shortest distance from the ideal solution and the longest from the non-ideal [88]. Simplicity, rationality, comprehensibility, good computational efficiency, and ability are the advantages of TOPSIS methods [89].

The ideal solutions are not probable, and each alternative solution has some intermediate ranking between the ideal solution and the worst solution [90]. Regardless of the absolute accuracy of rankings, the comparison of several different solutions under the same set of selection criteria allows an accurate weighting of relative solution suitability and hence an optimal solution selection. TOPSIS method was applied to determine which sampling point is more or less polluted.

3.1.2.3 Simple Additive Weighting method

Simple Additive Weighting (SAW), also known as the weighted and simple weighted scoring method. This is commonly used for multiple decisions attribute (MADM) tools. The basic concept of SAW method is to find the weighted sum of performance ratings on each alternative on all attributes. SAW method requires the process of normalizing the decision matrix to a scale comparable to all existing alternative ratings [91].

3.2 Heavy Metal Contamination as Specific Pollutant

3.2.1 Lake Nasser

3.2.1.1 Study area

Six sites were selected within the main channel of Lake Nasser for water sampling, fish catching and sediment collection, starting from site Abu-Simbel (1) in the south, followed by Armina (2), Tushka (3), Korosko (4), Kalabsha (5) and High Dam site (6) situated in the northern part of the lake (Fig. 7).

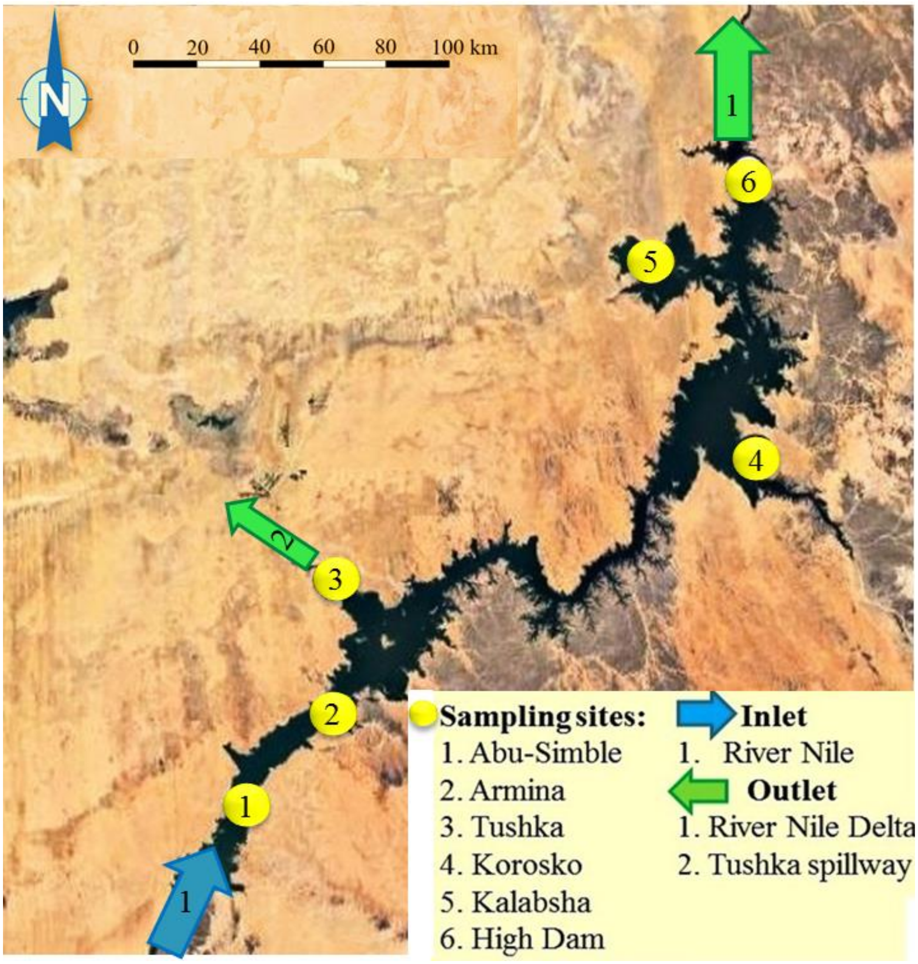


Fig. 7 Sampling sites and main water supplies/inlets and discharge/outlet points of Lake Nasser

3.2.1.2 Sampling procedures

3.2.1.2.1 Water samples

Water samples were collected in polyethylene bottles (2 L) [92]. The samples were acidified with nitric acid to prevent organic matter alteration by bacterial activity and transferred in an ice-box to the laboratory.

3.2.1.2.2 Sediment samples

Three replicates of sediments were collected with the aid of an electronic vibrational core sampler tube (vibracorers), which enables sampling efficiently to a depth of eight meters [93]. Following the packing of sediment samples in polythene bags and chilled in an ice box, they were transported to the laboratory for further analysis. The samples were dried overnight at 105°C to constant weight for heavy metal analysis.

3.2.1.2.3 Fish samples

Nile Tilapia (*Oreochromis niloticus* L.) is a native fish species to Egypt and one of the most common fish used in the Egyptian cuisine and in fisheries in Aswan governorate. A total of 30 individuals were collected by local fisherman in March 2019.

3.2.1.3 Sample preparation

3.2.1.3.1 Water samples

The concentration of heavy metals in water samples was measured according to APHA [78] standards, with the aid of an Atomic Absorption Spectrophotometer (AAS).

3.2.1.3.2 Sediment samples

The digestion of sediment was performed based on USEPA [94]. Fifteen mL of concentrated HNO_3, HF and $HClO_4$ were mixed into a Teflon beaker with 0.5 g of sediment. The samples were sealed afterwards with a lid and kept for 3 h at room temperature, then evaporated until they turned into a liquid solution. Following that, 5 mL of $HClO_4$ was added and vaporized to drought. Concentrated HCl (10 mL) was added to samples and placed back on a hot plate until the solution became clear. Then, it was filtered and supplemented with deionized water up to 100 mL in a volumetric flask.

3.2.1.3.3 Fish samples

Various fish organs were extracted through dissection. Muscle and liver organs were removed and their preparation for the measurement of heavy metals was carried according to [95]. Therefore Cd, Cu, Pb and Zn contents were measured according to Krishnamurty [96]. First, the samples were dried and then digested on steam bath at approximately 80 °C for 3 h, followed by addition of 14 mL of concentrated HNO_3 and 7 ml of 30 % H_2O_2, in this order. All samples were diluted to 50 mL with ultra-distilled water and stored in polyethylene containers at room temperature until further measurements.

3.2.1.4 Atomic Absorption Spectroscopic Measurement

Heavy metal concentrations were measured with the aid of an AAS (Model ICE series 3000 AAS) with a GF 5000 graphite furnace in water, sediment and fish samples. In case of fish samples, the precision of the analytical procedure was checked by using standard reference materials (dogfish muscle (DORM 4) and liver (DOLT 5) Canadian Research Council) in five replicates. The precision of analysis was calculated according to Farkas et al. [97].

3.2.1.5 Metal pollution index (MPI)

To assess the metal pollution, metal pollution index (MPI) was used according to (Abdel-Khalek et al., 2016) using the following equation:

$$MPI = (CM_1 \times CM_2 \times CM_3 \times \ldots \ldots . \times CM_n)^{1/n} \qquad (1)$$

Where, CM_1 is the concentration value of first concerned metal, CM_2 is the concentration value of second concerned metal, CM_3 is the concentration of third concerned metal and CM_n is the concentration of n_{th} metal (mg/kg dry wt) in the tissue sample of a certain samples.

3.2.1.6 Evaluation model of heavy metals

In this study, a comprehensive evaluation method was used to evaluate the correlation between the contamination with heavy metals and sample types (i.e., water, sediment, liver and muscles) of investigated items. The main evaluation indexes included the coefficient of determination (R^2), and Pearson correlation coefficient (Corr).

3.2.2 Lake Balaton

3.2.2.1 Study area

Four sites were selected within Lake Balaton for water sampling and fish catching starting from Keszthely site in Western Basin, followed by Tihany, Balatonfüred and Balatonalmádi situated in the eastern Basin (Fig. 8).

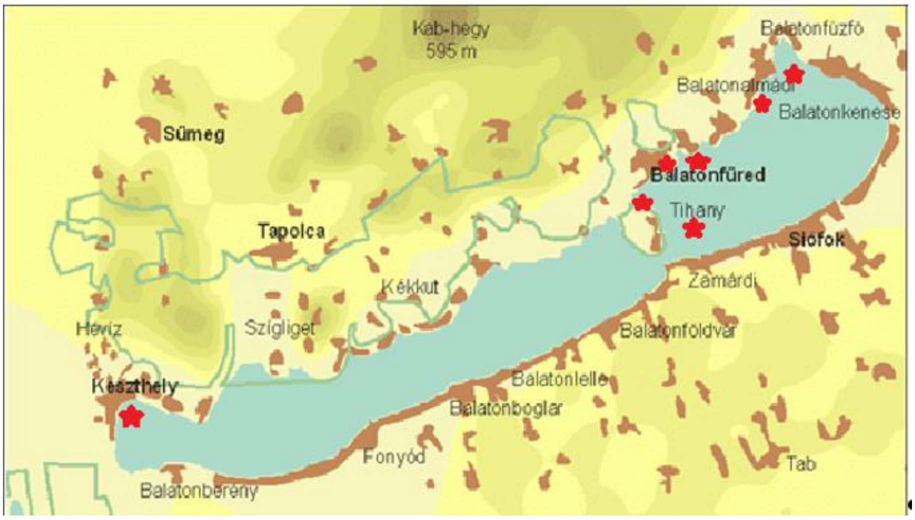


Fig. 8 sampling sites of Lake Balaton

3.2.2.2 Samples procedures and preparation

Water and fish samples were collected and prepared in the same steps described in Lake Nasser part. Fish type collected was Bream (*Abramis brama* L.) in three different years (2013, 2019, and 2021).

3.2.3 Evaluation model for heavy metals in Lake Balaton

Data were expressed as mean ± SE. Differences among data were assessed statistically by one-way analysis of variance (ANOVA) as sources of variation. A multiple f-test was used to determine significance among means for significant main effects. The level of significance was set at ($p < 0.05$) with a confidence level of 95%.

4. RESULTS AND DISCUSSIONS

4.1 Physicochemical Parameters

4.1.1 Lake Nasser

The measured results of water chemistry parameters for Lake Nasser were given in Table 1 on basis of analyses has been carried out at nine measurement sites.

4.1.1.1 Aquatic environmental index

Aquatic environmental assessment method has been illustrated in detail for measurement site no. 1. The assessments were carried out according to Egyptian Governmental Decree No. 92/2013 [4]. The measured water chemistry parameters for the nine sampling sites on Lake Nasser and the limit values of Egyptian Governmental Decree No. 92/2013 [4] are summarized in Table 1.

Table 1. Measured water chemistry parameters of Nasser Lake and their limit values according to Egyptian Governmental Decree No. 92/2013

Parameter	Measuring points/sites									
	1 High Dam	**2 Dahmit**	**3 Kalabsha**	**4 Wadi-Abyad**	**5 El-Madiq**	**6 Korosko**	**7 Amada**	**8 Tushka**	**9 Abu-Simble**	***Limit value (Governmental Decree No. 92/2013)***
Chl-a (µg/L)	11.00	10.80	11.30	13.00	9.85	10.00	9.00	11.90	9.80	16.60
pH	7.66	7.97	8.32	7.84	7.80	7.90	7.81	7.83	7.87	10.00
NTU	8.00	7.80	10.00	10.80	6.00	5.60	6.00	5.00	5.00	25.00
EC (µs/ cm)	250	250	250	245	240	232	230	230	235	1000
DO (mg/ L)	4.50	5.20	5.00	4.50	5.40	5.20	4.90	6.30	6.70	6.66
COD (mg/ L)	8.70	7.80	8.55	11.00	7.60	7.60	8.00	6.00	6.50	10.00
BOD_5 (mg / L)	1.37	1.20	1.40	1.90	0.90	0.90	1.80	1.50	1.00	6.00
NH_4 (µg /L)	10.00	7.00	8.00	10.00	6.00	7.00	10.00	5.00	5.00	330
NO_3 (µg /L)	2000	2000	2200	2000	1900	1900	1900	2100	1600	2000
NO_2 (µg /L)	12.00	10.00	10.00	10.00	13.00	12.00	13.00	5.00	5.00	20.00
PO_4 (µg /L)	220	170	160	280	100	70.0	200	220	90.0	500
TP (µg/ L)	400	390	430	470	340	350	420	430	291	2000
TSS (mg/L)	17	17	18	18	16	16	17	18	16	50
Fecal coliform (no./100 mL)	30	25	30	28	15	25	28	40	15	200

The legal limit values for water and the ranking of water quality into five quality classes/categories according to the measured figures and specifications has been included in Table 2. The blue highlighted boxes indicate the classes/categories in which the actual measured water chemistry parameters can be assigned. The ranking is illustrated based on measurement results of High Dam site as shown in Table 2.

Table 2 Measured values of water chemistry parameters at Aswan High Dam No. 1 site. The blue figures indicate the categories into which the measurement results fall according to Egyptian Governmental Decree No. 92/2013

Parameter	Measured value	Quality classes (QC*i*) and categories				
		I. Bad	II. Weak	III. Proper	IV. Good	V. Excellent
Chl-a (µg/L)	11.00	>25	25	16.6	13.3	<10.00
pH	7.66	>11	11	10	9	8-7
NTU	8	>50	50	25	10	5
EC (µs/ cm)	250	>1500	1500	1000	800	<600
DO (mg/ L)	4.50	<4.00	5.30	6.66	7.51	>10.00
COD (mg/ L)	8.70	>15.00	15.00	10.00	8.00	<6.00
BOD_5 (mg /L)	1.37	>9.12	9.12	6.00	4.80	>3.60
NH_4 (µg /L)	10	<500	500	330	260	>190
NO_3 (µg /L	2000	>3000	3000	2000	1600	<1200
NO_2 (µg /L)	12	>50	30	20	10	<10
PO_4 (µg /L)	220	>750	750	500	400	<300
TP (µg/ L)	400	>300	300	200	1600	1200
TSS (mg/L)	17	>100	100	50	20	10
Fecal coliform (no./100 ml)	30	>304	304	200	160	>120

Chlorophyll-a value (11µg/L) was categorized to quality class IV at High Dam, site No.1 which is equivalent to quality category "good" since the measured concentration is below 13.3 µg/L according to Egyptian

Governmental Decree No. 92/2013 [4]. pH was ranked to quality category "excellent" according to Egyptian governmental decree [4] regarding measured value of 7.66. Turbidity category was excellent with recorded value below 10 NTU. Nonetheless, it was good based on Egyptian Governmental Decree No. 92/2013. Because it was below 6 mg/L, the DO category was weak. DO category was "weak" because it was below 6 mg/L comparing to Egyptian Governmental Decree No. 92/2013.

Total phosphorus value (0.40 mg/L) has been assigned into the excellent category (Table 2). Ranking of water chemistry parameters can be accomplished in the above-mentioned way with using the interval confine values for the different categories.

The individual "weights indices" (WI) for water chemistry parameters are summarized in Table 3. If water chemistry parameters show resembling results, then environmental mitigation actions should be planned according to the weight indices. (Fig. 3, axis x).

Using Eq. 2 the distance/deviation values were determined for all 14 water chemistry parameters and for all measurement sites as given as follows:

$$Q_{Di} = \frac{(C_{Mi} - C_{Lvi})}{C_{Lvi}} \times 100 \qquad (2)$$

Where: QDi is the deviation of the measured water chemistry parameter i from the legal limit value for parameter i (%), C_{Lvi} is limit value of water chemistry parameter i and CMi is the measured value of water chemistry parameter i.

Water chemistry parameter Deviation of DO from the legal limit value can be given as follows:

$$Q_{DDO\ (\text{High Dam})} = \frac{(6.66 - 4.5)}{4.5} \times 100 = 32\ \%$$

The parametric level analysis of water chemistry parameters (Fig. 9). On axis y the distance/deviation of water chemistry parameter from the limit value (hereinafter referred to as distance/deviation) is plotted in the function of the weight indices.

If deviation is positive like DO, it means that water chemistry parameter considered doesn't meet the legal specification.

The aquatic environmental index (Table 4) was calculated according to Eq. 3.

$$AEI = \frac{\sum_{i}^{n}= QC_i \times WI_i}{n} \quad (3)$$

Where: AEI is the aquatic environment index; QC_i is the quality class for water chemistry parameter i (2.); WIi is weight index for water chemistry parameter i (Table 3); n is number of water chemistry parameters used in the study.

Table 3 The weight indices (WI) of water chemistry parameters of Lake Nasser

No.	Parameter	WI
1	Chl-a (µg/L)	3.82
2	pH	2.24
3	NTU	4.05
4	EC (µs/ cm)	4.42
5	DO (mg/L)	7.32
6	COD (mg/L)	5.22
7	BOD_5 (mg /L)	6.73
8	NH_4 (µg /L)	9.75
9	NO_3 (µg /L)	12.64
10	NO_2 (µg /L)	8.51
11	PO_4 (µg /L)	8.82
12	TP (µg/L)	11.42
13	TSS (mg/L)	8.23
14	Fecal choliform (No./100 ml)	6.83

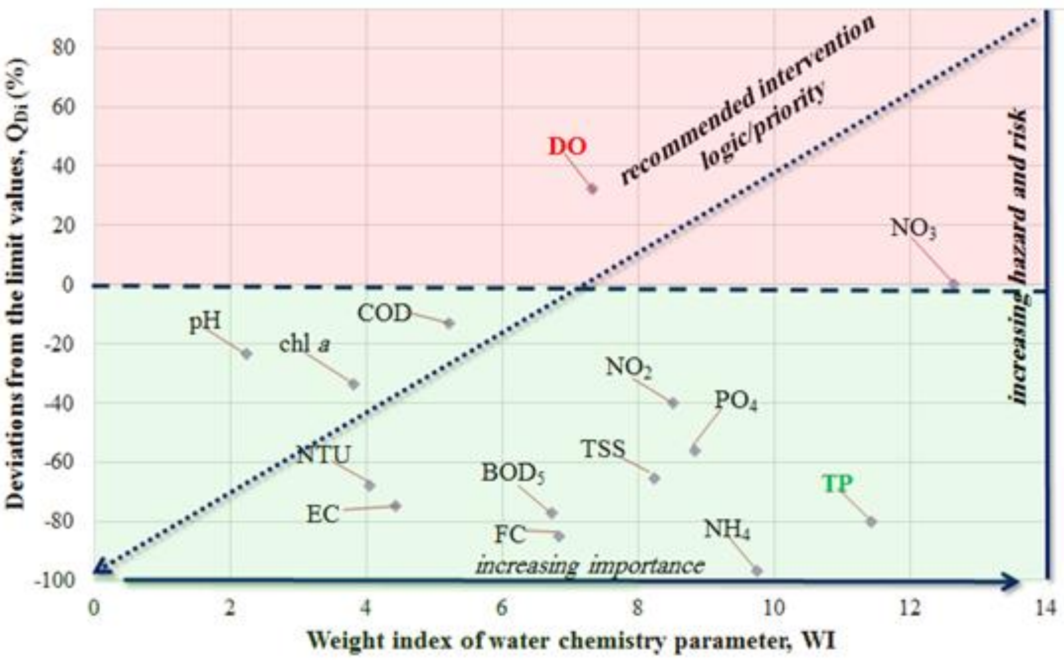


Fig. 9 Deviation of water chemistry parameters from the limit values in function of the weight indices for Aswan High Dam site based on Egyptian Governmental Decree No. 92/2013

AEI values calculations has been summarized in Table 4. which summarized the interpretation of AEI values and those were related to different water quality categories (excellent, good, proper, weak and bad).

Table 4 AEI values for the measured points of Lake Nasser

Number	Measuring point	Egyptian GD No. 92/2013	
		AEI value	Quality description
1.	Aswan High Dam	30.44	Good
2.	Dahmit	30.82	Good
3.	Kalabsha	29.38	Good
4.	Wadi-Abyad	30.15	Good
5.	El-Madiq	32.52	Excellent
6.	Korosko	31.09	Good
7.	Amada	31.98	Good
8.	Tushka	31.10	Good
9.	Abu-Simble	32.80	Excellent

Substitution method was used for determination of the mean AEI values and AEI intervals (Table 5). Low and top limit values of the intervals were determined by the mathematical averaging of the neighboring AEI figures. For example; (7.14+14.29)/2=10.71). In this way, the top figure of bad interval is equal to 10.71. Fig. 9 shows the deviations of water chemistry parameters from the limit values expressed in percentage for the nine measurement sites of Lake Nasser.

The highest distances/deviations were marked by red color and represented the most disadvantageous situation (Fig. 10). Water quality was influenced mostly by dissolved oxygen, COD and nitrate content (Fig. 10). Dissolved oxygen data was higher than the limit values in case of most measurement points, so it was defined as a highly important parameter due to the hot climate of Upper Egypt. The interpretation of the parameters has been discussed in the literature [6].

Table 5 Evaluation categories for the quality classes

Category	Mean AEI value	AEI interval
Bad	7.14	10.71 ≤ AEI
Weak	14.29	10.71 ≤ AEI < 17.86
Proper	21.43	17.86≤ AEI < 25.00
Good	28.57	25.00≤ AEI < 32.14
Excellent	35.71	32.14 ≤ AEI

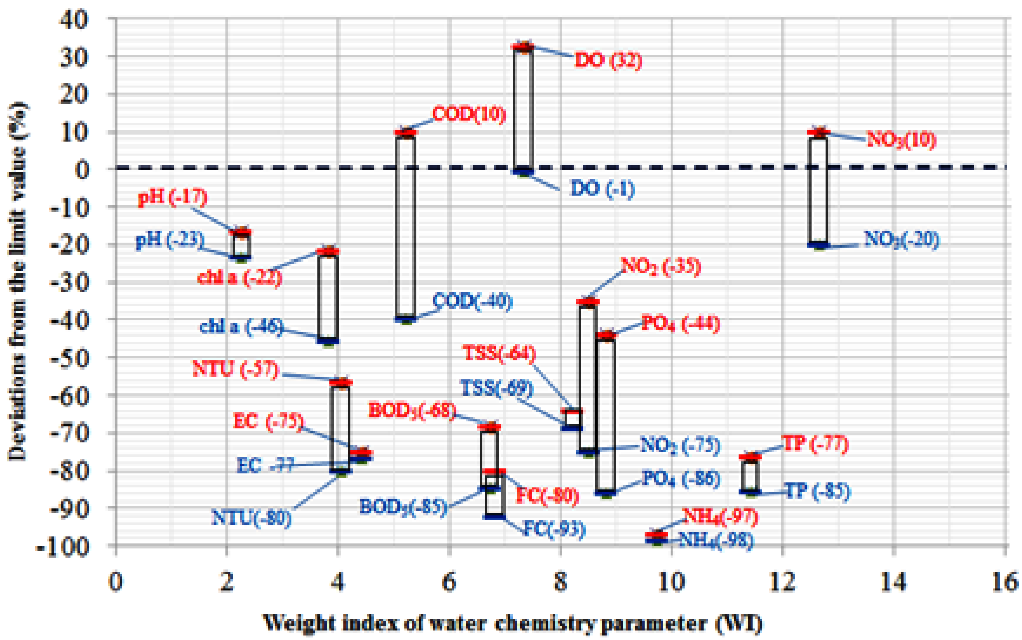


Fig. 10 Deviations of water chemistry parameters from the limit values, Q_{Di}, based on Egyptian Governmental Decree No. 92/2013 in function of weight index, where blue and red colors are best and worst values of the parameters, respectively

It can be seen that the water quality of Lake Nasser is influenced mostly by dissolved oxygen content and nutrient concentrations according to the Egyptian Governmental Decree No. 92/2013 [4]. The phosphorus content, nitrite and nitrate content are very important due to their high eutrophication potential. For the achievement of significant improvement in water quality of Lake Nasser, the concentrations of nitrate intake should be decreased. From the point of view of the other water chemistry parameters, water quality of the lake can be qualified as "proper", "good" or "excellent". The blue colored dashed line in Fig. 4 represented the concentration identical to the limit value. The points above the dashed line do not meet the environmental specifications. As seen in Fig. 10. NO_3 contents were above the limit values in case of two measurement points (Kalabsha and Tushka).

Water quality status exhibited "good" at seven sampling sites (High Dam, Dahmit, Kalabsha, Wadi-Abyad, Korosko, Amada and Tushka) and exhibited "excellent" water quality at two sampling sites (El-Madiq and Abu-Simble regions). Lake Nasser maps were prepared on the basis of Google maps available in Quantum GIS software to support the visualization of AEI results. The measured values (in case of AEI, the calculated values) were placed onto the GIS layers of Lake Nasser at nine measurement points. Chlorophyll-*a* content of Lake Nasser was illustrated in Fig. 11. Chlorophyll-a concentration was being changed between 9 and 13 μg/L, which were considered as "excellent" and "good" depending on the Egyptian GD No. 92/2013.

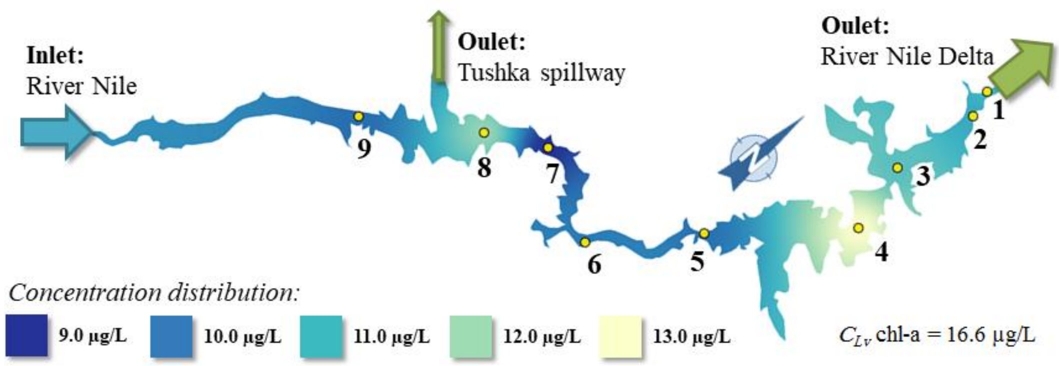


Fig. 11 Chlorophyll-a concentration distribution in the Lake Nasser

Dissolved oxygen (DO) content is one of the most important water quality parameters; it has an important role for aquatic life and human consumption, and it is one of the limiting factors as defined in Egyptian Governmental Decree No. 92/2013 for water quality assessment. It was qualified as "good" at one site (Abu-Simble) and "proper" at two sites (El-Madiq and Tushka) and "weak" at six sites (High Dam, Dahmit, Kalabsha, Wadi-Abyad, Korosko and Amada) in different section of Lake Nasser according to Egyptian Governmental Decree No. 92/2013 (Fig. 12).

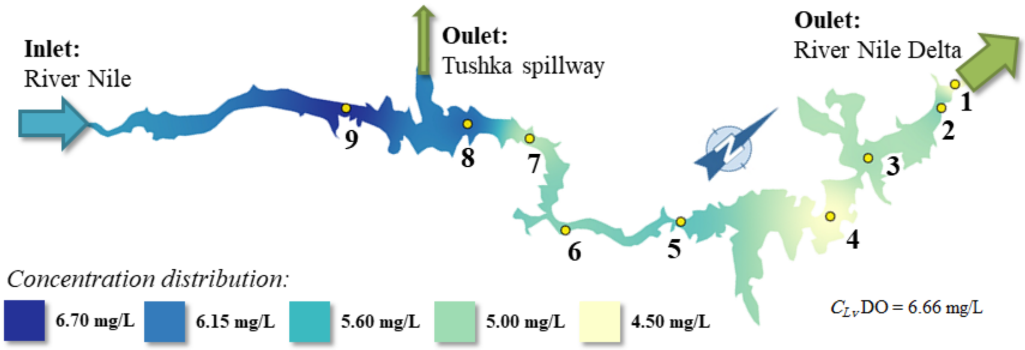


Fig. 12 Dissolved oxygen concentration distribution in Lake Nasser

Chemical oxygen demand varied between 6-11 mg/L, which has been qualified as "good" at six sites (Dahmit, El-Madiq, Korosko, Amada, Tushka and Abu-Simble) and "proper" at two sites (High Dam and Kalabsha) and "week" at one site (Wadi-Abyad). The contaminated part of the lake has been showed at Wadi-Abyad site regarding COD and BOD_5 values (Fig. 13). That due to the possible pollution effect of a nearby fertilizer manufacturing factory which could result in some discharge into the lake.

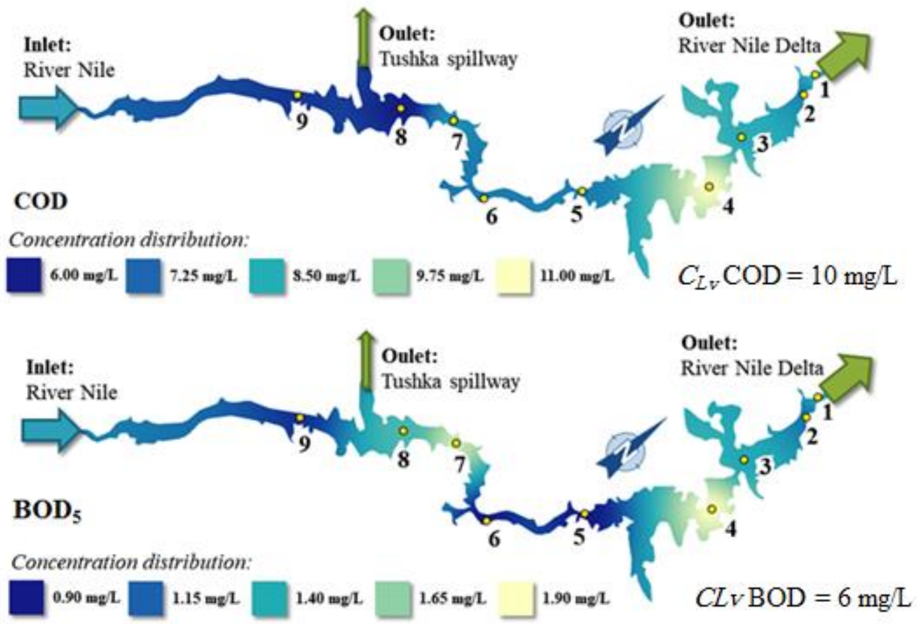


Fig. 13 Chemical and biological oxygen demand concentration distribution in Lake Nasser

The concentration distribution of N-nutrients along Lake Nasser has been illustrated in Fig.14 Ammonium concentrations were below the limit value (0.33 mg /L) which categorized as "excellent". Nitrite concentrations were approximately the same at all sites along the lake. According to nitrate distribution, Kalabsha region showed the highest concentration at the lake (2.2 mg/L) and at Tushka region, it was about the same (2.1 mg/L). This figure has been categorized as "weak"; however, those were still close to the limit value (2.0 mg /L).

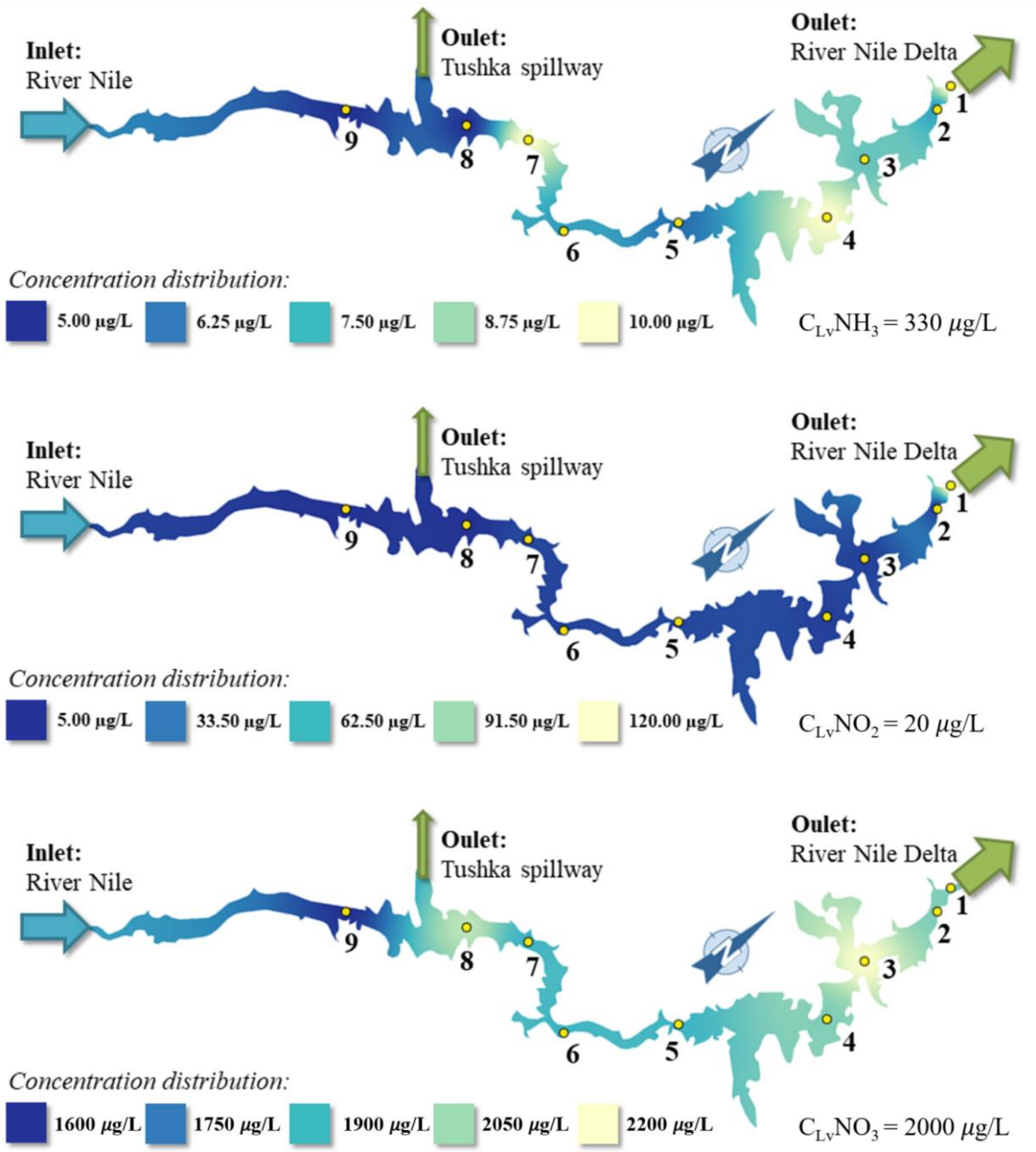


Fig. 14 The N-nutrient concentration distribution in Lake Nasser

It can be stated that the blue shaded areas in Figs. 15 and 16 represented concentration distribution of PO_4-P and TP respectively which are below the permissible limit according to Egyptian GD No. 92/2013 [4].

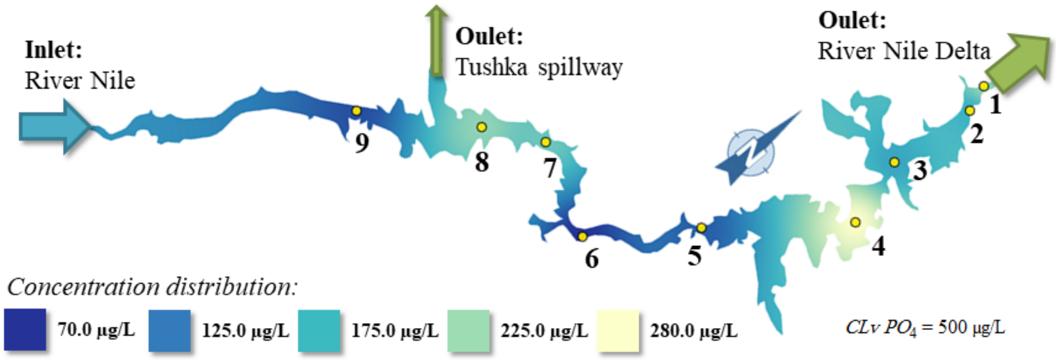


Fig. 15 Orthophosphate concentration distribution in the Lake Nasser

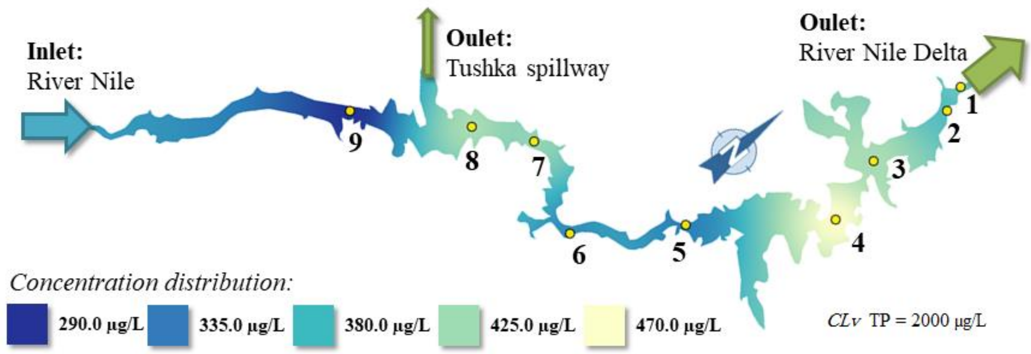


Fig. 16 Total phosphate concentration distribution in the Lake Nasser

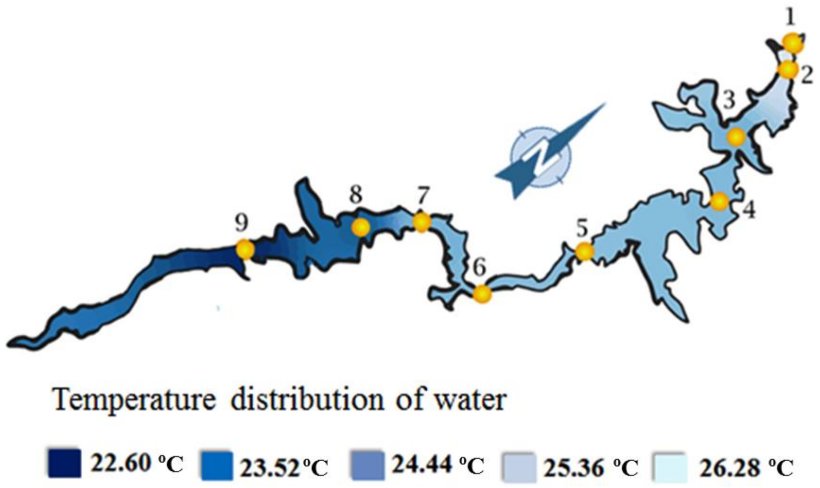


Fig. 17 Water temperatures of the nine sampling sites around the Lake Nasser

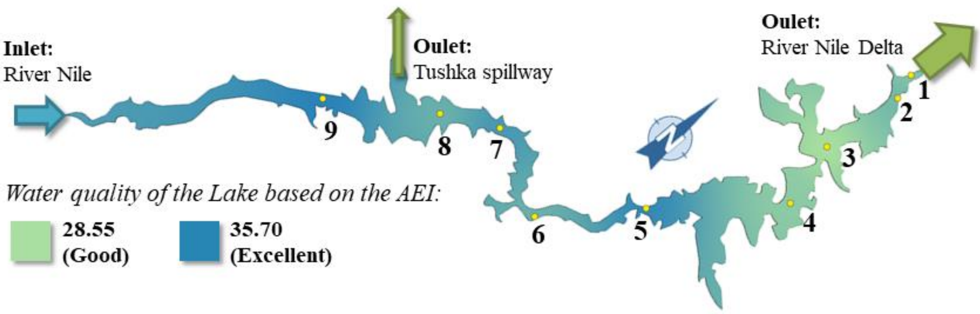


Fig. 18 Water quality status among the basins of Nasser Lake based on AEI values according to Egyptian Governmental Decree GD No. 92/2013

AEI values (28.55 and 35.70) were given in Fig 18. AEI results of the nine measurement sites as an outcome of the IDW-3D Analyst program used. The green-colored areas with AEI value of around 30.71 (the average of seven "good" sites) indicated the status of the water according to the specifications. The light green areas represented "good" water quality category, and the dark blue areas represented excellent water quality in Fig. 18.

There was a marked difference in dissolved oxygen contents between south and north parts of the lake as shown in Fig.8. This difference may be due to the increase in water temperature (Fig. 17) [98] [99] and the decrease in wind speed at Aswan High Dam site [100][101].

The results showed that at the southern part of the lake with average water temperature about 22.6 ^{o}C the average dissolved oxygen content is 6.6 mg/L (Fig. 12). Moreover, at the north part with average temperature of 26.3^{o}C the average dissolved oxygen content is 5.13 mg/L, so the dissolved oxygen content is higher at the southern part of the Lake due to lower water temperatures (Fig. 17).

The dissolved oxygen content (DO) is of vital importance for most aquatic species. When the aquatic species are exposed to less than 2.0 mgl/L oxygen for a short period of time it may eliminate most of biota in aquatic system [102]. While dissolved oxygen content values of 5.0 to 6.0 mg/L are usually fit for aquatic life [103] [104].

Chemical and biological oxygen demands provide information to calculate the organic matter content of water [105][106]. Results indicated that, COD and BOD_5 concentrations were close to the limit values of clear waters. The contaminated part of the Lake which is represented by yellow color on the map (Fig. 13.) is at Wadi-Abyad due to the runoffs agricultural chemicals into the lake. The increasing value of COD is in functional correlation with BOD_5. The increase in BOD_5 concentrations at sites 4 and 8 are due to the organic matters stemming from the respiration of plankton and bacteria in the lake [107] [108].

Nitrogen containing nutrient concentrations in Lake Nasser is affected by a number of processes. Nitrate content is stemming from River Nile inflow from the south and nitrification of ammonia which is consumed by algal uptake during growth. The decrease in nitrate depends on the consumption of these ions by phytoplankton as well as their reduction by denitrifying bacteria [109].

This may be due to nitrification of NH_3 and NO_2 produced by the biochemical decomposition of descending dead plankton into nitrate by nitrifying bacteria. A slight decrease in the amount of nitrite especially in the surface water zone can be due to biological uptake in the photic zone [110] and [111]. The absence of nitrite may be due to its oxidation process to nitrate as a result of well oxygenated bights water. Sources of ammonia (NH_4) include River Nile inflows from the south as shown in Fig. 14. The sinks include nitrification (conversion to nitrate), algal uptake during growth and reservoir outflow [112].

It can be supposed that the phosphorus load in the northern part of the lake may stem from the discharge of agricultural effluents containing large amount of fertilizers [113] as indicated by light green shaded areas in Figs. 15 and 16 where national agriculture projects in Wadi-Abyad and Tushka region (sites 4 and 8) are in operation. The average concentrations of total phosphorus ranged between 290 and 470 μg/L and orthophosphate varied between 70 and 280 μg/ L which is within the recommended limits of water quality in River Nile (2 mg/L). Total and orthophosphate concentrations increased at sites 4 and 8 and those decreased downstream.

The agricultural runoffs [114][115] into the Lake and pesticide residues from irrigated fields [116] result in phosphorus inputs into the water body of Lake Nasser. As a result of this changes in biodiversity of Lake Nasser could occur [117][118][109]. Phosphate concentrations in Lake Nasser increased southward and were weakly negatively correlated with phytoplankton biomass. Such negative relations were also found in some European temperate lakes [119]. Fig. 18 showed that water quality of Lake Nasser on the basis of the Aquatic Environmental Indices determined. The results are in harmony with the report of Ministry of Environmental Protection and Water Management of Egypt [120]. Good water quality can be observed at the northern part of the lake at site 3 which is indicated by light blue and green (Fig. 18).

Based on the outcome of the study, it can be stated that AEA can be expediently used for the evaluation of water quality changes and provides a collective indicator for mapping areas where the water quality is poor. In addition, AEA supports the prioritization of future mitigation actions.

AEI map (Fig. 18) showed lower AEI values on the northern part of the lake. This may be due to the use of fertilizers and pesticides in the agricultural areas and may suggest the intermittent supply of contaminating materials into the water body [121] [109].

4.1.2 Lake Balaton

Data on water physicochemical parameters of different sites were given in Table 6. Considering that measurement site 11 showed the lowest DO concentration (1.44 mg/L) with 16.30 OS (%), which is quite small and not appropriate for aquatic ecosystem as well as nutrient content, COD, Chla, turbidity and TOC showed high values in the same site.

4.1.2.1 Aquatic environmental index

The following steps were employed to carry the sampling methodology accordingly: first, the typology of the water body was established, followed by the selection of the cluster of water quality class based on threshold values specified by the Hungarian National Standard [77] and then compared of a two by- two strategy, followed by the aggregation of weighted indices obtained from the correlation of physical–chemical matrices and AEI [6]. The surface water quality categories can be ranked into five different classes from 1 to 5, simply based on the threshold values of physical–chemical water quality parameters, according to the Hungarian National Standard. Class No. 1 indicates a ‘‘bad” water quality state with a high pollutant content, class No. 2 indicates a ‘‘weak” quality state, with a high pollutant content but slightly better than the previous class, class No. 3 refers to a ‘‘proper” state, which represents a moderate case, class No. 4 refers to a ‘‘good” water quality condition and finally, class No. 5 is considered as ‘‘excellent” and represents a very low level of pollutants’ concentrations or pristine conditions (Table 7). To prove the compliance of these quality classes, four different types of mathematical equations were been developed for various groups of physical–chemical parameters. In the calculation of weight indices, numerical values were assigned to create a more precise relationship among physical– chemical parameters. According to Németh et al. [6] methodology, five uneven numbers 1, 3, 5, 7, and 9, respectively, were assigned as a numerical representation of the above degree of comparison.

Table 6 Measured results of physicochemical parameters and their limit values

n.d. no data

Site No	Chl-a (μg/L)	TU	pH	EC (μS/cm)	DO (mg/L)	OS (%)	BOD_5 (mg/L)	COD (mg/L)	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	TN (mg/L)	PO_4-P (mg/L)	TP (mg/L)	TOC (mg/L)
1	2.24	26.00	8.94^-	754^-	10.76^+	121^+	2	19.50	0.07	0.001	n.d.	1.82	0.02	0.07	18.03
2	2.12^+	24.30	8.76	743	8.86	104	n.d.	16.75	0.06	0.002	0.38	1.86	0.03	0.04	14.06
3	3.52	14.40	8.76	744	8.79	101	n.d.	14.50	0.01^+	0.001^+	n.d.	1.78	0.01	0.04	12.89
4	2.46	3.67	8.75	731	9.19	107	n.d.	12.25	0.02	0.001	n.d.	1.92	0.03	0.01^+	15.81
5	2.86	3.17	8.61	721	8.76	101	2	14.00	0.21	0.002	0.11	1.77^+	0.01^+	0.21	12.55
6	2.93	7.53	8.58	703	9.30	109	n.d.	24.75	0.033	0.002	n.d.	1.80	0.01	0.05	13.11
7	4.20	3.77^+	8.43	682	8.15	96	1	15.25	0.09	0.003	n.d.	1.92	0.01	0.09	13.75
8	4.45	16.30	8.61	678	8.03	97	4	21.50	0.06	0.002	0.64	1.94	0.01	0.28	14.89
9	4.80	14.60	8.69	653	9.46	113	n.d.	17.75	0.09	0.001	0.59	2.08	0.02	0.30^-	14.65
10	5.07	2.37	8.81	650	10.51	127	n.d.	20.00	0.22	0.002	n.d.	2.09	0.02	0.18	15.38
11	11.07^-	39.65^-	7.76^+	594^+	1.44^-	16^-	4	43.25^-	0.23^-	0.002	n.d.	2.43^-	0.12^-	0.20	22.33^-
12	6.62	23.70	8.24	640	6.98	81	n.d.	17.25	0.12	0.001	n.d.	1.99	0.01	0.06	14.27
13	6.16	31.90	8.73	670	8.31	99	n.d.	17.00	0.12	0.002	n.d.	2.05	0.01	0.01	16.62
14	6.01	6.23	8.71	673	10.29	120	n.d.	12.75	0.06	0.004^-	n.d.	1.98	0.01	0.03	13.14
15	6.81	7.59	8.50	737	9.73	115	n.d.	11.50^+	0.04	0.001	n.d.	1.88	0.01	0.05	12.02^+
Limit value	<15.00	50.00	8.30	<800	7.50	80.00	<2.50	<30.00	<0.05	<0.020	<0.06	1.40	<0.01	<0.12	<10.00

\+ indicates the relatively best quality

\- represents the highly polluted site

Intermediate even numbers were also been noted as relevant representations, such as 2, 4 and so forth. After the development of the matrix and normalization (i.e., the values of the matrices divided by the aggregate of all parameter values of the weight indices) the average value was calculated for each parameter. To calculate the weight indices (WI), the mean result needs to be multiplied by 100, to standardize the result as percentages. The WI indicates the priority of various employed physical– chemical parameters; hence, the WI of phosphorous shows the highest impact as compared to other parameters, whereas the turbidity value was found as the least important. Such an output leads to the conclusion that the phosphorous content has the highest contribution to the assessment of pollution or the one that endangers most the surface water quality compared to other measured physical–chemical parameters. The weight index values were determined based on long-term monitoring data of Hungarian water bodies. The weight indices were calculated using an Analytical Hierarchy Process (AHP) pairwise comparison methodology, which uses the deviations from good water status assessed according to Water Framework Directive. For validation, summing of all weight indices must be equal to unit. In case of Lake Balaton, the values of WI for the 15 employed parameters are given in Table 8. In these calculations, total phosphorus and orthophosphate contents comprise the maximum WI, with contributions of 16.62% and 15.75%, respectively. Water turbidity was considered as least influential weighted indices, with 0.98% and 1.18% contribution, respectively. Once the total summation of the weight index was approved as equal to unit, AEI has been calculated according to Eq. 3 as described earlier. The number of parameters used in this study is fifteen, n=15.

The substitution method was used for determination of mean AEI values and AEI intervals, which were summarized in Table 9. The low and top limit values of the intervals were determined by mathematical averaging of the neighboring AEI figures. For example, (6.67 + 13.33) / 2 = 10. In this way, the top figure of the bad interval is equal to 10. AEI evaluation carried for the year 2018 for Lake Balaton showed quality ranges between “weak” to “good”. In case of seven measurement sites, water quality fell in the “proper” quality class, whereas seven measurement sites have been classified as “good” water quality classes. The inlet point of River Zala showed “weak” quality of water. Accordingly, measurement site 15, Siófok measurement site,

Table 7 Surface water physicochemical parameters quality class developed by Németh [6] in harmony with Hungarian National Standard

Physicochemical parameters							
	Quality classes qCi and categories						
	Quality class	1	2	3	4	5	
	Quality category	Bad	Weak	Proper	Good	Excellent	Limit
	Parameter						values
1	**Chla, µg/L**	>22.5	22.5	15	12	<9	15
2	**TU, NTU**	>100.00	100	50	20	<10.00	50
3	**pH** $_{acidic}$	<5.00	5.50	6.00	6.50	7.00	7.80
4	**pH** $_{alkaline}$	>11.00	10.00	9.00	8.00	7.00	9.20
5	**EC, µS/cm**	>1200	1200	800	640	<480	800
6	**DO, mg/L**	<6.00	6	7.5	8.45	>9.38	7.5
7	**OS, %**	<64	64	80	90	>100	80
8	**BOD_5, mg/L**	>3.80	3.80	2.50	2.00	<1.50	<2.50
9	**COD, mg/L**	>45.00	45	30	24	<18.00	30
10	**NH_4-N,mg/L**	>0.075	0.075	0.05	0.04	<0.03	<0.05
11	**NO_3-N,mg/L**	>0.09	0.09	0.06	0.05	<0.04	<0.06
12	**NO_2-N,mg/L**	>0.05	0.05	0.03	0.02	<0.01	<0.02
13	**TN, mg/L**	>2.10	2.10	1.40	1.12	<0.84	<1.40
14	**PO_4-P, mg/L**	>0.015	0.015	0.01	0.008	<0.006	<0.01
15	**TP, mg/L**	>0.18	0.18	0.12	0.096	<0.072	<0.12
16	**TOC, mg/L**	>50	50	10	5.0	<2.0	10

From above Table, it was showed the highest result with a value of 26.94; whereas the smallest AEI is calculated for measurement site 11, with a value of 11.57.

The second poorest result also was recorded at measurement site 8 (Szigliget), with a value of 17.22 (Table 10) exhibited the worst result in the main body of the lake. In general, AEI has a mean value 23.31. The investigations covered water parameters stipulated in WFD 2000/60/EC [54] and Hungarian Governmental Decree No 10/2010. [65].

Table 8 The weight indices (WI) of water chemistry parameters of Lake Balaton

No.	Physicochemical water parameter	WI
1	Chla	1.23
2	TU	0.98
3	pH	2.59
4	EC	1.96
5	DO	7.81
6	OS	7.81
7	BOD_5	4.84
8	COD	9.79
9	NH_4-N	4.13
10	NO_3-N	4.13
11	NO_2-N	4.13
12	TN	10.50
13	PO_4-P	16.62
14	TP	16.62
15	TOC	6.84

Table 9 Evaluation categories of the quality class clusters in consideration with 15 measured parameters

Quality Category	Mean value	AEI interval
Bad	6.67	10.00 > AEI
Weak	13.33	10.00≤ AEI < 16.67
Proper	20.00	16.67 ≤ AEI < 23.33
Good	26.67	23.33 ≤ AEI < 30.00
Excellent	33.33	30.00 ≤ AEI

In consideration of the four basins of Lake Balaton, the measurements taken from Szigliget and Keszthely basins showed lower AEI values than Siófok and Szemes basin measurement points. As presented in Fig. 19 all AEI values at the eastern part of the lake (sites 8-12) did not reach the good AEI category, this showed the need to focus on water quality improvements in the eastern part of Lake Balaton.

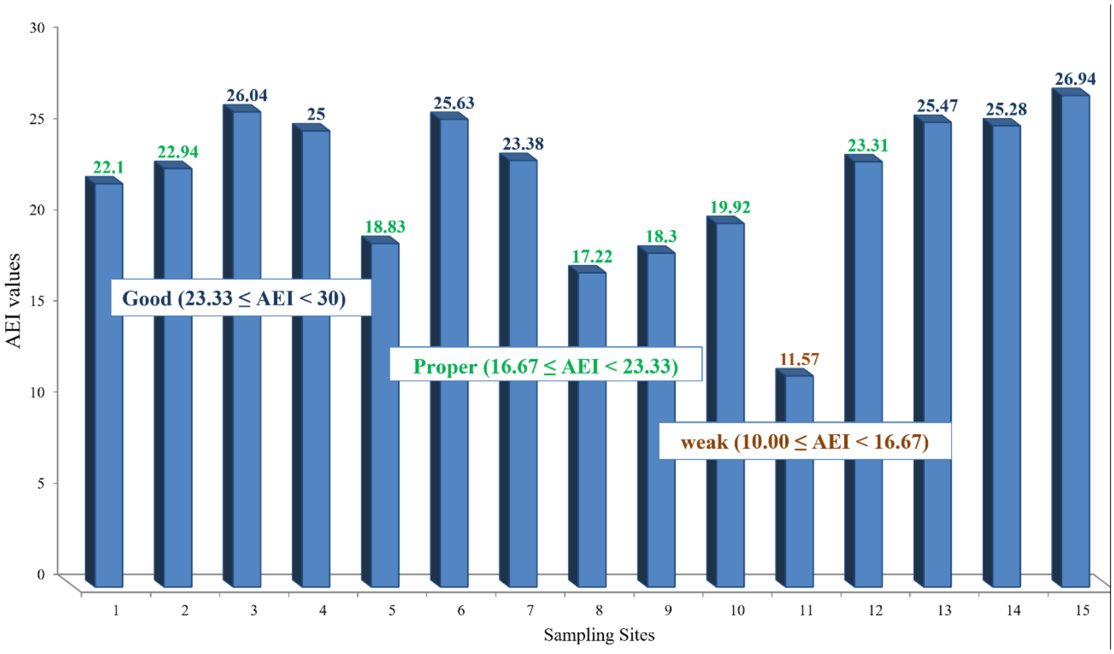


Fig. 19 Aquatic Environment Index values at fifteen measurement sites around Lake Balaton, blue-colored columns indicate the value of AEI

Data of AEI showed that in the western part of the lake the water quality was being deteriorated and indeed contains relatively higher pollutant load than the eastern part of the lake. Concisely, as GIS map output presented in Fig. 20 sites 8, 9, 10, 11, and 12 showed a clear difference from the rest measurement points and all these measurement points included in Keszthely and Szigliget basins. Being weak (10.00≤ AEI < 16.67), specifically at measurement site 11, refers that it has been polluted. The anthropogenic impacts were obvious, and the utilization possibilities were limited. In consequence, the mitigation techniques and measures are requested, and the financial implications are significant. Moreover, the average value of AEI for the whole lake was 22.13 and labelled as proper water quality class, (16.67 ≤ AEI < 23.33). Hence, it implies, water body is moderately polluted, the anthropogenic impacts can be observed on water body and/or the natural impacts influence the water body.

Table 10 Measurement sites and AEI value with quality classes

Measurement site	Measurement Site Name	AEI	Quality Class
1	Balatonalmádi	22.10	proper
2	Balatonfüred	22.94	proper
3	Tihany 1	26.04	good
4	Tihany 2	25.00	good
5	Balatonakali	18.83	proper
6	Révfülöp	25.63	good
7	Badacsonytomaj	23.38	good
8	Szigliget	17.22	proper
9	Balatongyörök	18.30	proper
10	Keszthely	19.92	proper
11	Zala River inlet	11.57	weak
12	Balatonberény	23.31	proper
13	Balatonfenyves	25.47	good
14	Balatonboglár	25.28	good
15	Siófok	26.94	good

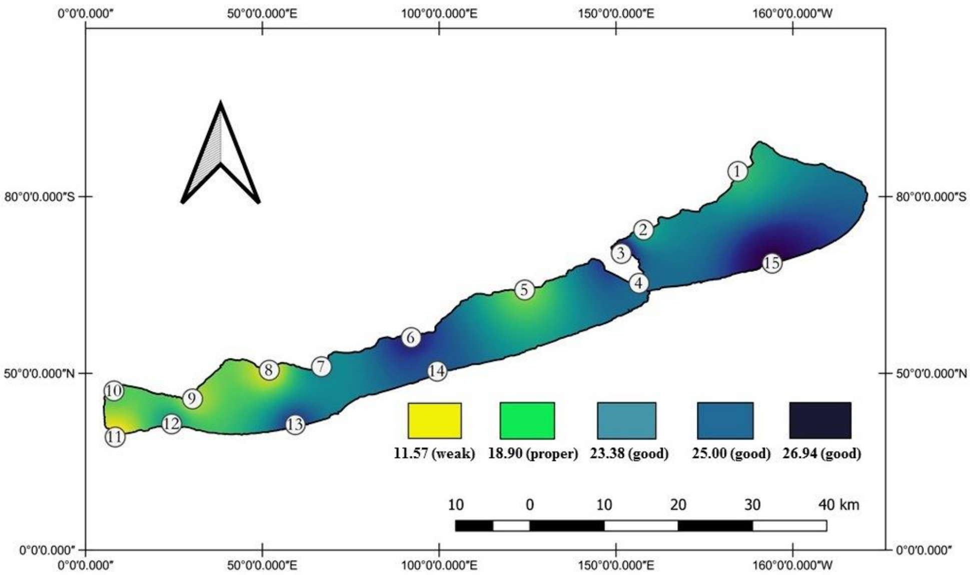


Fig. 20 Water quality status among the basins of Lake Balaton based on AEI values

4.1.2.2 Multi-criteria decision-making techniques results

Data on water quality parameters of different sites were given in Table 10. As the aim of the calculation was to detect polluted sites in Lake Balaton, so it should be considered that the closest value to 15 shows a higher water pollution level. So, identification of the polluted points has been defined by calculating the maximum and the minimum relative vicinity, which approximately near from the ideal answer calculated for 15 sites, which describe that the rank no.1 showed the highest water quality of the lake while the rank no. 15 showed the least water quality around the lake. Based on TOPSIS ranking evaluation, site 11 exhibited the most polluted water quality, and site 13 was the least polluted site. On the other hand, the most polluted site is 11, and the least polluted site is 15 in SAW ranking evaluation.

Table 11 showed that both ranking methods (TOPSIS and SAW) have the same coincides with the highly polluted site at Zala River inlet.

TOPSIS evaluation method showed dark blue shaded color (Fig. 21) at site 13 (Balatonfenyves) which indicated highest water quality and worst water condition at site 11 (Zala River inlet site) which appeared on the map by yellow shaded color. Regarding the preference distribution of sites around the lake, concerning the division of basins, the results showed that Szemes and Siófok basins represented higher quality than Keszthely and Szigliget basins.

The map represented in Fig. 22 showed that SAW evaluation method ranked Lake Balaton into 15 ranks. The dark blue shaded color at site 15 (Siófok) and site 13 (Balatonfenyves) illustrated the best case, and the worst water condition can be observed at the site 11 (Zala River inlet site) which appeared on the map by yellow shaded color. The results showed that Szemes and Siófok basins represented higher water quality than Keszthely and Szigliget basins.

Table 11 The ranking of locality pollution by TOPSIS and SAW methods

Site No.	Measurement Site Name	TOPSIS	SAW
1	Balatonalmádi	10	10
2	Balatonfüred	8	7
3	Tihany 1	2	2
4	Tihany 2	9	3
5	Balatonakali	11	11
6	Révfülöp	7	9
7	Badacsonytomaj	6	8
8	Szigliget	13	12
9	Balatongyörök	14	14
10	Keszthely	12	13
11	Zala River inlet	15	15
12	Balatonberény	4	4
13	Balatonfenyves	1	5
14	Balatonboglár	5	6
15	Siófok	3	1

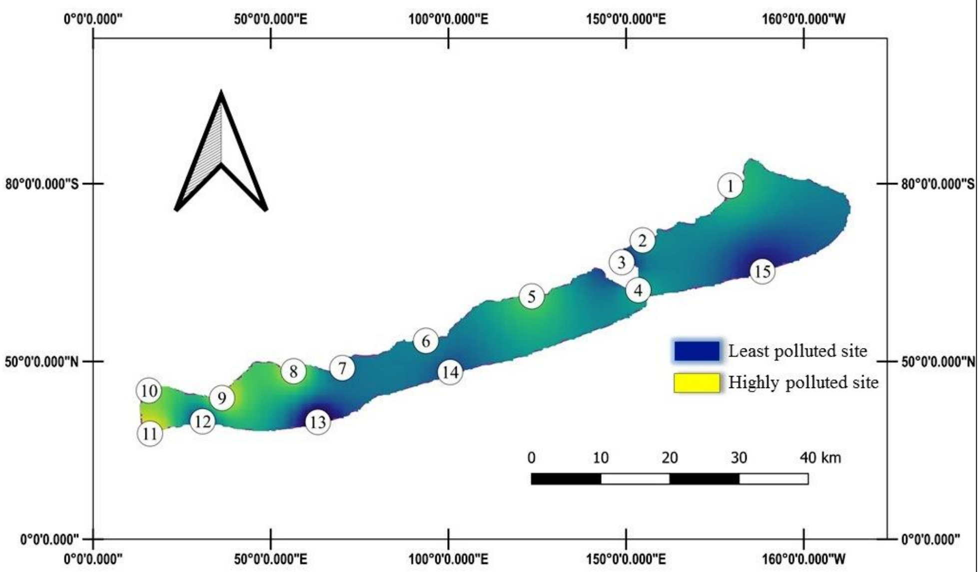


Fig. 21 The outcome of TOPSIS evaluation method along Lake Balaton

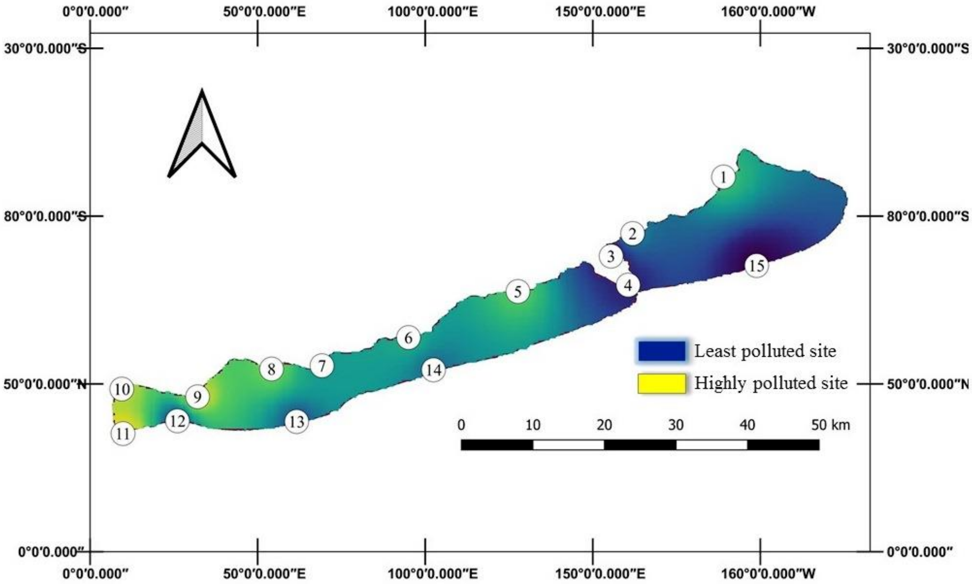


Fig. 22 The outcome of SAW evaluation method along Lake Balaton. Dark blue color illustrates the least polluted site, and light green illustrates highly polluted site

4.1.2.3 Comparison of the results with Sum of Ranking Differences

Sum of ranking differences is a simple but effective statistical tool to rank and numerically assess different solutions based on a reference [122]. The absolute values of differences for the ideal and actual ranking were summed up and the procedure is repeated for each (actual) method. SRD values obtained such a way to order the methods simply. If the ideal ranking is not known, it can be replaced by the average (maximum or minimum of all methods or by a known sequence). SRD corresponds to the principle of parsimony and provide an easy tool to evaluate the methods: The best method among them has a smaller summation. Models and other items can be similarly ranked. The purpose of using SRD in this study was to avoid the differences between two MCDM ranking evaluation methods and using AEI assessment method as a reference factor. Table 12 represented the ranking of water quality along Lake Balaton by TOPSIS, SAW methods, the average figures of the outcomes of TOPSIS and SAW methods and AEI values. AEI values were arranged in ascending order; the maximum value (no. 1) has the highest preference. Zala River inlet site showed the same rank in all evaluation methods (15). AEI values (green line), which were in conformity with TOPSIS evaluation method (blue line) and SAW evaluation methods (red line) has been shown in Fig. 23. The average value of the three methods has been used as gold reference. The underlying reason behind this method was related to avoid differentiation of results after the combination of methods. Fig. 24 showed the compatibility and difference between the rankings of methods for example sites 1, 3 and 11 showed matches in the ranking between three evaluation methods (TOPSIS, SAW and AEI). Table 12 represented SRD values, the smaller the sum the better the method. This translates into the TOPSIS value of 10.7 being closer to AEI (12) rather than to the SAW method (14.7).

The assessment results of the lake showed that in the western part of the lake, water quality was being deteriorated and indeed contained a relatively higher amount of pollutants than the eastern part of the lake. Concisely, as shown in Fig. 19, sites 8, 9, 10, 11, and 12 have shown a marked quality difference from other measurement points that are located in Keszthely and Szigliget basins. AEI values was weak ($10.00 \leq AEI < 16.67$), specifically at measurement site 11, which indicates that the measurement site has been polluted due to direct contamination of water with nutrients and chemicals due to agricultural activities of the region and load of Zala River [123]. Zala River carries about half of the pollution load into Lake Balaton [124]. DO values were higher than the limit values at all sampling sites except site 11 and 12, while the concentrations were 1.44 and 6.98 mg/L respectively. Critical DO value has been observed in site 11, which can cause serious effects in aquatic life. As proven by Wang et al. [125], DO values show healthy aquatic life in water if it ranges between 4 to 6 mg/L.

Table 12 The ranking of water quality by different evaluation methods

Water final evaluation	TOPSIS Rank	SAW Rank	AEI Rank	Gold reference (average)	Diff. TOPSIS	Diff. SAW	Diff. AEI
Balatonalmádi	10	10	10	10.0	0.0	0.0	0.0
Balatonfüred	8	7	9	8.0	0.0	1.0	1.0
Tihany 1	2	2	2	2.0	0.0	0.0	0.0
Tihany 2	9	3	6	6.0	3.0	3.0	0.0
Balatonakali	11	11	12	11.3	0.3	0.3	0.7
Révfülöp	7	9	3	6.3	0.7	2.7	3.3
Badacsonytomaj	6	8	7	7.0	1.0	1.0	0.0
Szigliget	13	12	14	13.0	0.0	1.0	1.0
Balatongyörök	14	14	13	13.7	0.3	0.3	0.7
eszthely	12	13	11	12.0	0.0	1.0	1.0
Zala River inlet	15	15	15	15.0	0.0	0.0	0.0
Balatonberény	4	4	8	5.3	1.3	1.3	2.7
Balatonfenyves	1	5	4	3.3	2.3	1.7	0.7
Balatonboglár	5	6	5	5.3	0.3	0.7	0.3
Siófok	3	1	1	1.7	1.3	0.7	0.7
SRD					10.7	14.7	12.0

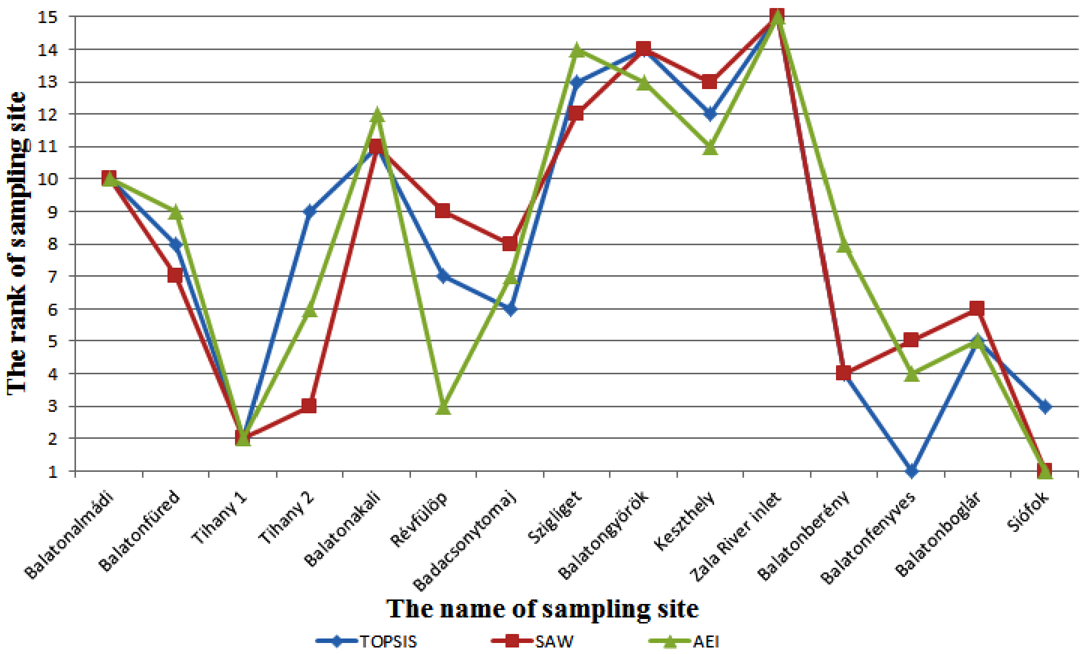


Fig. 23 Comparison of the results of the water quality evaluation methods

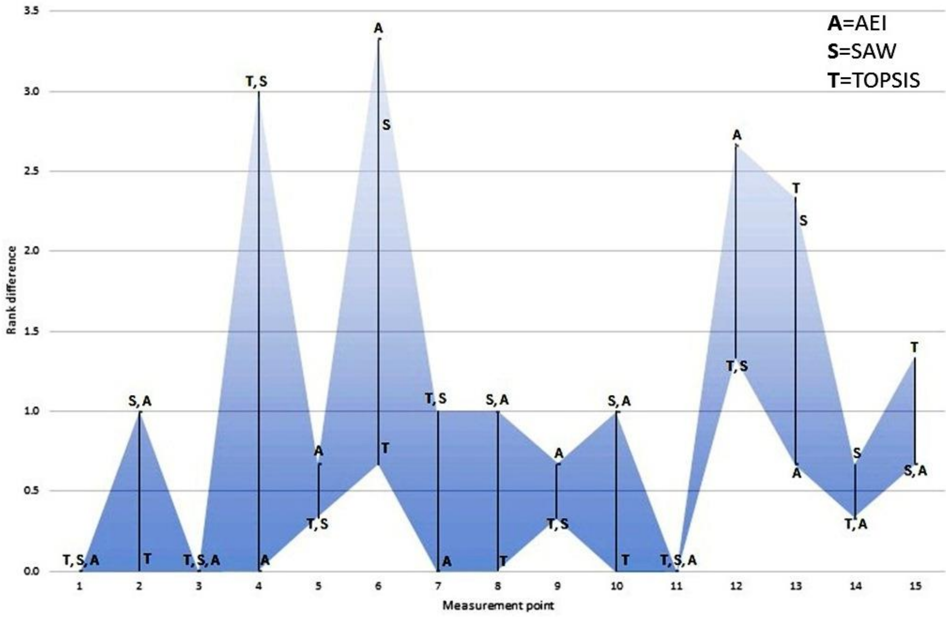


Fig. 24 Comparison of the results of the water quality evaluation methods based on the sum of ranking differences approach

The Most important parameters indicated in this study and positively affecting on water quality of the lake are the neutrients (N and P containing compounds). These nutrients inhancing cyanobacteria and responsible for algae blooms which is consequence of eutrophication. This is considered a favourable conditions of high level nutrients, which is necessery for Zooplankton growth [126]. The main cause of eutrophication is excessive nitrogen and phosphorus enrichment [127]. Eutrophication and blooms are remain major and growing environmental concerns for global water problem, which not only adversely impacts local ecosystems but also poses potential risks to public health [128]. The lower NO_3-N concentration indicated in the results due to the changes of NO_3-N into N_2 in reduction function by denitrifying bacteria under anaerobic conditions, which mitigates the nitrate concentration in water body furthermore, nitrogen gas is released into the atmosphere [129]. Only approximately 20% of the nutrients are absorbed and transformed into protein by organisms, and most of the remaining nutrients enter water or settle in sediments to form endogenous pollutants [130].

Chemical and biological oxygen demands provide information to calculate the organic matter content of water [106]. The results indicated that COD and BOD_5 concentrations were higher than the limit values at site 11 (4 and 43.25 mgL respectively). The contaminated part of the lake which has been represented in the western part of the lake due to the runoff agricultural chemicals come through Zala River inlet into the lake. The increasing value of COD is in functional correlation with BOD_5. The increase in BOD_5

concentrations at site 11 was due to the organic matters stemming from the respiration of plankton and bacteria in the lake [108]. That might cause the high mortality of fish in that area in collaboration with low oxygen concentration [131].

Draining of extensive marshlands and forcing rivers between embankments (mostly Zala River, the largest tributary to the lake) certainly had one serious consequence: accelerated silting of the lakebed, especially at the southwestern end of the lake [132]. However, since the pollutant and nutrient load of the tributaries must have been at a very low level, water quality deterioration did not occur. Dropping the water level during this period by some 3 meters resulted in the practical disappearance of the hypolimnion, increased sediment resuspension, and sensitivity to changes in the hydro-meteorological conditions [133]. The anthropogenic impacts are obvious, and the utilization possibilities are limited. In consequence, the mitigation techniques and measures are requested [134], [135] and the financial implications are significant. Moreover, the average value of AEI for whole lake is 22.13 and labeled as proper water quality class, ($16.67 \leq AEI < 23.33$). Hence, it implies that water body of the lake is moderately polluted, and the anthropogenic impacts on the lake can be observed. The results illustrated that Siófok area was the least polluted site on the lake according to AEI and SAW assessment methods (Figs. 20 and 22). In case of using TOPSIS method (Fig. 21), Balatonfenyves area was the least polluted site. The results demonstrated that all assessment methods agree that Zala River inlet area is the most polluted site.

The results showed that the value obtained from AEI analysis method was the same as the mean value between TOPSIS and SAW methods (Figs. 21 and 22). Therefore, it was found that using the three quantitative methods can contribute to a clear understanding of the quality of water that can be obtained. The practical solutions of the used assessment tools are providing a highlighting for crucial problems and suggest multiple solutions and management practices which can be applied with cooperation with governmental policies for restoring eutrophic impaired lakes and improving water quality. One of the solutions that can be applied for aeration problems is using Oxygen-carrying materials (OCM) which modified from natural zeolites. It used as capping agents and an oxygen-locking layer in anoxic conditions Lakes. It is contributing to the increasing of DO content from 1.5 mg/L to 3.5–4 mg/L as reported by Zhang et al. [136].

Specifically, several management practices have reported efficiencies of phosphorus removal such as biofilters, bio-retention, detention basins, porous pavements, wetland basins, and dry ponds [137]. Dynamical effects induced on a lake by the planned structures are also can be applied in phosphorus removal [138]. Geoengineering techniques have been used to control phosphorus and cyanobacteria in lakes promising greater and quicker chemical and ecological recovery by using coagulants such as aluminium sulphate, polyaluminium chloride and chitosan alone and combined with natural bentonite clays to remove of phosphorus from the eutrophic Lakes [139]. Physical (Hypolimnetic withdrawal method and Macrophyte harvest), chemical (Phosphate binder and Copper-based algaecides) and biological (Effective micro-organisms and Dreissenids) mitigation methods can be applied for nutrients reduction [140]. Several promising treatment have been investigated such as using phytoremediation removal techniques in the lakes to reduce the nutrient levels in water. This ecological restoration can be accomplished through aquatic plants that compete with algae for ecological resources, such as light, nutrients, and living space and use the nutrient to store it and use it in their vegetative growth [141].

4.2 Heavy Metals Contamination

4.2.1 Heavy metals contamination on Lake Nasser

Lake Nasser is the largest source of freshwater in Egypt. However, there are no point pollution sources with heavy metals in its hydrographic basin. The lake receives heavy metals via anthropogenic activities, such as fishing activities, sewage pollution, fishing boats and cruise ships, as well as others which are disposed off in wastes directly into the Sudanese main stem of River Nile [142]. The copper, zinc, lead and cadmium were selected in this study according to the recommendations of Egyptian Water Administration. High concentrations of copper and zinc are needed, as opposed to lead and cadmium which require low dosages, to cause severe environmental and human health issues. Humans are exposed to these heavy metals via consumption of water and fish, which bioaccumulate in various tissues, leading to both acute and chronic intoxications.

4.2.1.1 Heavy Metals concentrations in Water

Table 13 presented the mean concentrations of heavy metals dissolved in water in the six sampling sites of Lake Nasser. Which were below the limits imposed by the Egyptian Governmental Decree No. 92/2013 [4], environmental quality standards

[53](Directive 2008/105/EC) of European Union and by the guidelines for drinking water of USA [143], as well as by the aquatic life suitability standard of Canada [144].

Sites 3 and 6 exhibited the highest heavy metal concentrations, whereas the site 1 showed the lowest. The measured values of heavy metals from the current study were compared to those from different countries in Table 14.

Table 13 Concentration of Heavy metals in Lake Nasser and national and international guideline limit values according to various standards

Heavy metal concentrations (µg/L)	Measuring sites in Lake Nasser						limit values, µg/L			
	1	2	3	4	5	6				
	Abu-Simble	Armina	Tushka	Korosko	Kalabsha	High Dam	[a]EG (GD 2013)	[b]EQS	[c]CCME 2007	[d]USEPA 2018
Cu	0.80	2.68	6.700	2.67	1.98	4.70	10	10	4.00	13.00
Zn	7.13	7.56	11.80	7.66	9.00	9.11	10	10	50.00	50.00
Cd	0.025	0.025	0. 065	0.03	0.03	0.06	1.0	≤0.08	1.00	10.00
Pb	0.01	0.02	0.040	0.03	0.03	0.04	10	1.2	10.00	15.00

[a] EG (GD 2013) Egyptian Governmental Decree No. 92/2013

[b] EQS 2008 (Environmental Quality Standards in the Field of Water Policy, Directive 2008/105/EC).

[c] UESEPA 2018 (United States Environmental Protection Agency, Drinking Water Standards and Health, 2018).

[d] CCME 2007 (Canadian Council of Ministers of the Environment For the Protection of Aquatic Life)

In comparison with the registered heavy metal concentrations in various worldwide lakes, it can be concluded that the heavy metal concentrations in Lake Nasser are in fact significantly lower compared to Kenya [145], China [146], USA [147], Lake Constance [148], Lake Geneva [149] and Lake Balaton [150].

Table 14 Global overview of mean heavy metals concentrations in water of different water bodies in different countries

Lake Location /concentration element (µg element/ L)	Pb	Cd	Zn	Cu	References
Nasser Lake	0.028	0.039	8.70	3.26	current study
Constance Lake (Germany, Switzerland and Austria)	0.050	0.250	1.500	1.100	[148]
Baikal Lake (Russia)	1.5	7	1-5	1	[151]
Vemband Lake (India)	3.94	1.63	74.93	7.31	[152]
Caizi Lake (China)	2.42	0.12	34.33	2.54	[146]
LosMolinos Lake (Argentina)	0.07	-	3.75	0.67	[153]
Geneva Lake (shared between Switzerland and France)	<0.050	0.005	-	0.770	[149]
Lake Balaton (Hungary)	0.040	0.002	0.970	0.460	[150]
Lake Texoma, Oklahoma–Texas (USA)	<15	20	59	24	[147]
Lake Victoria (Kenya)	1.054	0.070	144	1.568	[145]
Lake Victoria (Mwanza and Winam Gulfs)	22-823	0 -70	18 -50	--	[154]
Tana Lake (Ethiopia)	3-6	30-60	110-160	110-150	[155]
Tanganyika Lake (Tanzania)	7-120	<10.00	10.00	<6.00	[156]

4.2.1.2 Assessment of environmental prominence of minerals in sediment stores in comparison to SQGs

Table 15 summarizes the measured values of heavy metals in sediment and compares them to quality guideline values, which comprise the minimum critical concentrations, which has been represented by the toxic effect threshold (TET). The concentration of copper varies between 13 and 21.8 µg/g; high concentrations were recorded at site 3 (21.8 µg/g), followed by the site 6 (21 µg/g). However, the lowest copper concentration was recorded at site 1 (13µg/g). The concentrations of zinc were high in all investigated sampling sites. To determine the state of metal pollution, the Sediment Quality Guidelines (SQGs) were applied as reference. SQGs were derived from the sediment quality pollutant concentrations using Chemical and Biological Impact Database [157] [158].

Table 15 Heavy metals concentrations in sediment of Lake Nasser and sediment quality guidelines for selected heavy metals

Elements concentrations (mg/kg)	Measuring sites/heavy metal concentrations alongside Lake Nasser						*SQG				
	1	2	3	4	5	6					
	Abu-Simble	Armina	Tushka	Korosko	Kalabsha	High Dam	[a]TEC	[b]PEC	[c]PEL	[d]SEL	[e]TEL
Cu	13.00	15.80	21.80	18.00	18.00	21.00	31.0	149	197	110	86
Zn	19.00	25.00	45.00	30.00	38.00	40.00	121	459	315	820	540
Cd	0.165	0.178	0.35	0.27	0.31	0.356	0.99	4.98	3.53	10.0	3.00
Pb	0.95	2.00	3.00	2.00	2.00	3.00	-	128	91	250	170
MPI	2.49	3.44	5.57	4.16	4.54	5.23					

*SQG: Sediment quality guideline (Jones et al. 1997 and USEPA, 1999)

[a] TEC: Threshold effect concentration (MacDonald et al. 2000).

[b] PEL: Probable effect level for dry weight (Smith et al. 1996).

[c] SEL: Severe effect level for dry weight (Persaud et al. 1992).

[d] TET: Toxic effect threshold for dry weight (EC & MENVIQ 1992).

[e]PEC: Probable effect concentration (MacDonald et al. 2000).

However, the usage of SQGs simultaneously with municipal data requires caution. This is important especially in the risk evaluation of heavy metal loads from sediment samples. The recorded values were well correlated with the water flow along a south to north latitudinal gradient. In conclusion, the sediment from Lake Nasser can be considered safe for agriculture activities as well as for aquatic biota [18].

4.2.1.3 Heavy metal concentrations in fish organs

Fish length and net body weight were ranged between 21.5 - 32.8 cm and 225.5 - 500.5 g in weight, respectively (Table 16).

Table 16 The mean length and net body weight of Nile Tilapia (*Oreochromis niloticus* L.) sample collected from six sampling sites during March 2019 from Lake Nasser

Sampling sites	Sampling sites	Mean length (cm) ± SD	Mean body weight (g) ± SD
1	**Abu-Simble**	31.30 ± 4.18	500 ± 27
2	**Armina**	28.00 ± 5.60	450 ± 19
3	**Tushka**	29.60 ± 3.50	300 ± 15
4	**Korosko**	21.50 ± 3.18	225.50 ± 26
5	**Kalabsha**	32.80 ± 5.00	500.50 ± 15
6	**High Dam**	25.00 ± 2.50	350 ± 18

Table 17 showed the concentrations of Cu, Zn, Cd and Pb in fish muscles compared to the standards of heavy metal levels of the European Community [159], Food and Agriculture Organization [160], FAO/WHO limits [161], World Health Organization [162] and Ministry of Agriculture, Fisheries and Food of UK [163]. The copper concentrations varied between 1.2 µg/g at site 1 to 9.17 µg/g at site 3. Zinc concentrations exhibited the highest concentration (15.70 µg/g) at site 3 and the lowest (8.5 µg/g) at site 1.

Table 17 Heavy metals concentrations in fish muscle of Nile Tilapia (*Oreochromis niloticus* L.) of Lake Nasser and comparison of HMs concentration values with standard levels stipulated by different regulations

Elements concentration (mg/kg)	Measuring sites						Standard levels(mg/kg)				
	1	2	3	4	5	6	[a] EC 2005	[b] FAO 2012	[c]FAO/WHO 2011	[d] WHO 1989	[e] MAFF 2000
Cu	1.20	2.25	9.17	2.25	5.26	6.18	10	30	30	30	20
Zn	8.50	12.78	15.70	13.20	13.65	14.9	-	30	40	100	50
Cd	0.15	0.15	0.23	0.18	0.20	0.24	0.05	0.05	0.5	1	0.2
Pb	0.10	0.20	0.50	0.20	0.20	0.50	0.20	0.5	0.5	2	2
MPI	0.63	0.96	2.02	1.02	1.30	1.82					

[a] EC 2005 (European Community, Commission Regulation No. 78/ 2005)

[b] FAO 2012 (Food and Agriculture Organization, Animal Feed Resource Information System, 2012)

[c] FAO /WHO limit 2011(The Joint FAO/WHO Expert Committee on Food Additives, WHO Technical Report Series 960)

[d] WHO 1989 (Heavy Metals Environmental Aspects, 1989 Environment Health Criteria. No. 85)

[e] MAFF 2000 (Ministry of Agriculture, Fisheries and Food, Aquatic Environment Monitoring of UK, Report No. 52, 2000)

Cadmium concentrations recorded the lowest concentrations (0.15 μg/g) at sites 1 and 2. In site 3 agriculture activities affect water quality, influencing directly water and sediment dwelling biota.

Table 18 showed the concentrations of cadmium, zinc and lead which were within the certified limits of standard samples. Regarding copper, both standard fish samples (DORM 4 and DOLT 5) were below certified values and within acceptable limits (96.11 % confidence level). Table 19 presented the concentrations of heavy metals in fish liver. The highest heavy metal concentrations (Cu, Zn and Cd) in fish liver were measured at site 6, in the northern part of the lake (28.90, 58.10 and 0.50 μg/g, respectively) whereas the lowest values were recorded at site 1, in the southern part of the lake (Cu: 13.80, Zn: 37.50 and Cd: 0.3 μg/g respectively). The lowest lead concentration was recorded at site 2 (0.1 μg/g) and the highest at site 3 (2.1 μg/g).

Table 18 Mean ± SD value of heavy metal content in Canadian standard fish samples, DORM 4 and DOLT 5

Metal (mg/kg dry weight)	Measured Values DORM4 (n = 30)	Certified Values DORM4	Measured Values DOLT5 (n = 30)	Certified Values DOLT5
Cu	14.90 ±0.23	15.70 ± 0.46	31.53 ± 2.5	35 ±2.40
Zn	52.00 ± 2.50	51.60 ± 2.80	106.82 ± 1.50	105.3 ± 2.40
Cd	0.295 ± 0.017	0.299 ± 0.018	14.01 ± 0.52	14.5 ±0.60
Pb	0.415 ± 0.050	0.404±0.062	0.166 ± 0.027	0.162 ± 0.032

Table 19 Heavy metals concentrations in fish liver of Nile Tilapia (*Oreochromis niloticus* L.) of Lake Nasser

Elements Concentrations Mg/kg	Measuring site					
	1 Abu-Simble	2 Armina	3 Tushka	4 Korosko	5 Kalabsha	6 High Dam
Cu	13.80	15.20	25.80	22.60	22.90	28.90
Zn	37.50	38.00	55.70	43.00	49.00	58.10
Cd	0.30	0.30	0.50	0.40	0.50	0.50
Pb	0.90	1.00	2.10	1.50	1.98	2.00
MPI	3.44	3.63	6.23	4.90	5.77	6.40

4.2.1.4 Heavy metal distributions among Lake Nasser

Heavy metals distribution along the lake offers a better understanding of the level of lake contamination [164]. This way, the contamination with heavy metals and where the highest concentrations are to be expected is much better represented. An overall picture as this may help authorities to draw people's attention to the potential risk of heavy metal contamination [165]. Such mapping can help with proper implementation of preventive measures. However, it is necessary to emphasize the fact that currently there are no heavy metal contamination sources in Lake Nasser hydrographic basin, providing a solid basis for the future development of agricultural activities in the region and efficient water management in Egypt.

4.2.1.4.1 Copper

Copper content in water, sediment and both fish muscle and liver has represented in Fig. 25. It highlighted the lowest copper concentrations with blue, which is the best water quality in terms of contamination with this heavy metal, whereas the yellow highlights indicate high concentrations. The decreasing copper concentrations in studied samples were in liver > sediment > muscle > water. Sediment and liver samples exhibited higher concentrations in the lake (13-21.8 and 13.8-28.9 mg/kg respectively), supporting the hypothesis of its bioaccumulation in fish liver and sediments. Some researchers indicated that elevated levels of heavy metals such as Zn and Cu in surface sediments come from mine effluents, vehicular emission and commercial and industrial sources [166].

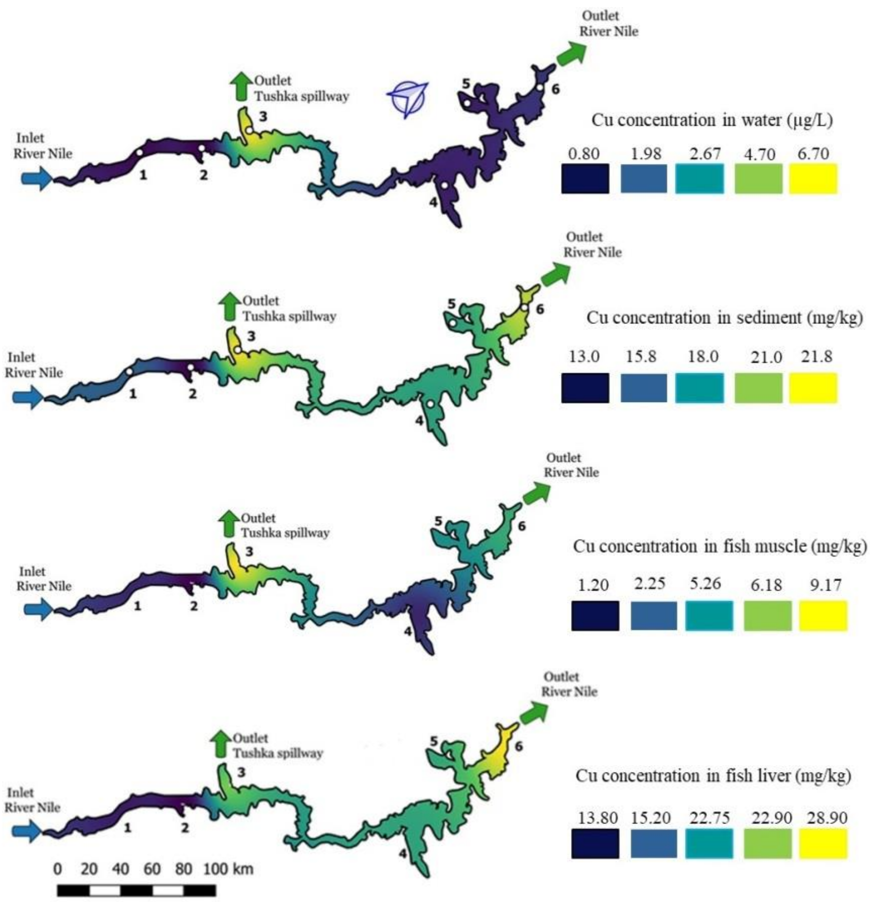


Fig. 25 Copper distributions along the lake in water, sediment, fish muscle and fish liver

4.2.1.4.2 Zinc

Zinc concentrations in water, sediment, fish muscle and fish liver has been illustrated in Fig. 26. Blue color highlights the lowest Zn concentration, which indicates the best water quality with respect to this heavy metal, whereas the yellow indicates high concentrations. The sequence of Zn concentrations in the samples were in order of liver > sediment > muscle > water. The results showed that water exhibited the lowest concentration (Table 13), whereas sediment and liver samples exhibited the highest values (19-45 and 37.5-58.10 mg/kg respectively). The results showed that zinc concentrations in the edible tissues of fish were within the normal variation according to the Canadian fish standard (51.60 ± 2.80 mg/kg) (Table 18).

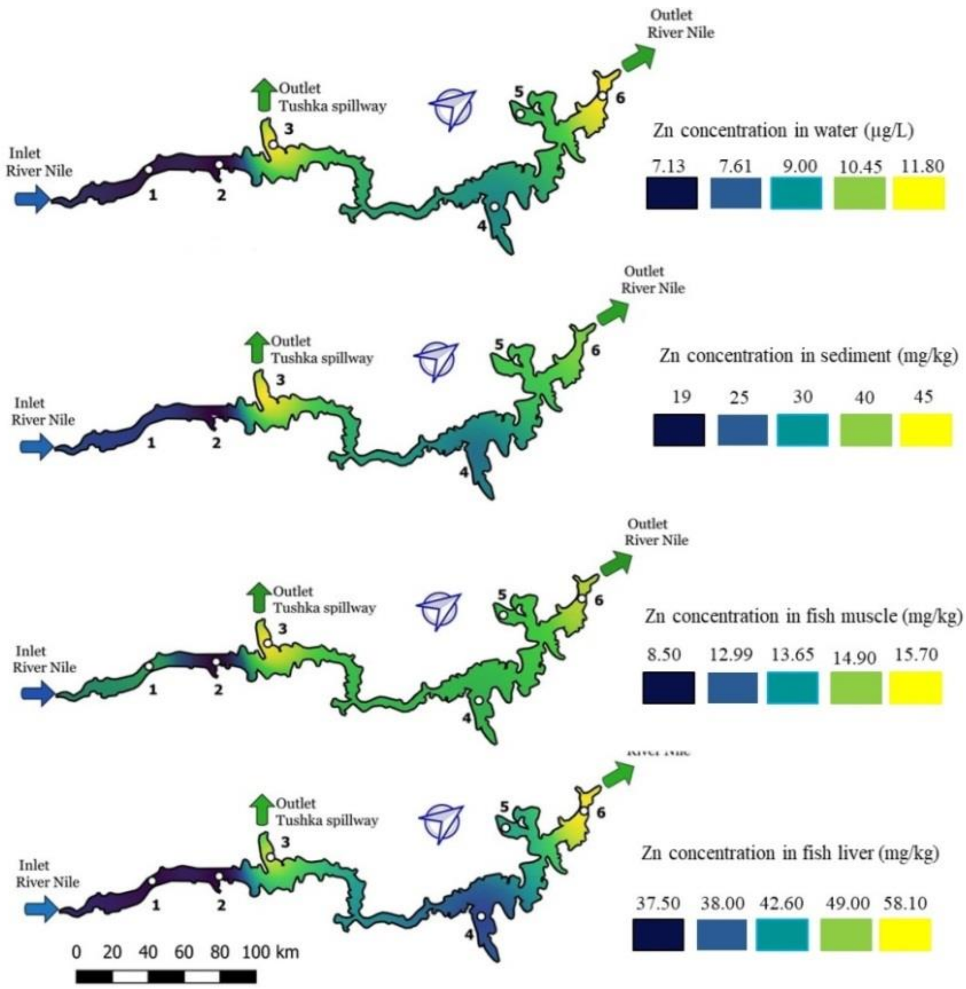


Fig. 26 Zinc distribution along the lake in water, sediment, fish muscle and fish liver

4.2.1.3 Lead

Accumulation of lead in fish tissues can induce oxidative stress due to production of Reactive Oxygen Species (ROS), which induce potential synaptic damage and several malfunction implications in fish, as neurotoxicity. Moreover, exposure to lead has a negative effect on the immune responses in fish [166]. Fig. 27 highlights the lead concentrations in water, sediment, fish muscle and fish liver; the blue color refers to the lowest concentrations, indicating the best water quality with respect to this heavy metal, whereas the yellow color indicates high values. The gradient of lead concentrations in samples is in the following order sediment > liver > muscle > water. The results showed that water exhibited the lowest concentrations (Table 13), whereas the sediment and liver samples exhibited the higher concentrations in the lake (0.2-3 and 0.9-2.1 mg/kg respectively).

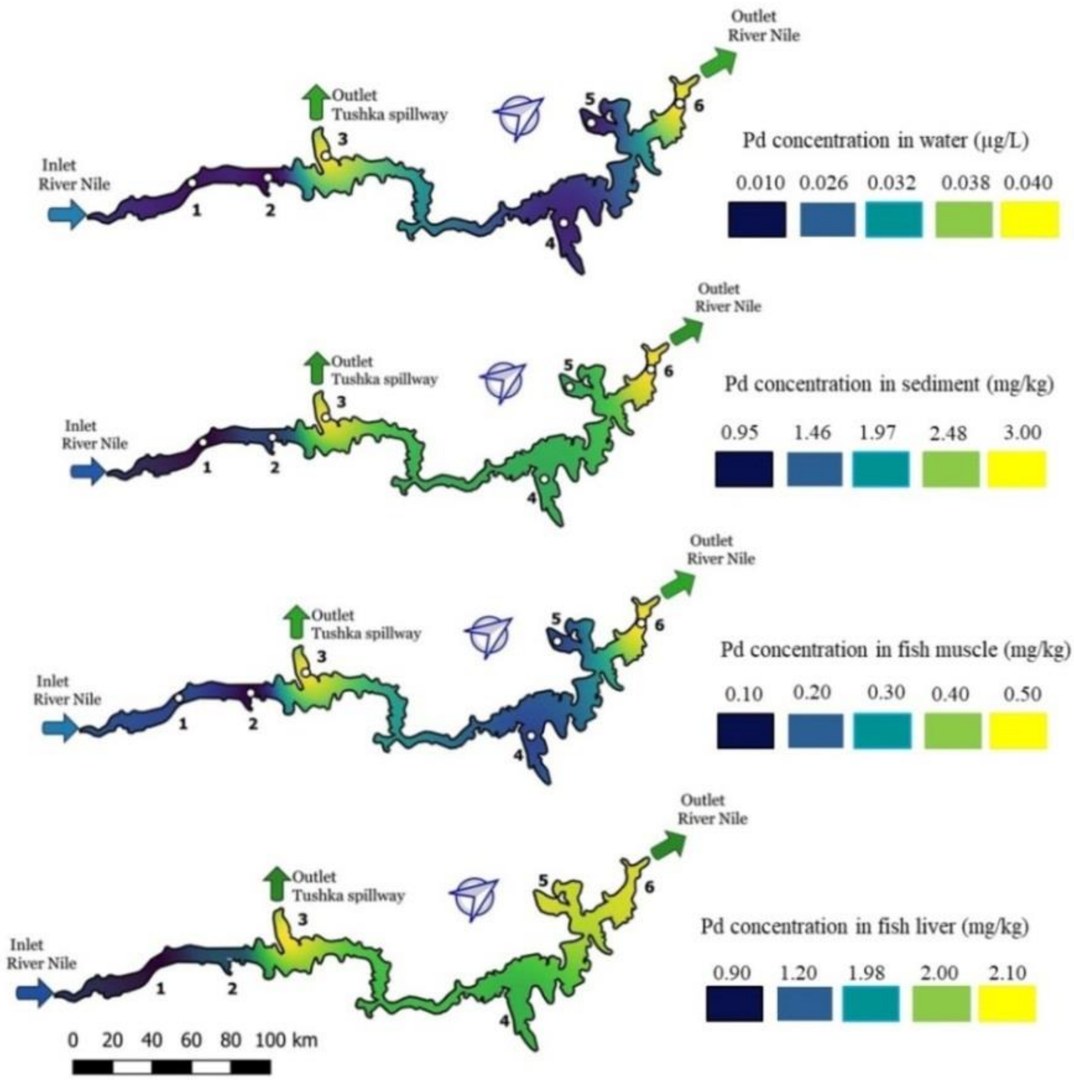


Fig. 27 Lead distribution along the lake in water, sediment, fish muscle and fish liver

4.2.1.4 Cadmium

Cadmium induces harmful effect on living cells, their membrane deterioration and destroys the DNA structure. Such severe damage result from the displacement of these heavy metals from its original binding sites [167]. Fig. 28 has been showed cadmium concentrations in water, sediment, fish muscle and fish liver. The blue color refers to its lowest concentrations, whereas the yellow indicates the highest values.

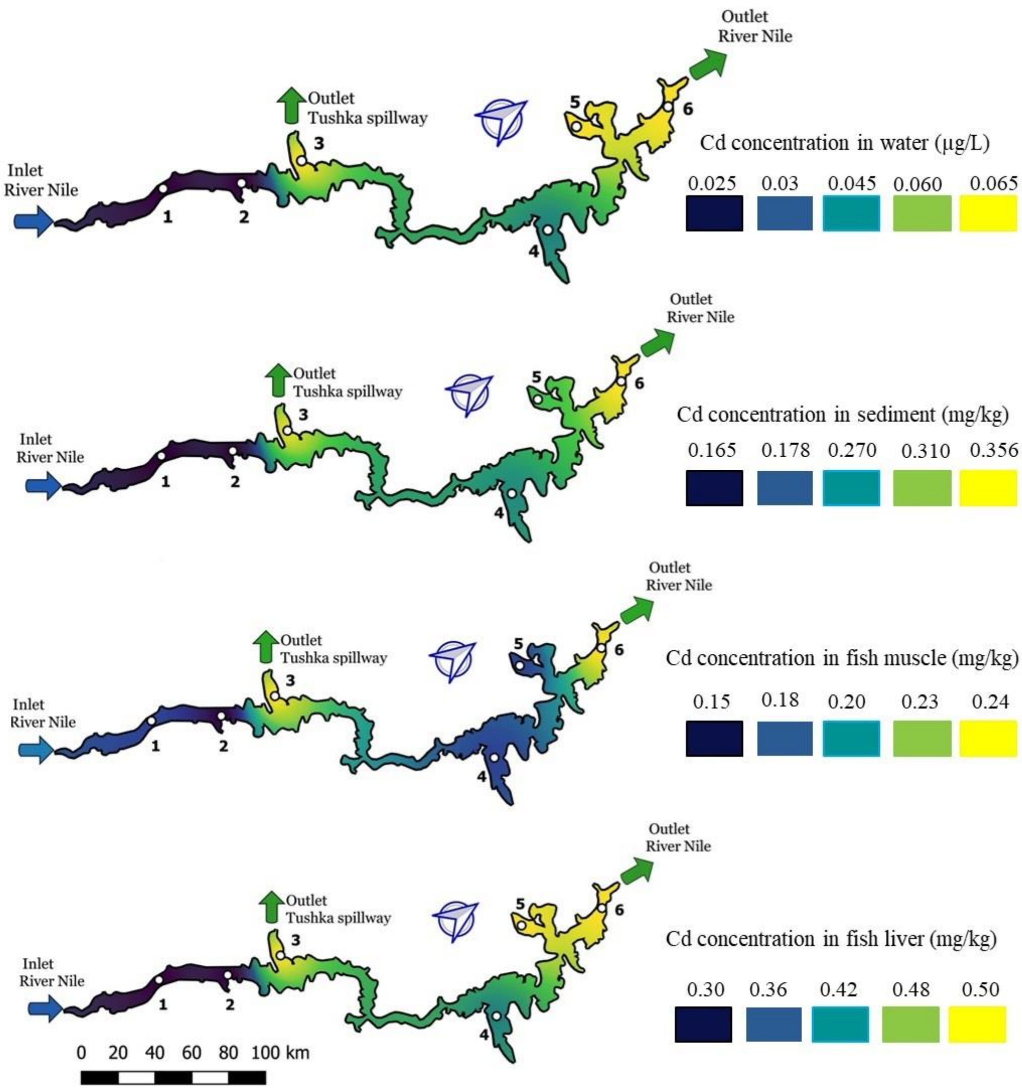


Fig. 28 Cadmium distribution along the lake in water, sediment, fish muscle and fish liver

The gradient of cadmium concentrations in samples was sediment > liver > muscle > water. The results showed that water exhibited the lowest concentrations (Table 13), whereas the sediment and liver samples exhibited the highest concentrations in the lake (0.3-0.5 and 0.18-0.356 mg/kg respectively). Trace concentrations of this metal can negatively affect the metabolism and growth of fish by altering their DNA structure, causing dysfunction, disruption of cell membranes, inhibition of enzyme activities and oxidative phosphorylation. Equally, it induces direct toxic effects in humans, through food intake. Cadmium bioaccumulation was reported to induce nephrotoxicity and cause a specific renal failure as well as other associated health issues [168].

4.2.1.5 MPI

The evaluated MPIs ranged from 0.63 mg/kg to 6.40 mg/kg with the mean of 3.54 mg/kg. The highest MPI value has been reported in fish liver samples at sites 6 and 3 (6.40 and 6.23 respectively) and in sediment was at sites 3 and 6 (5.57 and 5.23 respectively), while the lower MPI value were in fish Muscles at site 1 (0.63 mg/kg) (Fig. 29). The findings of MPI in the present study were much lower than that of *Rutilus rutilus* in Pluszne Lake [169]. To understand the ecological risk related to heavy metal contamination, metal pollution index (MPI) has been calculated. The MPI provides comprehensive information about metal toxicity in a particular sample and offers an understanding of the quality of the aquatic environment.

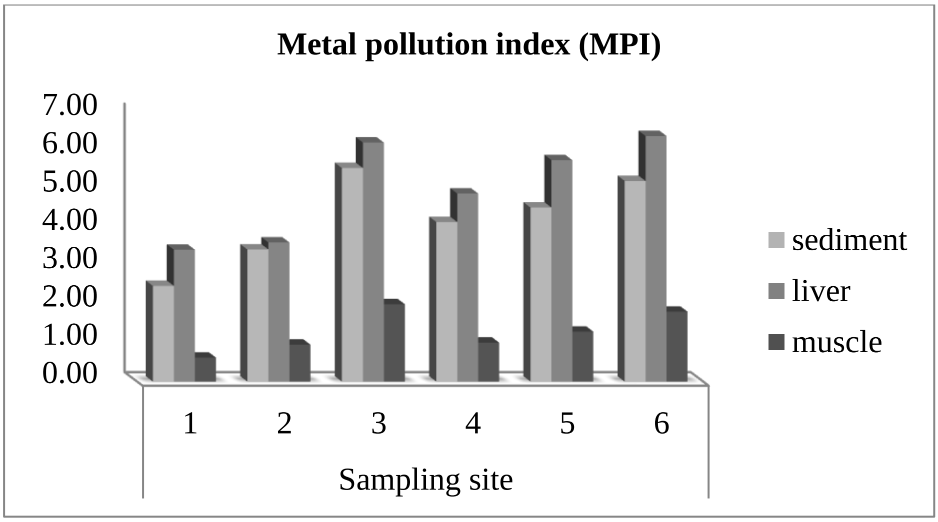


Fig. 29 Metal Pollution Index for each sampling site

The northern part of the lake showed higher contamination with heavy metals compared with the southern part, except site 3 which is highlighted by yellow in Fig. 30. The high recorded values for all measured heavy metals in this site are perhaps related to the ongoing agricultural activities in Tushka region, nearby Tushka spillway outlet. The overall water quality of Lake Nasser is below maximum distribution in water permissible levels of international standards and specifications. Therefore, it can be concluded that water of Lake Nasser is safe for human consumption, agricultural activities and animal husbandry. Maintaining the water quality of the lake within these acceptable values represents an important mission for the sustainable development in Egypt, therefore all necessary actions must be implemented for protection of Lake Nasser. Fig. 31 showed the correlation between the contamination with heavy metals and the types (i.e., water, sediment, liver and muscles) of investigated items. The cluster tree shows a high positive correlation between zinc and lead concentrations in water and its accumulation in sediment and fish liver (0.9 and 0.81; 0.94 and 0.93, respectively). The correlation between copper concentrations in water and fish muscle (0.88) was higher than that of liver samples (0.73).

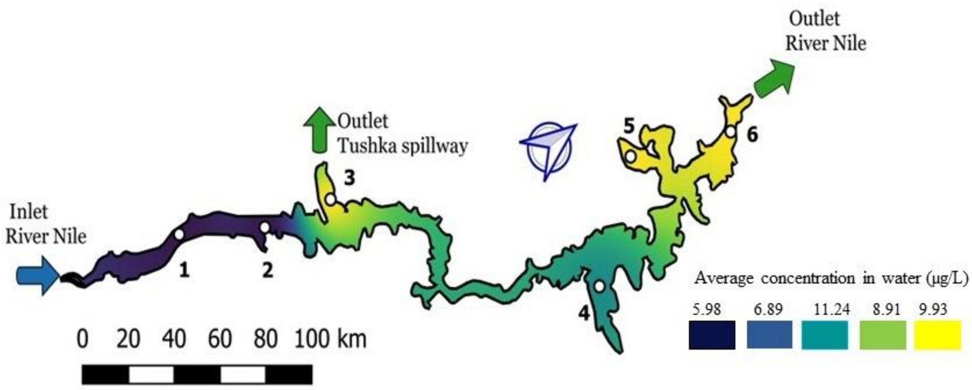


Fig. 30 General overview on Lake Nasser of mean concentrations of heavy metal

Copper is directed towards cell tissues in higher amounts than it does in liver, in order to participate in the protective role of the antioxidant enzymes. On the other hand, copper concentration in water exhibited a high positive correlation with sediment (0.91), given that the latter usually adsorbs the dissolved metals. In case of cadmium, the results showed a positive correlation between its concentration in water and in fish muscle, sediment and fish liver (0.91, 0.82 and 0.73 respectively). Fig. 31 confirmed the increased risk for cadmium, because this element does not accumulate in the sediment in a large amount. However, it does accumulate in muscle in greater proportion. That is emphasize that Cadmium is not essential for fishes' metabolic processes, and is potentially dangerous at lower concentrations compared to the essential metalloids [170]. Fish organs comprise an effective target for predicting the effects of water pollutants, as a result of the positive correlation between the bioaccumulation of heavy metals in fish tissues and their concentration in water. Therefore, the current study emphasized the importance of better understanding of heavy metals bioaccumulation in fish organs. Moreover, another aim of this survey was to provide a comprehensive image of the heavy metal status in this lake. One major advantage of the current study, as opposed to other previous attempts, was the high accuracy of heavy metal measurements by using certified reference materials (CRM) within certain ranges.

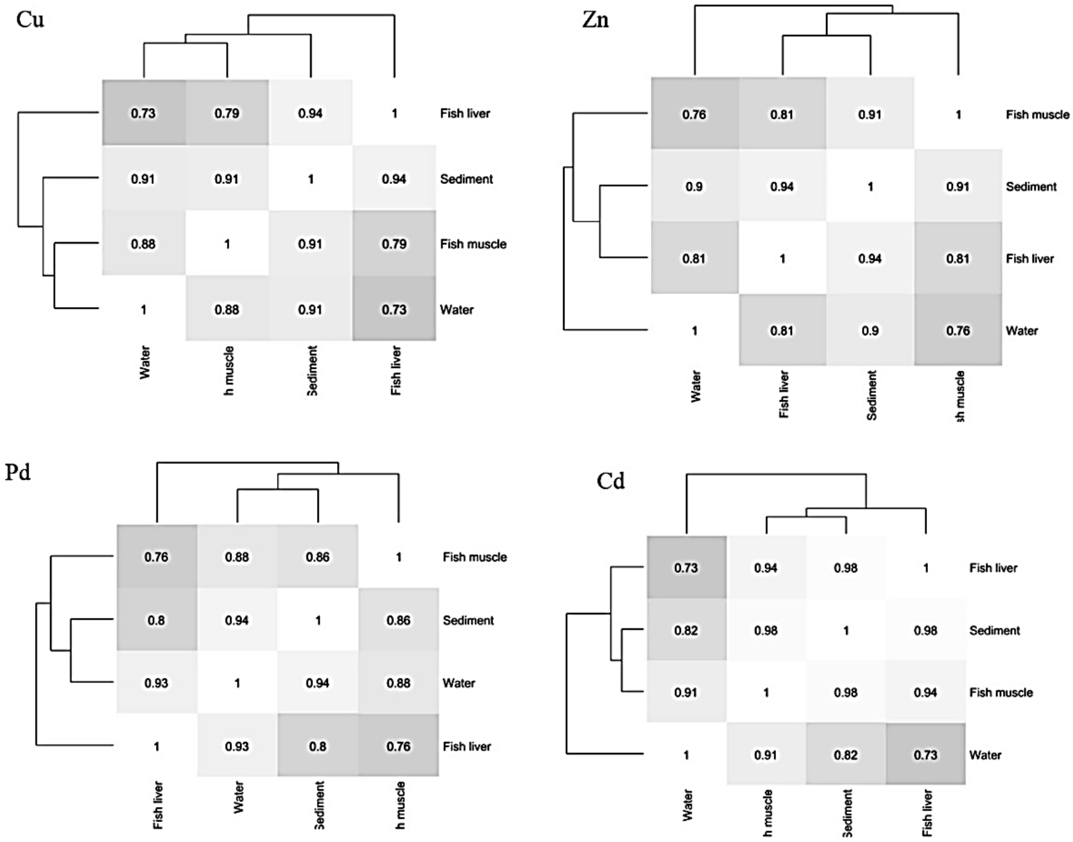


Fig. 31 Integrated correlations between elements in water, sediment, fish liver and fish muscles samples in Lake Nasser

4.2.2 Heavy metals contamination on Lake Balaton

HMs concentrations in water of Lake Balaton has summarized in Table 20. Cu, Zn, Pb and Cd were below the permissible limits values with relative elevation in western basin compared with the eastern basin. No significant difference has been reported between Tihany and Balatonfüred in case of Cd and Pb metals (Fig. 32). The small letter above the bar graphs a, b and c etc. show statistically significant difference between variables. In this procedure of statistical analysis sampling site considered as a factor could affect on HMs concentrations. The null hypothesis is there was no significant difference between sampling points.

Table 20 Concentration of Heavy metals in Balaton Lake and national and international guidelines limit values according to various standards (Mean ± SD)

Heavy metal concentrations (µg/L)	Measuring sites in Lake Balaton				limit values, µg/L			
	Western Basin	Eastern Basin						
	Keszthely	Tihany	Balatonfüred	Balatonalmádi	[a]GD 2010	[b]EQS	[c]CCME 2007	[d]USEPA 2018
Cu	0.819±0.035	0.40±0.0270	1.15±0.0168	0.37±0.0077	10	10	4.00	13.00
Zn	1.795±0.013	1.028±0.0790	1.34±0.0267	1.18±0.0563	75	10	50	50
Cd	0.018±0.003	0.004±0.0001	0.003±0.0002	0.006±0.0001	*0.08-0.25	≤0.08	1.00	10.00
Pb	0.102±0.001	0.008±0.0030	0.006±0.0002	0.012±0.0002	*0.3-1	1.20	10.00	15.00

The concentrations of cadmium, copper, lead and zinc proved to be much higher in organs of bream comparing to water samples. Among tissues, higher metal concentrations were found in liver samples. The comparison of HMs level in organs of fish population of Lake Balaton has given in Fig. 33. It presumes to be true until evidence indicates otherwise. If two variables have different letters, they are significantly different. Zn concentrations in liver showed higher significant concentration comparing to muscle and gills (b and c respectively). In case of Cu, the maximum concentrations have been reported in liver as well, followed by gills then muscle. Meanwhile, there is no significant difference between gills and muscle in case of Cd. This can be explained due to the major toxicity of cadmium. The importance of focusing on studying cadmium toxicity and its bioaccumulation in muscle because it is a highly toxic element as it accumulates in the tissues, which is the eatable part consumed by humans. Therefore, it was necessary to study the biological effect related to cadmium element in the biological cell deeply. Generally, Heavy metals can accumulate in the fish liver more than the tissue and gills [171].

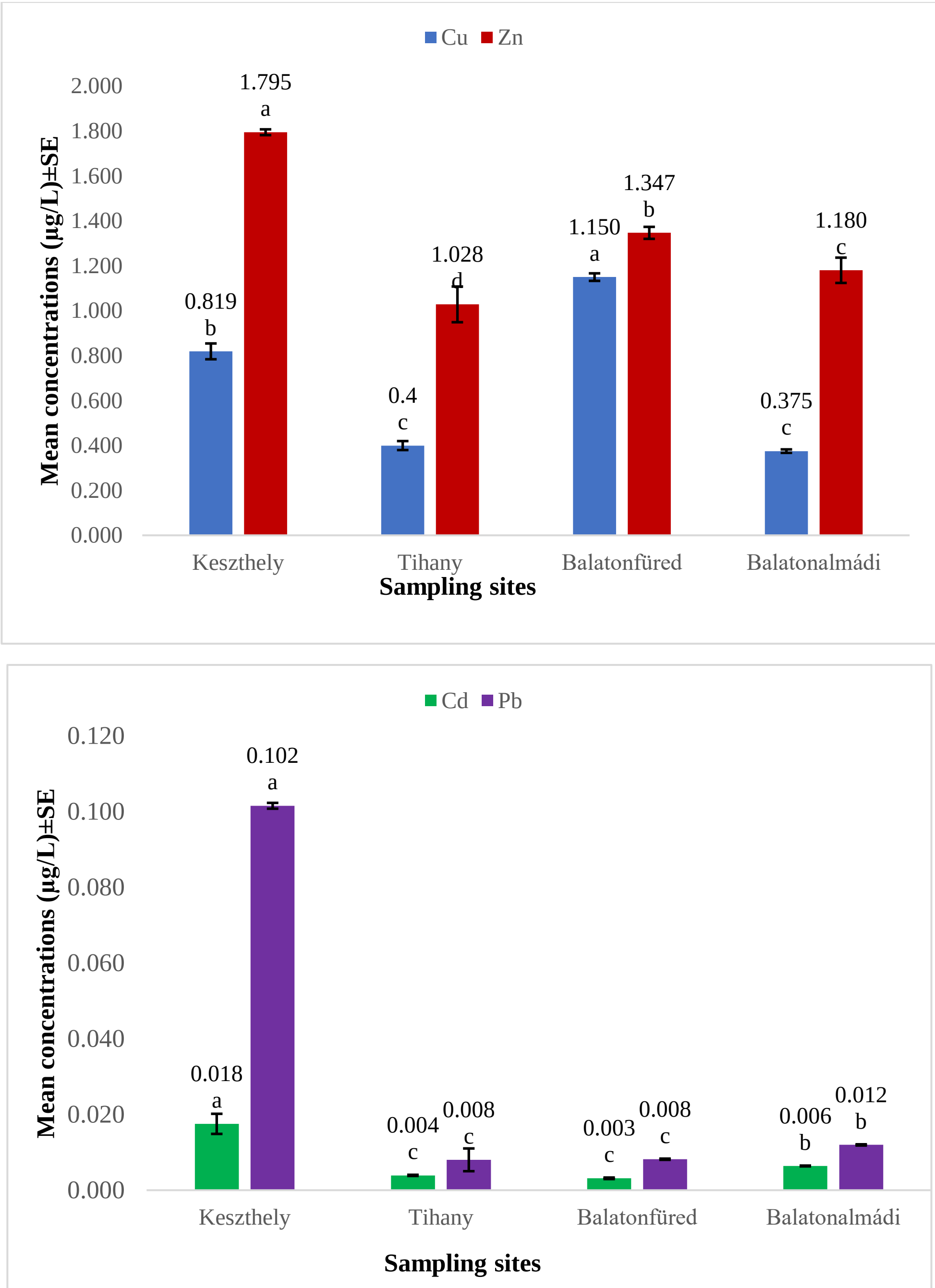


Fig. 32 Heavy metals concentrations in water of Lake Balaton (µg/L)

Data were expressed as mean ± SE. Differences among data were assessed statistically by one way analysis of variance (ANOVA) as sources of variation. A multiple f-test was used to determine significance among means for significant main effects. The level of significance was set at ($p < 0.05$) with a confidence level of 95%. a-c Means within a bar chart without common superscript letter are significantly different between sampling sites

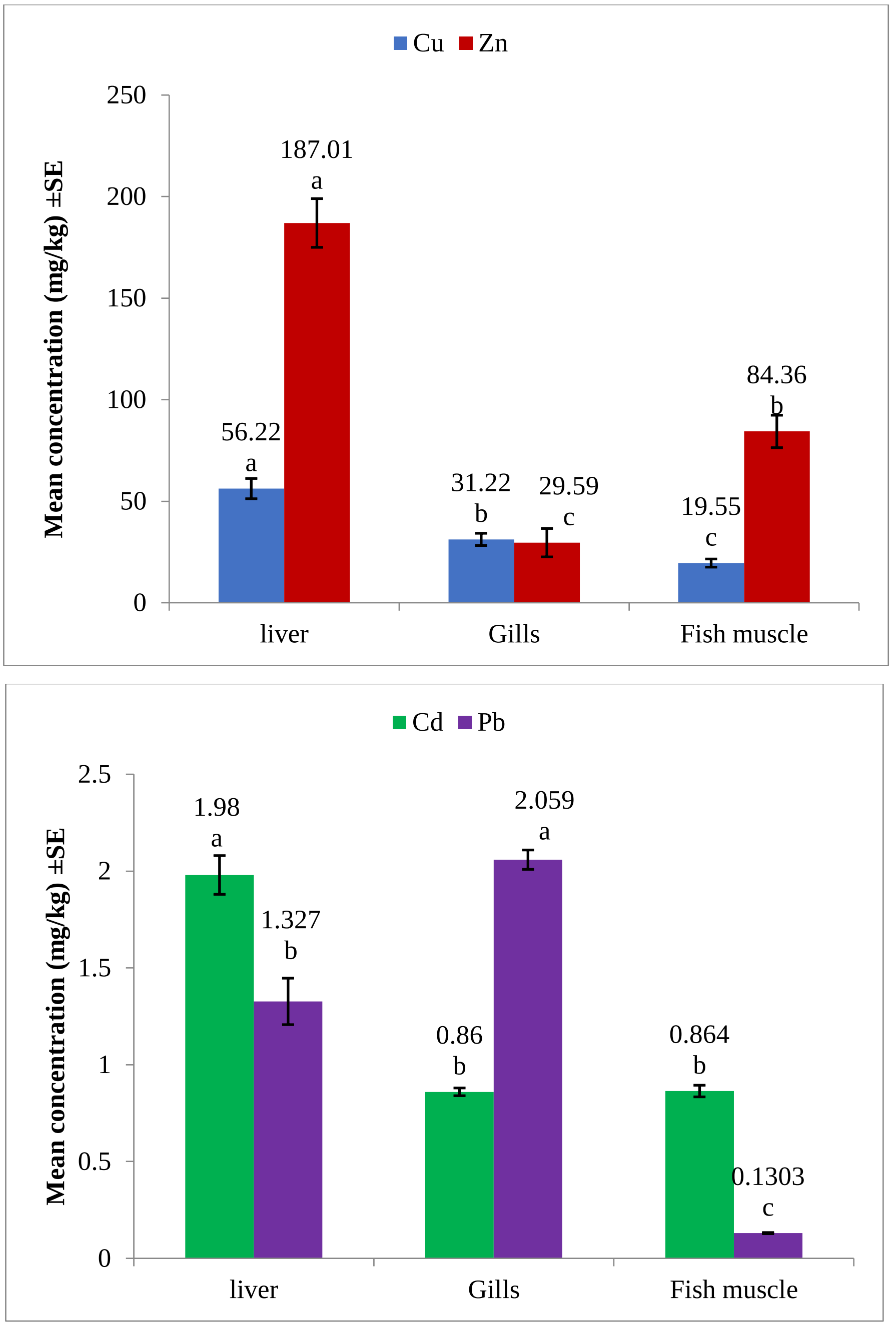


Fig. 33. Comparison of heavy metals level in organs of Bream (*Abramis brama* L.) fish population of Lake Balaton (mg/ kg)

Data were expressed as mean ± SE. Differences among data were assessed statistically by one way analysis of variance (ANOVA) as sources of variation. A multiple f-test was used to determine significance among means for significant main effects. The level of significance was set at ($p < 0.05$) with a confidence level of 95%. a-c Means within a bar chart without common superscript letter are significantly different between samples type

The result showed that the metal pollution index in liver samples significantly higher than gills and muscle (value 12.89, 6.36 and 3.69 respectively). (Fig. 34).

To understand the ecological risk related to heavy metal contamination, the metal pollution index (MPI) has been calculated. The MPI provided comprehensive information about the metal toxicity in a particular sample and offered a better understanding of the quality of aquatic environment [171].

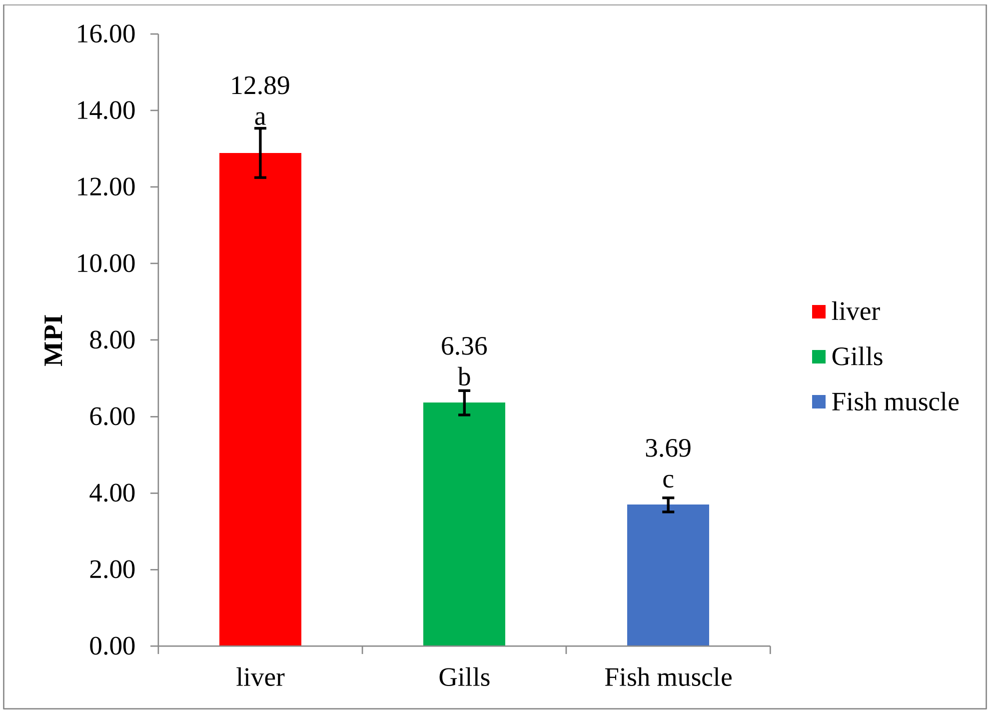


Fig. 34 Metal pollution index (MPI) of organs of Bream (*Abramis brama* L.) Fish Population of Lake Balaton

Data were expressed as mean ± SE. Differences among data were assessed statistically by one way analysis of variance (ANOVA) as sources of variation. A multiple f-test was used to determine significance among means for significant main effects. The level of significance was set at ($p < 0.05$) with a confidence level of 95%. a-c Means within a bar chart without common superscript letter are significantly different between samples type

Fig. 35 has showed the comparison between 2013, 2019, and 2021. The highest concentrations of Cd, Pb, and Cu has been reported in 2013 (Cd=0.86, Pb=0.37, and Cu=34.11). Meanwhile, the highest concentration of Zn was seen in 2019 and 2021 (84.36 and 82.12 respectively). There were no significant differences between 2019 and 2021 in the case of Cu and Zn, however, there was a highly significant difference between 2013, 2019, and 2021 in the case of Cd and Pb.

The results of 2021 showed a clear improvement compared to 2020 and 2019, which reflects the importance of applying the directive regulations. The most toxic trace elements have been decreased due to awareness of society to HMs danger.

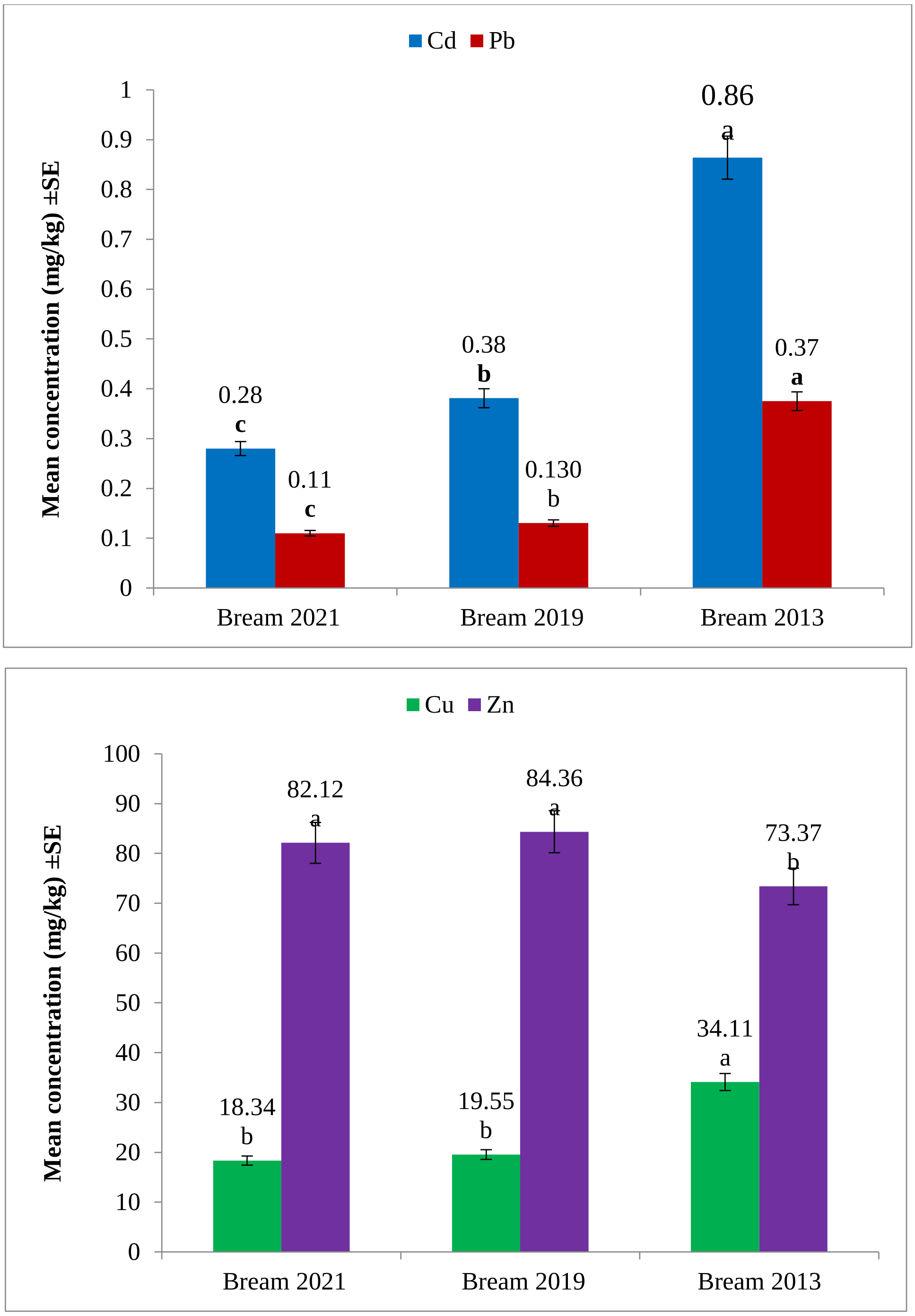


Fig. 35 Mean concentrations of Heavy metals on bream tissues collected in 2013, 2019 and 2021 from Lake Balaton (mg/kg), data were expressed as mean ± SE. Differences among data were assessed statistically by one way analysis of variance (ANOVA) as sources of variation. A multiple f-test was used to determine significance among means for significant main effects. The level of significance was set at ($p < 0.05$) with a confidence level of 95%. a-c Means within a bar chart without common superscript letter are significantly different between three selected years' time intervals

Cadmium induces harmful effect on living cells, their membrane deterioration and destroys the DNA structure. Such severe damage results from the displacement of these heavy metals from its original binding sites. This metal can negatively affect the metabolism and growth of fish by altering their DNA structure, causing dysfunction, disruption of cell membranes, inhibition of enzyme activities and oxidative phosphorylation. Toxic effects have been investigated include damage to the brain, kidney, and lungs [172]. Therefore, our finding indicated that there is a natural mechanism happened in the cells to detoxify the hazard effect of exposure to cadmium element. Which may explain the Zn^{2+} -mediated protection against Cd^{2+} -induced toxicity in these cells (Fig. 36). Zinc has been shown to antagonize the toxic effects of heavy metals such as Cd^{2+} in some systems [173].

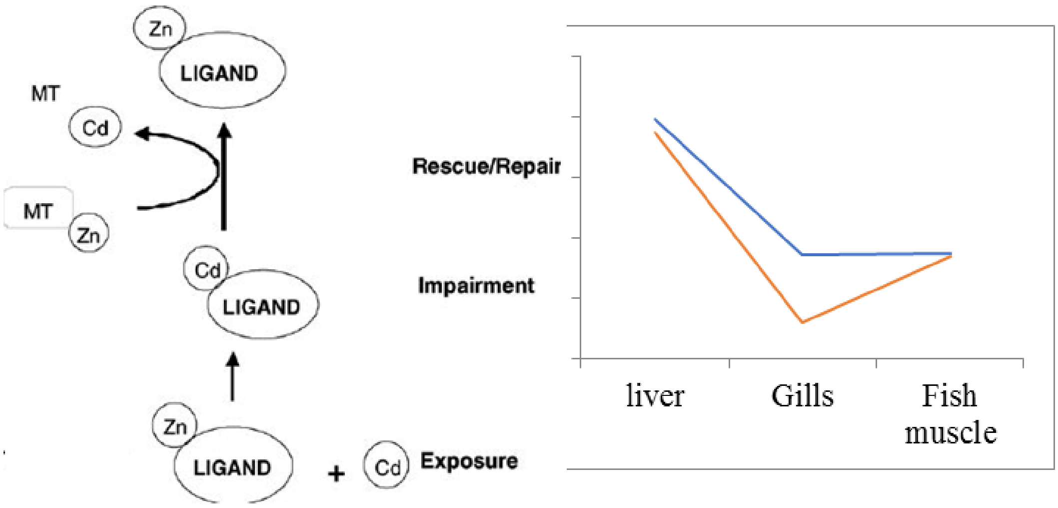
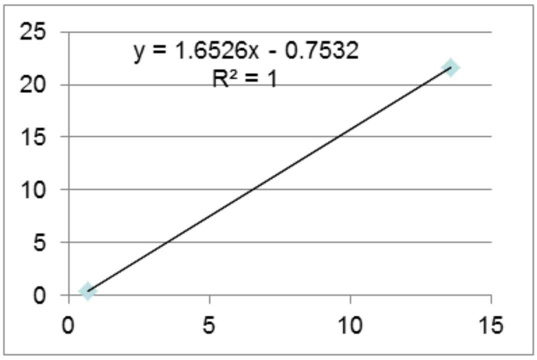


Fig. 36 Cellular mechanisms for heavy metal detoxification

The results indicated that heavy metals concentrations significantly improved in Lake Balaton. HMs source in the lake come from natural, industrial and agricultural sources which located in the catchment area. The anthropogenic heavy metal input originates from local municipal sources, waste deposits, heavy road and rail traffic along the 210-km-long lakeshore, boating, and atmospheric deposition [26]. Therefore, continuous monitoring and management must be provided to support decision-makers in assessing the health of Lake Balaton's aquatic environment.

4.2.2.1 Relation between concentration of heavy metals and fish size

Negative correlation has been detected between mean concentration of metals and fish size (Fig. 37). Table 21 showed the average whole weight of small size Bream was 28.29±0.20 g in comparison to the average weight of 2013 was 188.53±21 g. Mean concentration was 9.31±0.18 and 17.49±1.54 mg/kg respectively. Similar dependencies between element enrichment and age or size of fish samples were described by Garcia-Montelongo et al. [174] and [175]. In general, it has been accepted that the rate at which trace elements accumulate in living organisms is influenced by their specific uptake, detoxification, and elimination mechanisms [176]. Therefore, negative correlations between mineral concentration and fish size do not necessarily imply that there is a particular mineral concentration at the beginning of the growth period and no new mineral is absorbed; Rather, it is determined by the difference in the feeding rate with the developmental stage of the individuals. In agreement with this hypothesis are the following facts: (1) In low-pollution waters, minerals in fish are mainly absorbed by nutrition and (2) The feeding rate of fish decreases with the growth of individuals [26].



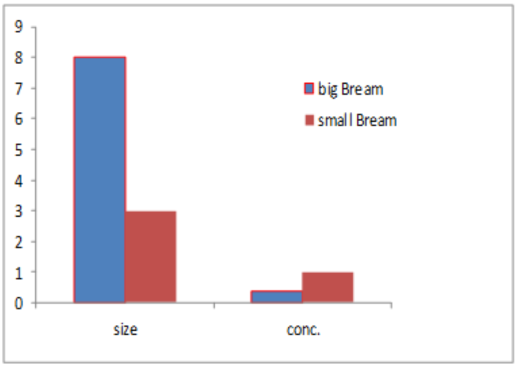


Fig. 37 Mean and standard deviation of heavy metal concentrations calculated per size classes in the tissues of bream collected from the Western basin of Lake Balaton

Table 21 Mean Length and weight of fish samples

	Small Bream size	**Big Bream size**
Latin name	*Abramis brama*	*Abramis brama*
Average length (cm)	12.5±0.11	21.66±0.86
Average whole weight (g)	28.29±0.20	188.53±21
Mean Conc. (mg/kg)	9.31±0.18	17.49±1.54

Consumption of fish is by far the most important source of exposure to HMs associated with ingestion in humans and animals, although plants and livestock also contain HMs due to the bioconcentration of seawater, fresh and marine waters. Human's risk ingesting dangerous levels of HMs when they eat contaminated fish. Because HMs are odorless and invisible and accumulate in the meat of fish, they are not easy to detect and cannot be avoided by trimming the skin or other parts. This study showed that the tested fish has no toxic level that causes health problems for humans. [177]

Heavy metal analyses in water and the edible parts of the fish indicated that water quality is good and fish are safe for human consumption. Heavy metal concentrations in fish muscles and livers meet the specifications stipulated by the international limits.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Lake Nasser

Lake Nasser, a man-made Lake, represents the national freshwater bank of Egypt. It is recognized that improving the water quality management in Egypt is an indispensable mean of the future and a mean to cope with the challenges of water scarcity and healthy water supply. It has been defined as a crucial development objective in governmental plans. However, the increasing pressure on water resources due to the increasing demand for a rapidly growing population and the heavy financial burden to achieve this goal is a real challenge. An important factor affecting the AEI value in Lake Nasser is the water temperature. It is the most important factor affecting on most of the physicochemical parameters in water of Lake Nasser.

In conclusion, the status of water quality management can be summarized in terms of completed, realized and ongoing procedures as follows: environmental protection procedures are being implemented, laws and regulations are in force, water quality standards are being developed, water monitoring and quality controls are in operation, etc. Egypt has made remarkable progress in water quality management over the last decades. Water quality of Lake Nasser is good and safe for all uses.

Lake Nasser serves as the national water reservoir in Egypt. Heavy metal analyses in water, sediment and edible parts of fish indicated that water quality is excellent and that the fish are safe for human consumption. The sediment fulfilled a major role by absorbing dissolved metals from the aqueous form. The concentration of heavy metals in fish muscles and livers meets the specifications stipulated by international limits. Therefore, continuous monitoring and management actions must be carried to support appropriate decision-making in assessing the health of Lake Nasser. The current study also strongly suggests that legal actions are needed to be implemented by authorities to overcome pollution in the adjacent areas of Lake Nasser by reducing future pollution levels. However, it was given that the current survey focused solely on a single fish species, future studies should widen their scope by including other aquatic organisms, such as other common fish species and macroinvertebrates.

5.2 Lake Balaton

The primary objective of using different environmental impact assessment methods in this work was to determine the state of water quality in Lake Balaton. TOPSIS & SAW methods declared water quality variations clearly as those were expected based on analysing water quality parameters. Based on the rankings of those methods water quality needs to be improved in western parts of the lake by using several geoengineering treatment techniques. Therefore, this technique can be used for environmental managers to make decisions easily where they are facing the implications of several complicated parameters. Conducting a water quality assessment is necessary for environmental managers to identify the vulnerability of the lake, and future plans are needed to upgrade water quality. TOPSIS and SAW methods are useful for ranking different sites along the lake, meanwhile, the advantage of AEI is that can apply to one site. The applications of using TOPSIS-based approaches became popular in water quality assessment techniques. Few kinds of research, however, consider correlation among water quality indicators or couple them with water quality standards in a reasonable manner. The major difference in MCDM evaluation methods and AEI assessment method is that contribution of WQI classes has been omitted in the calculation of MCDMs. The ranking method based on SRD utilizes a portion of information overlooked until now. SRD corresponds to the principle of parsimony; it provides an easy way to rank methods. The heavy metal analyses in water and the edible parts of the fish indicated that the water quality is good and the fish are safe for human consumption. The heavy metal concentrations in fish muscles and livers meet the specifications stipulated by the international limits. Heavy metals can accumulate in the fish liver more than the tissue and gills. In bio-monitoring studies regarding the heavy metal pollution of fish as indicator organisms, significant positive correlations could generally be observed between the level of heavy metals accumulated in the organs of fish and the pollutant load of the water. To understand the ecological risk related to heavy metal contamination, we calculated the metal pollution index, which provides comprehensive information about the metal toxicity in a particular sample and offers an understanding of the quality of aquatic environment. Therefore, continuous monitoring and management must be provided to support decision-makers in assessing the health of Lake Balaton’s aquatic environment.

6. NEW SCIENTIFIC FINDINGS

The new scientific findings obtained during my PhD research in several theses are as follows:

6.1 The application of various assessment techniques helps the interpretation of complex data matrices to better understand the water quality and the ecological status of the studied systems.

6.2 The application of a novel evaluation approach that enabled the integration of a wide range of physicochemical parameters recorded at a large spatial scale throughout the lake areas.

6.3 The demonstration of the multi-criteria decision-making techniques (TOPSIS, SAW) and AEI assessment used to characterize the quality status of the considered lakes provide reliable quality rankings of the study sites.

6.4 Indicating that the N- and P loads as factors with the greatest environmental risk for Lake Balaton, while for Lake Nasser, the most critical factor was proven to be the water temperature.

6.5 Declaration of the benefits of combining different methods are maximization of the advantages of these methods and avoidance of the inherent differences between methods, by promoting the Sum of ranking differences (SRD), a novel statistical method that is rapidly becoming popular in various fields of applied science.

6.6 Investigating a biomonitoring study regarding heavy metal pollution by analyzing water and fish samples in particular; liver, gills, and muscles.

6.7 The current study provides new data concerning the trace metal pollution of Lake Nasser and Lake Balaton and highlighted spatial-temporal trends in contamination.

6.8 Usage of a comprehensive evaluation method to evaluate the correlation between the contamination with heavy metals and sample types (i.e., water, sediment, liver, and muscles) of investigated items. The main evaluation indexes included the coefficient of determination (R^2), and Pearson correlation coefficient (Corr).

6.9 Investigating the ecological risk related to heavy metal contamination; the metal pollution index (MPI). Which provides comprehensive information about the metal toxicity in a particular sample and offers an understanding of the quality of the aquatic environment.

6.10 Investigating the effects of heavy metals bioaccumulation in the aquatic ecosystem, via water, sediments, and fish organs.

6.11 Confirming the successful finding that Zinc has been shown to antagonize the toxic effects of heavy metals such as Cd^{2+} in biological systems (detoxification effect).

6.12 Observation of the most toxic trace elements that have been decreased due to awareness of society to HMs danger.

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