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Review

Overview of the Eutrophication in Romanian Lakes and Reservoirs

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Abstract: In this paper, attention is drawn to the deterioration of Romanian surface water ecosystems due to eutrophication, an important environmental issue both at national and international levels. An inventory of existing studies dealing with the issue of the eutrophication of lakes and reservoirs in Romania is made, aiming to identify the main problems Romania is facing in monitoring, classifying, and managing eutrophic ecosystems. On Web of Science, the keyword "Eutrophication", with "Romania" as country/region, leads to 50 publications, which are analyzed in this review. The number of articles found does not reflect the real environmental issue represented by eutrophic lakes and reservoirs in Romania. At a national level, only 126 lakes and reservoirs have been monitored and assessed between 2018 and 2020, in terms of ecological status/ecological potential. Thus, at a global evaluation, 77% of natural lakes and 33% of artificial ones do not reach the quality objectives. The results of this study showed that the frequency of measurements taken by water quality indicators is not the strongest point of measurement campaigns, as it is not sufficient for the diagnosis of eutrophic lakes, and supplementary measures must be undertaken to better understand and mitigate this phenomenon.

Keywords: lake; reservoir; eutrophic; water quality; Romania; literature review

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1. Introduction

Water is an essential resource for humanity, especially in the context of climate change. As climate change progresses, the threat of excessive nutrient enrichment of aquatic ecosystems increases worldwide [1]. This aspect represents a major water resource management challenge, especially regarding the synergistic effects of the two phenomena [2]. An integrated understanding of how climate change affects nutrient dynamics and how they interactively determine algae flowering can support sustainable nutrient management and long-term policy making [3]. Climate change has a quantitative and qualitative impact on water resources. Therefore, increasing temperatures and evaporation lead to reduced water availability and increased demand. On the other hand, extreme events can cause much larger surface runoff and floods, which deteriorate water quality [4].

An example of qualitative degradation is water eutrophication, which is recognized as one of the biggest problems affecting water quality today. Eutrophication occurs when high concentrations of nutrients, such as nitrogen and phosphorus, are present in water, depending on hydrological conductors and mass balance in a water body and the corresponding catchment area. By releasing nutrients into the watershed from urban or agricultural sources, human activity essentially contributes to the emergence of artificial eutrophication, which modifies the color, taste, and smell of water, generating excessive algae flowering that can cause many problems, such as deoxygenation and water toxicity, ultimately disrupting the normal functioning of the ecosystems.

In 2008, eutrophication affected 37% of lakes and reservoirs worldwide and 53% of those in Europe [5]. Currently, the nutrient enrichment of aquatic ecosystems is considered by lake managers to be the most important stressor for lakes [6], followed by climate change, hydrological and morphological changes, and the introduction of alien species [7]. It is thus seen that global eutrophication is accelerating [8], which leads to water degradation, the loss of certain uses, and economic and health impacts [9]. That is why many lakes around the world are so damaged that they can no longer provide vital ecological services [10].

Eutrophication represents an anthropogenic pollution, requiring interdisciplinary knowledge to understand the phenomenon. Thus, in the specialized literature, the phenomenon of eutrophication is associated with limnology [11], agronomy [12], hydrology [13], climate science [4,14] water biology [15], and even social sciences [16,17]. The eutrophication of inland waters is currently prevented, managed, and remedied through management practices of aquatic ecosystems or land adjacent to them [18]. Thus, all nations are concerned with the protection and restoration of aquatic ecosystems through Sustainable Development Goal 6.6. Lake restoration programs have largely focused on reducing the nutrient load and mitigating the impact of eutrophication. By managing nutrients alone, however, the combined consequences of human activity and global climate change, which can influence quantitatively and qualitatively the volumes of water in lakes/reservoirs, cannot be countered [19]. Thus, experts consider necessary and urgent measures that could counteract the effects of climate change on the ecosystems of lakes [20]. Now, it is difficult to predict how the eutrophication of lakes will cope with various human stresses and climate change [21]. It is known that climate change alters the hydrological environment, increasing the vulnerability of ecosystems [22] and accentuating the eutrophication of lakes, but there are still less well-known phenomena, such as the seizure of organic carbon by lakes [23]. In this context, it is essential to monitor the water quality of lakes on a regional and global scale, as well as to develop effective methods of management of lake water, with an understanding and awareness of their trophic state.

One of the conclusions of the 5th Intergovernmental Panel on Climate Change (IPCC) Evaluation Report (AR5) was that algal flowering has increased in frequency and intensity due to global warming; however, there is limited evidence and low confidence in the future effects of climate change on the phenomenon of eutrophication [24]. Also, Saraiva et al. in 2019 predicted an intensification of eutrophication in the Baltic Sea by the end of the 21st century, under the auspices of climate warming and high nutrient loads [25]. In the work by Sinha et al. [26], the social decisions about climate change mitigation, which will dramatically impact eutrophication in the 21st century, were analyzed. They examined the impact of changes in land use and land management and concluded that excessive nitrogen runoff will greatly affect the global ecosystem. This study also identified the regions that are particularly susceptible to increases in eutrophication because of changes in rainfall and the large-scale use of fertilizers. Romania is among the most vulnerable regions, in terms of intensive application of fertilizers.

The water resources of Romania are quite modest, about 134.6 billion m^3, occupying the 21st place among the European states [27]. Romania's water resources consist of surface water—rivers, lakes, reservoirs, the Danube River (≈90%) and ground waters (≈10%). The water resources' temporal distribution is unequal: the Carpathians, with a surface area of 27.9% of the territory of Romania, accommodate 65.3% of the surface water resources; the most important volume of the river flow is registered during spring (50%). Because of the excessive use of surface water (lakes and rivers), in the last 50 years, the rapid exhaustion of water resources and a simultaneous increase in pollution were observed [28]. Therefore, it was necessary to prevalently build reservoirs.

Regarding the number and total surface area of the Romanian lakes, there is a certain dynamic; many natural lakes have disappeared by damming and draining, on the one hand, and others have appeared as a necessity to ensure the volumes of water for consumption, on the other hand [29]. Romania has built over 1900 reservoirs, so nowadays in Romania, about 3450 lakes and reservoirs occupy 2620 km^2, representing 1.1% of the total Romanian surface area. Of these lakes, only 372 have areas larger than 0.5 km^2, of which 117 are natural lakes and 255 are reservoirs. Of the natural lakes, 52% are in the Danube Delta. The natural lakes total around 2.3 billion m^3 of water and approximately 132.3 billion m^3 of water is stored in reservoirs [29].

The quality of Romanian waters is monitored by the National Administration "Romanian Waters" (NARW) and the frequency of measurement of physicochemical and biological data is according to the European norms. During 2018–2020, NARW monitored and assessed 1062 water bodies (rivers, lakes, and reservoirs) in terms of ecological status (for natural lakes)/ecological potential (for reservoirs). Among these, 26 are natural lakes, representing 2.45%, and 100 are heavily modified water bodies, representing 9.42%.

A general worsening in water quality, because of economic activity, population increase, and urbanization, led the European Union (EU) to create and enact the EU Water Framework Directive (WFD) [30]. The goal of this directive is to bring all ground and surface waters to "good status" (both ecologically and chemically) to safeguard biodiversity, natural ecosystems, human health, and the availability of clean water. The WFD states that a waterbody's ecological status should be determined by how different it is from the reference condition or the predicted ecological quality in the absence of human intervention and must be tailored to the specific types of lakes. The recommended frequency of surveillance monitoring parameters indicating the physicochemical quality and biological elements is given in the WFD, and the corresponding values for lakes and reservoirs are presented in Table 1. Also, according to the WFD, the EU member states are required to act if any of the monitored parameters exceed the threshold value, by switching to an intensive monitoring program [30].

Table 1. The recommended frequencies for lake monitoring parameters in the WFD, in months.

Biologic				Hydro-Morphologic		Physico-Chemical						
Phytoplankton	**Other Aquatic Flora**	**Macroinvertebrates**	**Fish**	**Hydrology**	**Morphology**	**Thermal Condition**	**Oxygenation**	**Salinity**	**Nutrient Status**	**Acidification Status**	**Other Pollutants**	**Priority Substances**
6	36	36	36	1	72	3	3	3	3	3	3	1

One of the significant issues in water management acknowledged by European water policy is the eutrophication of surface water bodies [31], and eutrophication indices are now used together with other indices to determine the ecological quality of water. By 2050, half of the world's population is expected to be at risk, due to the nutrient pollution and eutrophication of aquatic ecosystems, making it one of the most dangerous issues relating to water quality [32]. Thus, the effective management of nutrients is necessary to meet the water-related aims of the global Sustainable Development Goals (SDGs) [33].

The quality objective for a surface water body is considered to be achieved when the respective water body fits into the category of very good or good ecological status (for natural water bodies) or the category of maximum or good ecological potential (for reservoirs of heavily modified water bodies). According to NARW's evaluation of ecologic states, highlighted in Figure 1, of the 26 natural lakes, 27% have a good or high ecological status, 57.6% have a moderate ecological status, 7.7% have a poor ecological status, and 7.7% have a bad ecological status. From a physicochemical point of view, 38.5% of the natural lakes reach the quality objectives, while from a biological point of view, just 27% meet the quality criteria [29].

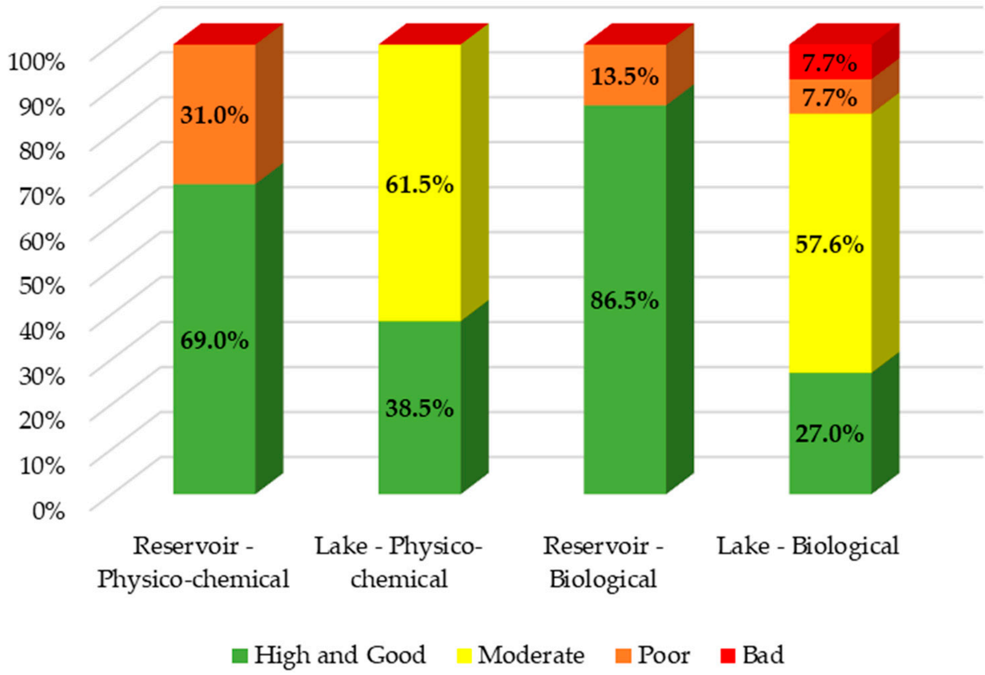


Figure 1. The trophic state of Romania's lakes/reservoirs according to NARW.

NARW specifies that the main reason for a failure to achieve the quality objective for natural lakes is the eutrophication process, which is can be due to the following reasons: (a) most of the monitored natural lakes are situated in areas of plains and are shallow (with depths between 3 and 7 m), which lead to the rapid development of algae (specially *Cyanophyceae*) during the summer; (b) in the proximity of these lakes, agricultural activities are mainly carried out, which lead to the enrichment of the water with nutrients; (c) near the lakes, there are also recreational areas, which affect the water quality; (d) the lakes age, which is a natural phenomenon that can affect the water quality. Referring to the assessment of the ecological potential of the surface water bodies, according to NARW, out of the 100 monitored water bodies, 69% have good ecological potential and 31% have moderate ecological potential [29].

The present document investigates how the publications in Romania reflect the potential impact that climate change could have on the phenomenon of eutrophication of water, but also how the Water Framework Directive has managed to bring about improvements in the diagnosis and rehabilitation of eutrophic and hyper-eutrophic ecosystems. In this context, a synthesis of the current literature that deals with the eutrophication of lakes and reservoirs in Romania is made, aiming to identify the main problems Romania is facing in the classification and management of eutrophic ecosystems. The main objective of the study is to improve the understanding of how the publications relate to the water quality data at national level and to facilitate the measurement of eutrophication, which is a challenging task.

2. Materials and Methods

This paper presents a mapping literature review of existing studies found in the Web of Science (WoS) database, regarding Romanian eutrophic lakes/reservoirs. WoS gives access to multiple databases that reference cross-disciplinary research, which allows for in-depth exploration of specialized sub-fields within an academic or scientific discipline [34].

As the eutrophication of aquatic systems has been a topic for academic and societal debate for the past five decades, a simple search in WoS with the keyword "eutrophication" leads to 37,654 studies that have investigated the relationship between eutrophication and water quality. The first studies related to eutrophication appeared in 1975 and the interest in this topic has constantly increased; there were six studies in 1975, but, for the last three years, there have been over 2500 studies published per year.

The search for this study was undertaken in October 2023, using the keyword "eutrophication", and choosing Romania as a country/region. As a result, 176 studies were listed, starting from 1992. Only the studies dealing with reservoir or lake eutrophication were kept in this list; 98 papers about the Black Sea's water quality issues were excluded, thus leaving 78 articles. Among these 78 papers, 22 have Romanian authors but do not refer to the eutrophication of the lakes in the Romanian territory, and 6 papers deal with water/air quality problems, but without correlating this phenomenon with eutrophication. Thus, these works were not considered in this study, with only 50 papers remaining for in-depth analysis. The methodology for the review of these 50 papers can be explained in the following two steps: (i) how eutrophication indicators were determined, either using the authors' own measurements or using NARW data; and (ii) measuring permanent changes in the trophic state of Romanian lakes, due to anthropogenic activities.

3. Results and Discussion

The results of this research indicate a reduced number of eutrophic lakes/reservoirs investigated, which is curious, considering that this is such an important topic.

Lakes and reservoirs are complex ecosystems because the interplay between their physical, chemical, and biological components determines their dynamics. The extent of their eutrophication can be assessed using eutrophication indicators, which provide information on nutrient concentrations, particularly those of phosphorus and nitrogen, as well as oxygen regime, water transparency, and chlorophyll a. Alternatively, specific indicators that consider direct human influences in the monitoring and evaluation of water quality have been proposed (hydroclimatology, socioeconomics, land use, lake characteristics, and so on) [3].

In line with global trends, Romanian research on eutrophication increased in the last decade (Figure 2) [34]. A list of the considered articles is available in the Appendix A. According to the data, two notable articles can be seen to correlate with the unfolding of national and international research grants/contracts (eight from twelve papers in 2017, three from five in 2020).

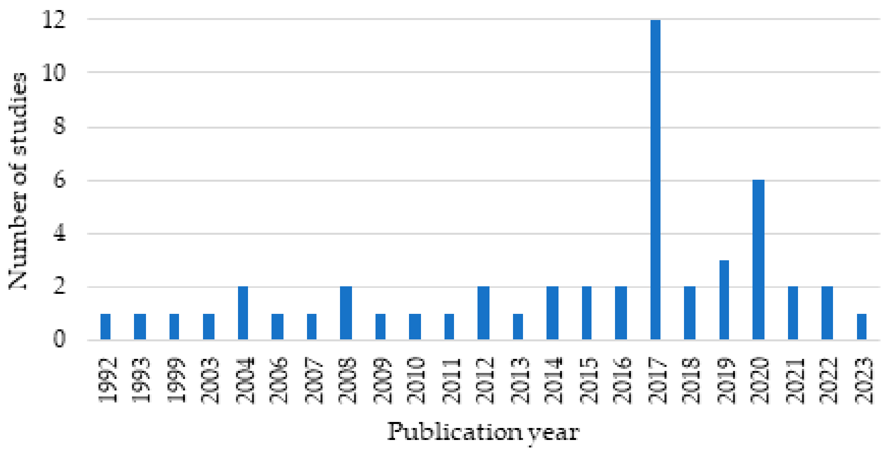


Figure 2. Number of studies on lake/reservoir eutrophication in Romania published per year.

Of the 50 analyzed papers, 17 are conference articles (of which 4 are published in journals), while 33 are journal papers. Some papers present the results of international projects, so there are also authors from 17 other countries, not only from Romania. There are 155 keywords defined by the authors, but eutrophication, water quality, and nutrients are the ones that appear most frequently, at 23, 10, and 7 times, respectively. The most cited works are ref. [35] with 120 citations, ref. [28] with 35 citations, ref. [36] with 31 citations, and ref. [37] with 26 citations; 14 studies do not have any citations yet.

Out of 50 studies, 21 assess water quality indices (eutrophication indices), 8 use water quality models, 14 address how eutrophication affects aquatic organisms, and 7 present ways and equipment to rehabilitate eutrophic ecosystems, as shown in Figure 3. As can be seen, out of the total studies, 32 are based on the measurements of the authors, 14 assess the trophic stage based on the measurements made by NARW, and 4 studies do not contain measurements. Also, five articles use both their own experimental data and the data monitored/measured by NARW. There is also a study that is based on data monitored by the Hungarian state for a cross-border river, the Tisa River.

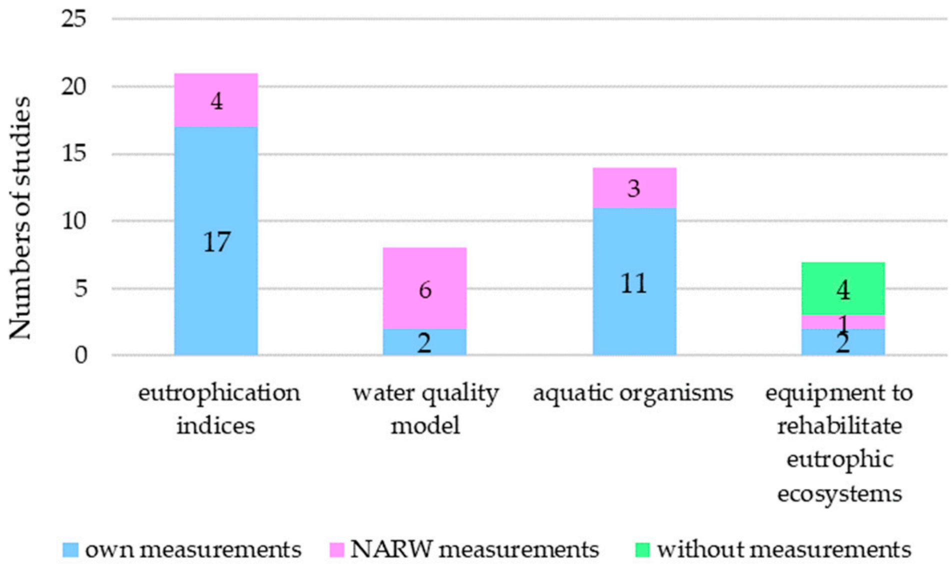


Figure 3. Number of studies on eutrophic lakes/reservoirs in Romania, by subject and data used.

In the analyzed manuscripts, 20 lakes and reservoirs were studied: 13 natural and 7 artificial. Thus, the percentage of Romanian lakes that have been the topic of published works on eutrophication is less than 5% of the country's total lake ecosystems. There is an overall study on all lakes in Romania, and 17 works that analyze the trophic evolution of some lakes in the Danube Delta. In this inventory of studied lakes, all the lakes in the Danube Delta are considered as one whole.

In 2009, NARW published a report regarding the national water trophic state and presented a map containing the investigated water bodies [38]. This map is presented in Figure 4, where the 20 lakes and reservoirs from the analyzed works are also highlighted; the bigger the circle, the higher the number of studies on that specific reservoir. The name of the lakes/reservoirs and their corresponding number is presented in Appendix A. Most studies deal with lakes and reservoirs in hilly and plain areas, where the trophic state of water bodies is more vulnerable. Considering the results of the national Integrated Nutrient Pollution Control Project, which specifies the area susceptible to pollution with nutrients, it can be noticed that only a few lakes and reservoirs (5, 8, 9, 13) are placed in clean zones. Also, the project does not present any data for the Danube Delta or the Black Sea coast [39].

It is also observed that the interest for some lakes is higher than for others, which is reflected in the number of existing studies for the same lake. Of the 50 studies regarding the eutrophication of lakes in Romania, almost 34% deal with the problem of natural lakes in the Danube Delta, approximately 12% study the trophic state of the anthropic lakes near Bucharest, 6% study the Izvorul Muntelui reservoir, which is the largest reservoir on the inland rivers, and 6% study the cascade of hydropower reservoirs on the Bistrița river (downstream of the Izvorul Muntelui reservoir).

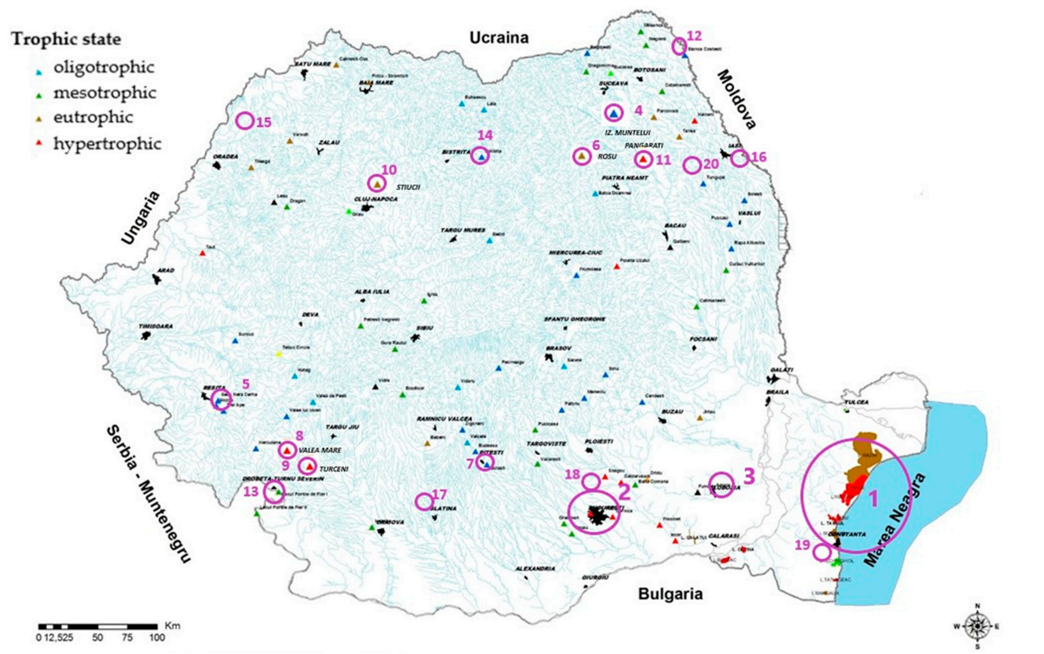


Figure 4. Distribution of lakes and reservoirs (including their trophic state) on the Romanian territory [38].

A summary of the bibliographical analyzed sources is presented further on.

Romanescu et al., in 2014, conducted a thorough examination of the quality and physicochemical properties of Romanian lacustrine systems [28]. It was the first national study of this kind, based on the authors' own measurement data recorded over ten years (from 2001 to 2010), in addition to data from NARW. The study reports that the majority of the anthropic lacustrine surfaces are found in the central (Transylvania) and northeast (Moldavia) regions, and the majority of reservoirs were constructed in mountainous regions (for flood control and hydroelectric power) and in dry regions (for water supply and irrigation). In terms of trophicity, the study notes that there are 17 oligotrophic lakes and 33 hypertrophic lakes, while the remaining ones (86) are classified as intermediate.

As mentioned before, most papers study the natural lakes in the Danube Delta.

The first study appeared in 1992 and pointed out that the increase in the nutrient loads, as well as in the phosphorus (P) -nitrogen (N) ratio, in the Danube waters, were the main factors that induced the upward development of the trophic state in the Danube Delta lakes [40]. From 1980 to 1989, the total reactive phosphorus concentration (TRP) in the lower part of the Danube river grew by about 5.7 times, while the atomic N–P ratio lowered by 25–85 times. In 1993, Cristofor et al. analyzed the concentration of TRP and DIN between November 1985 and November 1990 [37]. For nitrogen, the lowest values of 0.1 mg/L were recorded in October 1989 and 1990, while the highest was 1.8 mg/L in April 1988. For dissolved phosphorus, the highest value of 0.3 mg/L was recorded in August 1989, and the lowest of 0.02 mg/L in April 1986. Coops et al. (1999) investigated the state of the lakes in the Danube Delta based on satellite images, which investigated the turbidity and algae biomass in the water mass [36]. The analyses carried out correlated with the effects of climate change, so the authors investigated the effects that decreasing water levels, rising temperatures, and changing the residence time of water had on the ecosystems studied. The researchers suggest that the management policy of the Danube Delta should allow for the maintenance of intermediate levels of connectivity (for example, by blocking certain channels), to be able to avoid the predominance of macrophytes attributed to the intensification of eutrophication. Cristofor et al., in 2003, reported that the biodiversity and productivity of aquatic systems have been disrupted by the drainage of about 80% of the former flood plan, a decrease of approx. 45% of the sediment transport capacity and the flood mitigation capacity of about 4.5 km^3, as well as the chemical changes in water and sediment caused mainly by rapid eutrophication [41]. Thus, the process of eutrophication was initiated on the one hand by the characteristics of the lakes, and on the other, by the nutrient's regime.

Cremer et al., in 2004, conducted a pilot study aiming to verify whether diatomic assemblies have the potential to reconstruct the history of eutrophication of the Danube Delta lakes [42]. They note that the available database of limnological parameters is relatively small and should therefore be expanded during future monitoring campaigns. It also concludes that the sequence of sedimentary diatoms does not reflect eutrophication trends in the delta lakes. The average total phosphorus (TP) concentration ranges from 0.08 to 0.150 mg/L stating that most lakes recently are eutrophic or even hypertrophic. Regarding the taxa found, it identifies 234 diatoms (57 genera). Geta et al. in 2004 reported that, between 1992 and 1993, the concentrations of TRP (0.0133 up to 0.953 mg/L) and dissolved inorganic nitrogen (DIN) (0.15 up to 0.65 mg/L) were higher than the reference values (1980–1982) (0.003–0.034 mg/L for TRP and 0.09–0.8 mg/L for DIN). The continuous decrease in the N–P ratio is also noted, demonstrating that phosphorus was gradually replaced by nitrogen as a limiting factor, which is supported by the observed changes in the composition of phytoplankton, from the predominance of green algae to blue-green algae [43]. In 2006, Galatchi et al. reported the mean values of inorganic constituents obtained during a measurement campaign spanning from 1997 to 2000 [44]. The pH levels varied between 7.65 and 8.40, dissolved oxygen between 7.5 and 10.3 mg/L, and mean transparency between 19 and 112 cm. TP concentration shows important variation, from 0.0097 up to 1.033 mg/L, while the total nitrogen (TN) ranged from 0.0362 to 6.335 mg/L, leading to a high variation in the ratio N–P of 1 to 59.75. Godeanu et al., in 2007, identified three main causes of the appearance of eutrophication in the lakes associated with the Danube Delta, namely the over-administration of chemical fertilizers, which, by washing of precipitation, reached the bodies of water, and fisheries contributing to the supply of substantial amounts of nutrients and non-conforming trash pitches that brought additional quantities of organic substances, carbohydrates, oils, detergents, etc. to the lakes [45]. Thus, based on studies carried out between 1993 and 2005, it was determined that it was imperative to take urgent measures, specific to each lake, to effectively combat the eutrophication process. It was noted that the number of taxon of the zooplankton organisms was relatively reduced, varying between 12 and 44, suggesting that there is not great biodiversity as a result of the instability of the ecosystem, caused by the pollution. Regarding the values of different water quality indicators, the study reported that transparency varied between 21 and 51 cm, dissolved oxygen between 5.94 and 10.30 mg/L, TN from 0.13 up to 3.5 mg/L, and TP from 0.015 to 1.25 mg/L. The N–P ratio varied between 1.72 and 59.72. To mitigate the eutrophication in Lake Tașaul, associated with the Danube Delta, Alexandrov, in 2009, recommended reducing the intake of nutrients from sources associated with the river Casimcea (estimated to contribute approx. 3 tons TP/year and 660 tons TN/year), but also carrying out detailed and systematic monitoring of the water in the lake. For assessing the eutrophic state of the lake, the study used eight sampling stations (with data collected between 2005 and 2007) and the water quality indicators' values were as follows: pH levels between 7.6 and 9.6, DO between 3.9 and 17.1 mg/L, TN from 0.85 up to 3.8 mg/L, TP from 0.023 to 0.9 mg/L, and chlorophyll a (Chl a) from 0.009 to 0.42 mg/L. The N–P ratio varied between 4.7 and 451 [46]. A spectral analysis of specific phytoplankton pigments was applied by Torok et al. in 2017 as a diagnostic marker to establish the distribution and composition of phytoplankton taxonomic groups [47]. Sampling campaigns were performed throughout 2014, and nine sampling points were established. The study reports a transparency value between 100 and 220 cm, a saturated dissolved oxygen (DO) value from 3.22 to 11.27%, TP from 0.008 to 0.49 mg/L, TN from 0.246 to 0.866 mg/L, and Chl a from 3.23 to 28.45 mg/L. Enache et al., in 2019, investigated *Daphnia* distribution and abundance in 24 lakes from the Danube Delta, considering food accessibility and several abiotic parameters (depth, turbidity, pH, and so on) [48]. The study reported a negative correlation between Daphnia density and transparency and a positive one with turbidity, suggesting that Daphnia may play a less important role in the food web of the Danube Delta lakes than in some other European shallow lakes. It also suggested that a more extensive project would be needed to understand the complex and dynamic lake ecosystems in the Danube Delta.

Banaduc et al., in 2020, found that climate change in the lower Danube basin affected the ecological state of the lakes studied, inducing potential risks in terms of natural products and services [49]. Thus, these lakes can be negatively influenced by the decline in the quality and quantity of the water, the increase in the quantities of suspensive materials and nutrients, the intensification of the phenomenon of eutrophication, and the increasingly low hydrological connectivity. For analyzing the variability of the habitat, the study considered three types of variables: geographical, hydromorphological, and eutrophication (alkalinity, conductivity, total phosphorus, and chlorophyll a). It was concluded that synergic effects between geographical and eutrophication variables induced 82.95% of the community variance. Ispas et al. found in 2020, through their own measurements, that the lakes associated with the Danube Delta did not comply with the maximum permitted limits in terms of nitrogen and phosphorus content, sulfates, and detergents, which highlighted the more pronounced incidence of eutrophication [50]. In this regard, the authors recommended the more efficient management of water resources, with the controlling of eutrophication factors, reducing the anthropogenic impact on the environment, and the systematic monitoring of water quality. The N–P ratio varied between 5.72 and 68.53. The study, which used samples from 14 sampling stations, reported that, in terms of eutrophication, the indicators of TN (1.25 to 5.25 mg/L) and TP (0.08 to 0.33 mg/L) corresponded to the eutro-hypertrophic and hypertrophic stages, respectively. Other water quality indicator values were a transparency of 20 cm, a pH level of 8.33 to 10.33, and a DO value between 12.78 and 17.80 mg/L. Florescu et al., in 2022, studied the structure of the plankton community in the Danube Delta (Romania) and its relationships with environmental variables. Incident light, lake depth, surface area, and water conductivity were found to be important in controlling the variation in the structure of the plankton assemblages [51]. Also, they suggested the possibility of using, besides phytoplankton, nine species of zooplankton (rotifers) as indicators of specific environmental parameters.

Three of the examined papers address the issue of Danube water pollution, more specifically reservoirs and eutrophication-related phenomena. Cioboiu and Brezeanu, in 2017, noted the negative effects generated by hydro-technical constructions on the lower course of the Danube, including the development of the eutrophication process in the artificial lake ecosystems arising through these arrangements [52]. This study on the Iron Gate I reservoir, which relied on measurements presented in other studies, identified four stages in the development of zooplankton, with the first stage being characterized by an explosive increase in the zooplankton density and the last stage corresponding to the stabilization of the density number and the biomass at the level registered in 1974. The structure of the benthal invertebrates, e.g., zoobenthos, that used to populate the Danube has drastically changed; during the first year after the construction of the reservoir, 353 taxa disappeared (identified by the total or partial disappearance of the cryophilic, rheophilic and stagnophilic benthic populations). Nowadays, only about 90 taxa have been identified, but the loss in biodiversity did not mean a reduction in density and biomass. Ichthyofauna changed as well, and the number of species that feed on zooplankton increased. In Krtolica et al.'s study from 2021, three multilayer feed-forward neural networks with backpropagation learning were constructed for the prediction of water quality classes (for dissolved oxygen, nitrate–nitrogen, and orthophosphates) [53]. The dissolved oxygen model yielded the best prediction performances, with a prediction rate of 82.93%, an absolute error of 3.04%, and a good agreement between the predicted and measured water quality classes, as indicated by the model's Kappa Index value of 0.61. The other two models were also relatively good for prediction, having the following values: a prediction rate of 74.80% and 0.64 Kappa Index for NO_3, and, respectively, 71.55% and 0.17 for PO_4. Stankovic et al., in 2023, used macrophyte presence–absence data obtained from the Joint Danube

Survey (JDS3) to predict the water quality of the Danube River, pointing out the differences caused by the Iron Gates dam [54]. For each water quality variable (dissolved oxygen, nitrate–nitrogen, and orthophosphates), a multi-layer feed-forward artificial neural network model (ANN) was constructed. It also concluded that phytoplankton can be used to reveal hydromorphological degradation, being strongly influenced by extended residence time and hydrological obstacles. Furthermore, average site data demonstrated a definite positive correlation between phytoplankton biomass, TP, and TN, demonstrating once more the usefulness of phytoplankton as a biological quality component for evaluating the ecological state of the Danube. The disturbance of longitudinal connectivity resulted in an abnormally high concentration of Chl a in the Middle Danube, relative to the Lower Danube. Nonetheless, the study reported a strong correlation found between the Chl a and the total forms of nutrients, as well as between TP and Chl a ($p = 0.0012$); however, the TN–TP ratio seemed to be marginally significant ($p = 0.0577$).

Among the works examined, seven deal with the problem of eutrophication of lakes located around Bucharest, the capital of Romania. Among them, Anghel et al. in the year 2017 found that the level of contamination of the water in the lakes in the metropolitan area of Bucharest–Ilfov remained low during the monitoring period of 2013–2015 [55]. They appreciate that, in order to characterize the eutrophication process, it is not enough to sporadically evaluate these lakes by measuring the levels of concentration of nutrients; instead, systematic campaigns of measuring are necessary. In terms of water quality data, the values reported were pH levels ranging from 6.880 to 7.740, TP values between 0.017 and 0.230 mg/L, TN values from 0.05 to 1.276 mg/L, and biochemical oxygen demand (BOD) values from 0.000 to 2.520 mg/L. In the same year, Marcu et al. investigated the water quality of the lakes in Bucharest, finding that the excessive growth of algae species was correlated with high concentrations of phosphorus, carbon, and nitrogen, which amplified the phenomenon of eutrophication. Their results highlighted the increase in the content of adsorbed phosphates during the summer period and the decrease in the early autumn. It was also found that organic nitrogen accounts for 99% of the total nitrogen, while ammonia was best represented among ionic nitrate species, followed by nitrates and nitrites. The results of the water quality indicators reported were pH levels from 7.5 to 9.43, TP values between 0.07 and 0.46 mg/L, DO values from 7.58 to 9.43 mg/L, BOD values from 3.39 to 8.73 mg/L, and TN values ranging from 1.52 to 3.79 mg/L [56,57]. Stefan et al. also investigated the trophic stage of Snagov Lake, using data collected between April 2010 and October 2014 [58]. The results showed that the lake was eutrophic–hypereutrophic for all the parameters used for assessment. The values for the quality indicators reported were pH levels of 7.45–9.53, TP values of 0.007–0.28 mg/L, DO values of 5.1–21.9 mg/L, Chl a values of 0–0.138 mg/L, and a N–P ratio of 0.12–84.3. These values are likely due to lakes around Bucharest being contaminated by surface leaks and illegal spills of sewage and effluents, which generate increased eutrophication. Moreover, Dontu et al. conducted a study over 6 months, in 2017, to develop a preliminary database with fluorescent spectral data for Bucharest lakes [59]. The results showed a decrease in the fluorescence intensity of the microbial fraction of organic matter from spring to summer, while, in autumn, the values increased. The humic fraction of organic matter, which depends on the amount of precipitation, showed an opposite trend, with an increased release to the surface of the water mass during the summer.

In 2019, Radu et al., in their study on the assessment of the trophic state of lakes around Bucharest, found a higher level of nutrients than the limit permitted by law and a significant accumulation of nitrogen and phosphorus in the sediment layers, due to agricultural activities but also uncontrolled waste storage [60]. To remedy this situation, the authors suggested improving the local sanitation infrastructure and implementing appropriate sewerage systems. The data reported for water quality indicators were pH levels of 7.3–8.1, TP values of 0.005–0.35 mg/L, DO values of 2.9–9 mg/L, Chl a values of 0–0.138 mg/L, and a N–P ratio of 0.12–84.3. On the other hand, Popa et al., in 2020, measured the total concentration of organochlorine pesticides (OCPs) in the water of the lakes in the Bucharest area and compared it with the consensus-based sediment quality guidelines, to evaluate the ecological risks of sediments [61]. The total concentration of OCPs in water ranged between 0.0176 and 37.1 µg/L, while the pH level varied between 7.00 and 8.03 and the TN level between 1.1 and 6.8 mg/L. The highest potential adverse effects were associated with gamma-hexachlorocyclohexane exposure. The periodical draining and dredging of lakes lead to the resuspension of contaminants, increasing pesticide bioavailability and accumulation in sediments. In addition, it was observed that fluorescent dissolved organic matter might influence the OCP cycle.

As a result of anthropogenic pressures, phytoplankton in urban aquatic ecosystems (i.e., Bucharest lakes) had a diminished qualitative and quantitative capacity to maintain a good health condition, which had effects on the food web, as reported by Florescu et al. in 2022. The ecological status, as assessed by chlorophyll a, highlights that most of the investigated lakes were eutrophic and hypereutrophic [62]. The water quality values presented were pH levels from 6.30 to 10.66, DO values from 1.67 to 34.81 mg/L, DO% (saturation) ranging from 5.86 to 158, transparency values of 15–170 cm, TP values of 0.28–0.87 mg/L, and Chl a values of 0.032–68.83 mg/L.

Axinte et al. were concerned about the evolution of Lake Amara, so, in 2015, based on indicators of eutrophication, they included the lake in the eutrophic category [63]. However, there were existing fluctuations that were mainly determined by the climatic regime of the year, especially during summer. Thus, the influence of temperature changes on the proliferation of algae led to stand-out results: in the warmer years, like 2005 and 2012, the high nutrient concentrations and warm temperatures stimulated phytoplankton growth, while in 2007, a normal year regarding the temperature, the phytoplankton growth was lower. An analysis of the phenomenon of eutrophication correlated with climate variability was observed here. The reported values were TP values of 0.05–0.37 mg/L, TN values of 0.35–1.42 mg/L, and Chl a values of 1–10.3 mg/L. Later, in 2017, Axinte et al. performed a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the Amara Lake ecosystem to find the most adequate management solution, considering the forestation of the shore of the lake with *Acer campestre* [64]. The effects of this solution were evaluated by monitoring six years (2010–2015) of three water quality indicators: TP, with values of 0.017–0.23 mg/L, TN, with values of 0.023–1.27 mg/L, and pH, with levels of 6.88–7.74. The results of the water quality investigations performed led to the conclusion that, when considering the TP content, Amara Lake would return to a proper state only after 73 years, and supplementary methods to reduce the pollution must be created.

Three of the works included in this study follow the evolution of the quality of the largest accumulation reservoir in Romania—Izvorul Muntelui. Agafitei et al., in 2008, ranked this reservoir in the oligotrophic category, based on the calculation of its trophic status using the algorithm proposed by Caraus, so that the results obtained from the mathematical calculations confirmed the experimental conclusions after analyzing the physicochemical, biological, and bacteriological characteristics observed between 1998 and 2005 [65]. The water quality parameters considered were the dissolved oxygen, which depends on temperature, the organic matter, as a function of dissolved oxygen, and nitrogen, as a function of total phosphorus. The values reported were pH levels of 7.2 to 8.3, DO values of 6.7–11.0 mg/L, biomass values of 0–2.02 mg/L, TP values of 0.015–0.04 mg/L, and transparency values of 3 to 6 m. Based on the experience gained in the two studies previously recalled, the same collective expanded their activity in 2021 and started a regional study center for accumulation lakes in the hills of Moldova, Romania [66].

Dumitran et al. (2011) investigated the trophic state of the Izvorul Muntelui reservoir and developed a mathematical model for the water quality indicators N, P, and algal biomass [67]. The data used ranged as follows: TN between 0.548 and 0.822 mg/L, TP between 0.04 and 0.05 mg/L, Chl a from 0.05 to 1.8 mg/L, and DO from 9 to 11.9 mg/L. According to the data, the Izvorul Muntelui reservoir was in the eutrophic state. The coefficient of determination had values of 0.96 for TN, 0.71 for TP, and 0.68 for Chl a.

The authors also proposed several solutions for the rehabilitation of the reservoir, namely artificial circulation or destratification.

Another study referring to the Izvorul Muntelui reservoir is the one presented by Plavan et al. in 2012 [68]. They investigated the benthic communities and the characteristics of abiotic factors in an aquaculture area and compared these parameters with the reference values. Three sampling points were used and the following data for the water quality parameters of the lake sediments were reported: NH_4 values from 2.79 to 7.77 mg/100 g sediments, NO_3 values from 0.22 to 0.26 mg/100 g sediments, PO_4 values from 0.026 to 0.067 mg/100 g sediments, and a N–P ratio between 117.62 and 157.62. In terms of numerical density, the sites close to the floating cages presented an average growth of 12.3 times and a biomass growth of 2.8 times. The results also showed a minor tendency of eutrophication of the lake in the area near the aquaculture sites.

Codruta, in 2015, studied the eutrophication evolution of the Gozna and Secu storage reservoirs on the river Bârzava during 2006–2010 [69]. As a result of physicochemical and biological analyzes, some conclusions and imposed measures were drawn. On the other hand, in 2016, Zolt et al. developed a mathematical model for the same reservoirs, based on multiple nonlinear correlations between biomass and nitrogen, phosphorus, water temperature, biological oxygen demand, and transparency [70]. From a trophic point of view, the two reservoirs fall into a mesotrophic category with a eutrophication tendency, because of human activity in the area. The model was calibrated and validated using data for physico-chemical water characteristics, obtained in sampling campaigns from 2001 to 2009. The measured values reported varied as follows: (i) for Gozna reservoir, a pH level from 6.5 to 8.77, water temperature from 1 to 23 °C, DO values from 6.90 to 11.70 mg/L, BOD values from 0.8 to 3.0 mg/L, TN values from 0.29 to 1.42 mg/L, TP values from 0.01 to 0.225 mg/L, and biomass values from 0.61 to 6.32 mg/L; and (ii) for Secu reservoir, a pH level from 6.15 to 8.82, water temperature from 1 to 21 °C, DO values from 5.80 to 12.40 mg/L, BOD values from 0.8 to 2.70 mg/L, TN values from 0.3 to 1.42 mg/L, TP values from 0.01 to 0.06 mg/L, and biomass values from 0.81 to 5.90 mg/L. The maximum errors reported when applying the model were 30% for the Gozna reservoir and 60% for the Secu reservoir.

Penning et al. (2008) tested two methods to classify macrophyte species and their response to eutrophication pressure: one based on percentiles of occurrence along a phosphorous gradient and another based on the trophic ranking of species, using canonical correspondence analyses in the ranking procedure [35]. The methods were tested at Europe-wide, regional, and national scales, as well as by alkalinity category, using 1147 lakes from 12 European countries, including Romania (19 lakes). In their dataset, combined data on light measurements and chlorophyll data were lacking for many lakes. Therefore, they used TP as an index for eutrophication. The data collected within the REBECCA project macrophyte database showed general trends in response to eutrophication pressure, but variations in the responses of individual macrophyte species concerning their classification, in line with the pressure gradient throughout Europe and lake type, were high. This might be partly because the total P data used now represent a summer average value in most cases, but not in all, and seasonal changes in values were unavailable in this dataset.

Dumitran et al., in 2010, forecasted the eutrophication phenomenon observed in Rosu Lake while taking the ecosystem's dynamics into account [71]. Four state variables were considered in the model: TP, TN, zooplankton biomass, and phytoplankton biomass. The data collected on the reservoir's physical, chemical, and biological characteristics from 2007 were as follows: TP values of 0.01–0.02 mg/L, TN values of 0.7–1.2 mg/L, and Chl a values of 0–0.02 mg/L. The results and experimental data agreed quite well, with the root-mean-square error RMSE values being as follows: 0.33 for TP, 1.47 for Chl a, and 1.98 for TN. Also, the behavior of the eutrophic reservoir Golești was described by Dumitran et al. (2012), using a biochemical model coupled with a thermal one [72]. The following data were used to calibrate and validate the model over the period 2008–2009: average water temperature from 2 to 23 °C, DO values from 6.91 to 13.3 mg/L, TN values from 0.2 to

1.18 mg/L, TP values from 0.044 to 1.43 mg/L, and Chl a values from 1.78 to 5.3 mg/L. Overall, the model's results agreed well with the study period's data, with the RMSE value for TN being 0.53, for TP 1.13, and for Chl a 1.67.

Boariu et al. (2013) investigated how river hydrodynamic and water quality will be modified in the Stone Bridge–Tudor Vladimirescu Bridge sector of the Bahlui River, due to the future use of this area for recreational purposes [73]. The authors mention the risks of water quality degradation due to the changes in river hydrodynamics, and also the ecological implications.

The Someș River (Romania/Hungary), an unregulated, eutrophic tributary of the Upper Tisza River, was modelled by Istvanovics et al. in 2014, to investigate the link between phytoplankton increases and the anthropogenic changes in the river network [74]. The observed mean phytoplankton biomass profiles in the Someș River were faithfully replicated by the TAPIR model, which is based on the PHOSFATE model, coupled with nitrogen emission and phytoplankton growth modules. According to the results, the lower two-thirds of the river were protected from additional algal growth by the P-determined biomass capacity. The potential for managing pollutant emissions to restore a diverse and healthy ecosystem (with a good ecological status) was defined by the hydromorphological status of the river, and, when drastically altered, a large river such as the Someș, cannot be returned to a near-pristine hydromorphology. The authors argue that the WFD should also impose the preservation of hydromorphological status, in the case of untouched large rivers. Artificial waterbodies and point emissions in the Someș catchment have significantly altered the network topology from the perspective of phytoplankton development. Hypertrophic fishponds added high amounts of algae to the downstream river sections, while large hydropower reservoirs raised the mean water level at the catchment's outflow by an order of magnitude. The authors conclude that specific river network structural characteristics may indicate other major rivers' susceptibility to eutrophication, and, when the spatial distribution and concentration values of nutrient emissions are also known, these can be used for a habitat assessment system concerning riverine phytoplankton.

Cirtana and Capatana, in 2016, evaluated the ecological potential of the Valea Mare and Turceni reservoirs for the period 2013–2015 [75]. They considered the average annual values of five physicochemical parameters of water quality. The measured values reported varied as follows: for Turceni reservoir, DO values varied from 7.2 to 11.11 mg/L, TN values from 0.318 to 1.31 mg/L, TP values from 0.046 to 0.081 mg/L, and the pH level from 7.13 to 7.8; for the Valea Mare reservoir, the DO values varied from 9.2 to 12.67 mg/L, TN values from 0.28 to 1.095 mg/L, TP values from 0.01 to 0.046 mg/L, and the pH levels from 9.2 to 12.67. The analysis indicated that both lakes have moderate potential, and the interpretation of the results led to the conclusion that both lakes have good water quality.

A eutrophic closed ecosystem (the shallow lake Stiucii) was modeled by Dumitran et al. in 2017 [76]. The model was calibrated and validated using data spanning from 2001 to 2002 and replicated the spatial and temporal concentration of water quality constituents while analyzing a simple food chain. The evolution of phytoplankton, herbivorous zooplankton, ammonia, TN, and TP was simulated. The RMSE values for TN, zooplankton, and ammonia showed that the model's outputs and measured data had a good correlation (0.35, 0.2, and 0.21, respectively).

Radulescu, in 2017 and 2018, presented solutions for the rehabilitation of Pângărați reservoir and Techirghiol lake [77–80]. Pângărați reservoir has reduced its useful volume by 60% and often experiences eutrophication problems. To reduce the biomass in the lake, the authors suggested a novel and creative method that is perfect for cleaning floating vegetation, aquatic vegetation, or other floating solid material. The study reported the following values for the water quality indicators in three reservoirs on Bistrița River (Pângărați, Vaduri, and Reconstrucția): pH levels of 6.65 to 7.04, NO_3 values of 3.41 to 7.68 mg/L, and TP values of 1.22 to 1.54 mg/L. For Pângărați, the authors proposed first the use of a benthic barrier to cover the sediments and vegetation roots, compressing the aquatic plants and nearly completely preventing light from penetrating. Another proposed solution for dealing with the eutrophication phenomenon in Pângărați reservoir was the development of a mobile platform, powered by photovoltaic panels and containing a device for collecting/drying and compacting the vegetation. Furthermore, the collected vegetal material can be used in a biomass power plant to provide heat for a nearby building. For a natural lake near the Black Sea, Techirghiol, which had recently started to experience quality issues, Radulescu reports the following data, collected during an intensive sampling campaign between 2014 and 2016: pH levels of 8.33 to 8.34, DO values of 6.87 to 8.61 mg/L, TN values of 0.52 to 1.15 mg/L, and TP values of 4.02 to 4.21 mg/L. It must be noted that Lake Techirghiol is mainly used for therapeutic purposes. The solution proposed this time consisted of the same mobile platform, which, in this case, contained an aspiration system for collecting the sludge and sediments and a fiberglass tank for dewatering and drying the collected material. The final dried material was proposed to be used for agricultural purposes. In 2017, Radulescu studied the organic and inorganic sources of pollution in the Vadeni, Târgu Jiu, and Izbiceni reservoirs, on the Jiu river, and used data recorded between 2010 and 2016. The range of variation for the water quality parameters was as follows: pH levels of 7.5 to 7.6, DO values of 8.44 to 9.04 mg/L, NO_3 values of 1.15 to 3.03 mg/L, NO_2 values of 0.012 to 0.02 mg/L, NH_4 values of 0.19 to 0.31 mg/l, and PO_4 values of 0.01 to 0.03 mg/L [81]. All reservoirs were classified as being in the mesotrophic to eutrophic state, mainly due to wastewater discharge.

Lupu and Petrescu, in 2018, presented an invention for the ozonation of water in fish farms [82]. The authors mentioned the eutrophication phenomenon due to accidental spills of organic substances and its disadvantages and negative impacts on water quality. The device is powered by renewable energy sources (wind turbine and solar panel) and contains a compressor and an air turbine, as well as an ozone generation system and an injection one. The authors noted the benefits that such a device could bring to water quality and fish farms: no occurrence of eutrophication, improved water quality, and better conditions for fish development; its use does not depend on the water level, and it can be equipped with GPS sensors.

The trophic state of Lake Stânca–Costești is directly impacted by hydrological variability, as demonstrated in 2020 by Dumitran et al.'s analysis of hydrological data spanning a decade [13]. This resulted in the lake becoming hypertrophic, due to nutrient concentrations. The experimental data used were registered between 2008 and 2017 and the trophic state of the reservoirs was assessed using the following parameters: Chl a, with values from 0 to 15 mg/L, DO, with values between 2.8 and 4.1 mg/L, TP, with values from 0.0035 to 0.025 mg/L, and TN, with values from 0.25 to 2.92 mg/L. It was concluded that the Stânca–Costești reservoir's temperature rise—which is mostly dependent on internal heat transfer through turbulent and convective processes—may drastically change the habitat of aquatic organisms. Concluding this investigated case, climate change poses a great challenge for reservoir management, especially considering eutrophication. Thus, to be successful, restoration techniques for those lakes under future climate change may have to be enforced at a higher intensity and repeated more frequently.

Mateescu, in 2020, provided a brief overview of innovative solutions and experimental research related to recovering residual biomass collected from river basins, as well as from coastal areas close to hydropower units. The study also assessed the energy quality (their potential for biomethane production) of several macrophyte species from the Danube, its tributary, and along the Black Sea coast [83].

In 2020, Agafitei et al. investigated the Colibița reservoir, using data sampled between 2008 and 2018 [84]. To assess the trophic state, the study used an algorithm and SMS software. Even though the authors specified the use of numerous water quality parameter data (dissolved oxygen, organic matter, ammonium, saturation O2, chemical oxygen demand, and N–P ratio) they reported only DO (7.3–8.9 mg/L) and transparency values (3 to 6 m). In 2021, Agafitei et al. applied the same SMS software, aiming to verify the accuracy of the field and laboratory analyses performed from 2016 to 2020 on Galbeni reservoir [84].

The study reported transparency values between 2 and 10 m. The study emphasized the importance of the continuous monitoring of water quality parameters.

A brief synthesis regarding the water quality parameters reported in the studies and articles, as well as some consideration on sampling frequency and climate change, are presented further on.

The two most crucial nutrients for plant growth are phosphates and nitrates, and high concentrations of these nutrients will increase the biomass of algae. Of the 50 examined publications, 68% of them analyzed the concentrations of these nutrients in Romanian lakes. (Appendix A)

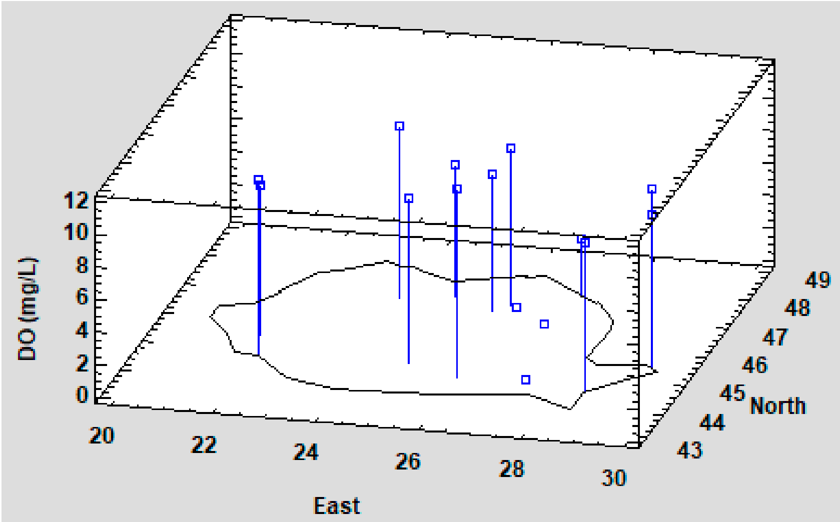
The presence of sufficient dissolved oxygen in the water column, with values greater than 40% of the saturation value, is critical for aquatic life. The amount of dissolved oxygen in eutrophic waters varies, due to its consumption in the water mass. As a result, a significant biomass of algae can deplete the water's oxygen content, sometimes to the point where fish cannot survive. In this respect, 90% of the research papers were based on the analysis of the oxygen regime in the water mass of the lakes.

Water transparency is a parameter that indicates the amount of light that can penetrate the water. Many algae generate a decrease in light in the water mass, causing an increase in turbidity. A common method of measuring this parameter is a Secchi disc. Of the analyzed papers, only 10 (20%) of them considered this index. The amount of algae in the water column is estimated by the concentration of Chl a. For algae to develop and use chlorophyllum pigments, they require oxygen and light. From the 50 papers investigated, the percentage of works that used Chl a as a study indicator is roughly 16%. The biomass of zooplankton is a parameter that indicates water quality based on the presence of invertebrates. Of the analyzed studies, just six considered this indicator. Based on the data presented in the considered articles, the distribution of the main water quality parameters (average values) over the Romanian territory, using Statgraphics Centurion 19, is presented in Figure 5a–e.

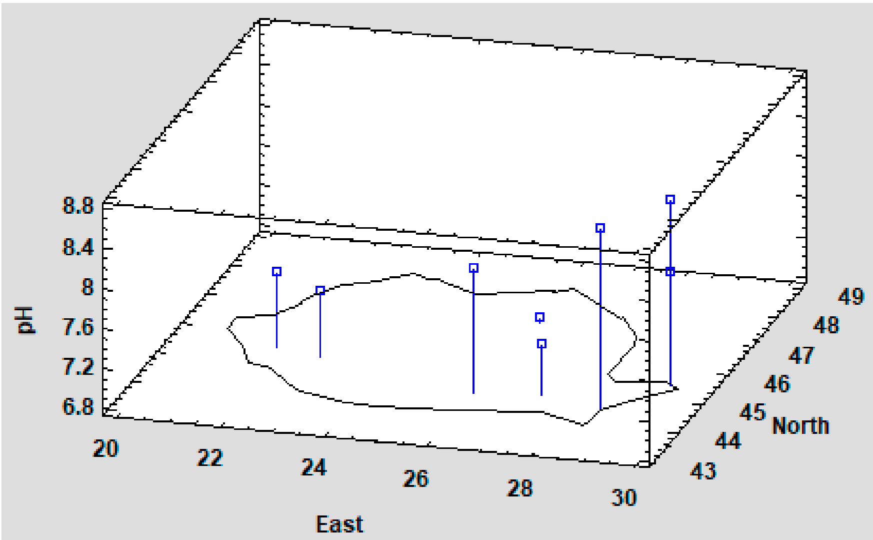
The successful implementation of the WFD in all European countries requires a common understanding of how to interpret the quality of lakes, independent of political and local interests, while simultaneously disregarding the fact that, in some areas, people's views may have been inured to high levels of eutrophication for a long time. Another significant problem is how well a rather limited sampling program, based on one or a few annual samplings, provides an adequate and correct definition of the ecological class.

Thus, there is a limited number of papers that consider the study of eutrophic lakes/reservoirs. Another limitation of this research may be the fact that the database used searches only in indexed journals that have digitized collections.

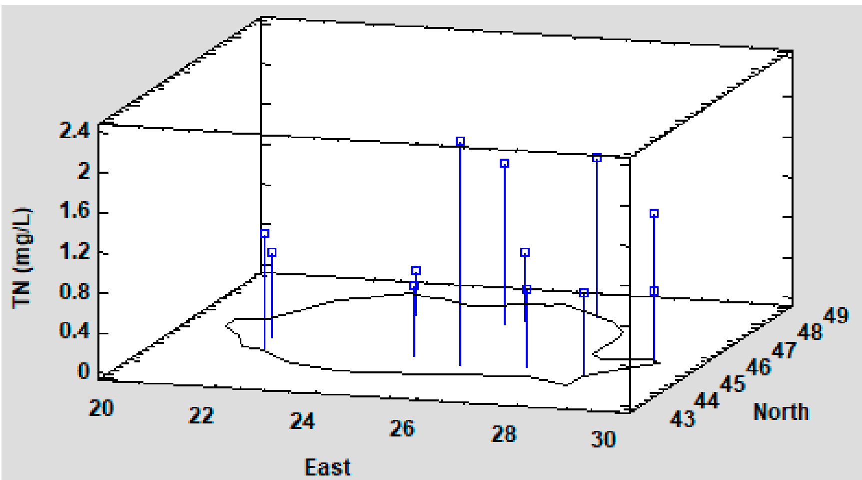
The World Health Organization and the World Meteorological Organization consider the hydrological and water quality monitoring data for lakes and reservoirs to be a high-level priority. Therefore, in relation to the eutrophication of lakes/reservoirs, a sampling frequency of at least once per month, and even twice per month during the summer, is recommended [85,86]. The temporal resolution of the measured data is also very important, as the timestep of the measurements can greatly influence the estimation of water quality indicators [80]. Hydrological and biogeochemical processes happen very often in minutes, and not in weeks or months [87], and this is recognized in many papers [88–90]. This observation emphasizes the need for high-frequency monitorization as, for example, the 60-day measurement time step is, in many cases, insufficient to catch the variability of one water quality variable. The influence of the sampling frequency on the estimation of flows [91] and the estimation of statistical criteria and the quality status of a water body from rare measurements is faulty [92].



(**a**)

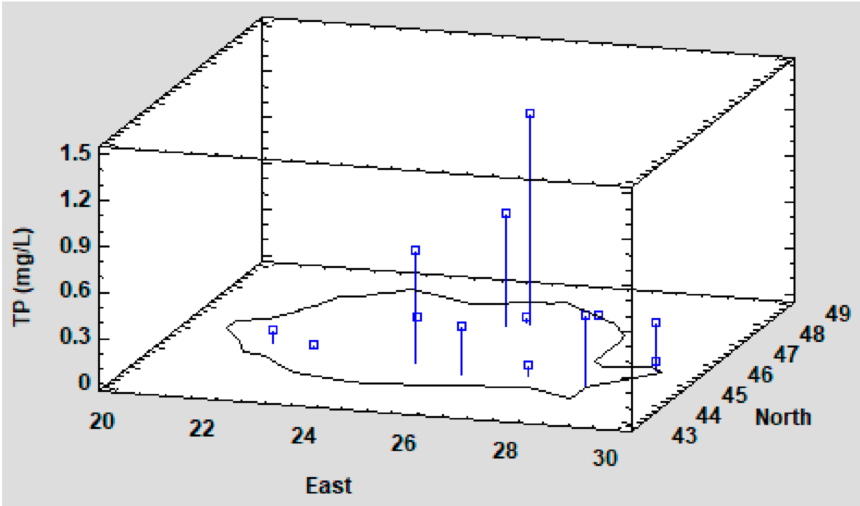


(**b**)

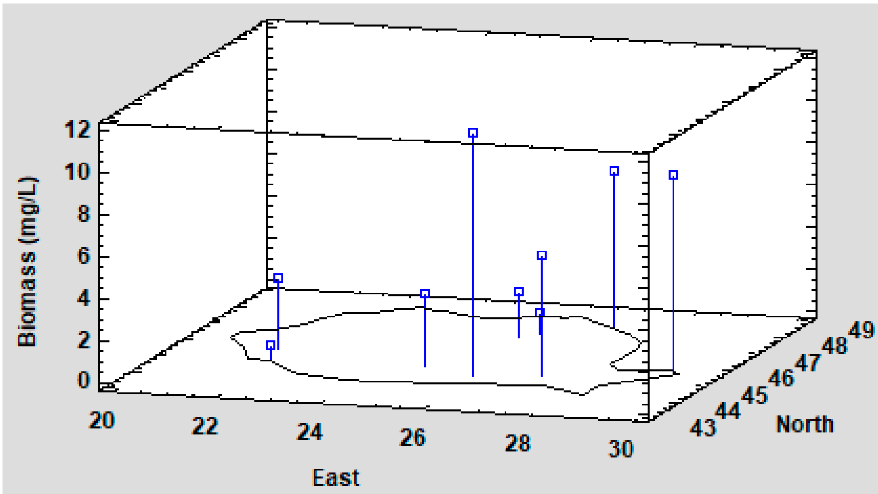


(**c**)

Figure 5. *Cont.*



(**d**)



(**e**)

Figure 5. (**a**) Values of DO (mg/L); (**b**) values of pH; (**c**) values of TN (mg/L); (**d**) values of TP (mg/L); and (**e**) values of biomass (mg/L).

On the other hand, in 2005, Søndergaard et al. [93] mentioned that, for their study, the data used were mainly collected by the local counties, as part of national and regional monitoring programs. These monitoring campaigns consisted of sampling monthly, or more frequently during summer for the lakes with surface areas of more than 5 ha, while the lakes between 1 and 5 ha were often sampled on a single or a few occasions during summer. This monitoring program allowed for a good appreciation of the trophic condition [93]. Thus, a better assessment of the trophic states of national waters was a result of significant funding allocated to water body monitoring programs.

In Romania, the sampling frequency of eutrophication indicators is four times per year and, sometimes, the data at which the measurements are made are not correlated with the critical periods, in terms of the eutrophic stages. We refer here to the periods with very high temperatures during summer, which have become more and more frequent in Romania for the last 20 years, which are often correlated with high nutrient inputs, against the irrational use of land (deforestation, large quantities of fertilizers applied on agricultural lands, but also faulty management of wastewater). A solution in this sense, which appears more and more frequently in specialized studies, is that of high-frequency measurements. Lately, an increasing number of studies in limnology used data from high-frequency measurements, with this technology even allowing for investigations in places where regular sampling would be complicated or even dangerous [94,95]. Thus, in 2020, Cunli et al. [96] showed that more than half of the high-frequency studies for lakes were undertaken in North America and Europe, and the main field of application was lake ecology, followed by physical limnology. Water temperature and dissolved oxygen have been the commonly measured parameters, and more frequent monitoring of eutrophication indicators is necessary to capture all the changes that appear in aquatic ecosystems, at least during the summer season, which is also the overall conclusion of our study.

The less developed countries in the EU, due to their economic situations, do not invest much in solving environmental problems, be they air, water, or soil, and even pay penalties for their failures to meet the assumed objectives. In this regard, most eutrophication studies carried out in Romania, as well as in its neighboring countries in Eastern Europe, are based mainly on data at the national level by the state authorities, which are not systematically conducted, and, thus, can lead to false conclusions regarding the state of water bodies. Of the total of 50 papers analyzed, 32 or 64% are based on the authors' own measurements; unfortunately, most of them were carried out over short periods, ranging from a few months to a maximum of 2 years. Also, the measurements made in these works do not capture the entire body of water, being carried out at a single sample point and, more than that, as values mediated on depth.

In recent publications, the idea of an imminent threat to aquatic ecosystems due to climate change combined with eutrophication is becoming increasingly popular [1,97–100]. However, the impact of rising temperatures, extreme temperatures, and disruptions in terms of precipitation (rapid floods or prolonged drought), as well as the occurrence of extreme phenomena, such as tornadoes, is estimated to be distinct for each ecosystem in particular. The effects of climate change on surface water ecosystems typically involve drastic changes in precipitation and temperature, which accelerate the eutrophication process in lakes [13]. Drought periods cause lakes and reservoirs levels to drop, which, when combined with lower groundwater and runoff flows, exacerbate the rise in temperature and decline in dissolved oxygen content. On the other hand, the concentration of nutrients in lake habitats is increased by floods. Also, Coops et al. emphasize the importance of investigating the effects that falling water levels, rising temperatures, and changing the duration of the water's residence time, all of which are associated with climate change, have on aquatic ecosystems [36]. This underlines the importance of systematic long-term monitoring campaigns for ecosystems exposed to these risks, to deepen our understanding of these interactions and to develop management solutions. Unfortunately, however, the flow of publications from Romania does not comprise these important aspects.

4. Conclusions

The number of articles found in this literature review does not reflect the real environmental issue represented by eutrophic lakes and reservoirs in Romania. The aim of the present study is to highlight the connection between the low interest in the subject of eutrophication and the lack of systematic national monitoring campaigns, provided that eutrophication is an important issue for many lakes/reservoirs in Romania.

NARW monitors and assesses only 26 natural lakes and 100 heavily modified natural lakes and reservoirs monthly for hydrologic parameters, while, for the physicochemical, morphological, and biological parameters, the frequency varies from once in three months to up to once in six years. This is insufficient when thinking of the more than 1900 lakes and reservoirs in Romania and can be one of the reasons why most of the Romanian publications related to eutrophication use the authors' own measurements and not official monitoring data. Compared to the global concern regarding the topic of eutrophication, with over 32,000 publications since 1975 and, nowadays, over 2500 published per year, it was found that fewer papers concerning Romania have been published.

It is still difficult to meet the goals of keeping EU waters in good condition and preventing their degradation, even twenty years after the WFD was first introduced. Numerous scientific papers outline water directive shortcomings as a tool for policy, considering the number of “good” surface water bodies increased by only 10% between 2009 and 2015 [101].

After carefully examining all 50 articles about the eutrophication of Romanian lakes, we arrived at the following conclusions: (i) very few of the articles discuss the connection between eutrophication and climate change; and (ii) a substantial number of the papers argue that systematic long-term measurement campaigns are necessary for Romanian lakes to improve our understanding of the evolution of water quality and, implicitly, the degree of trophicity. Therefore, it must be emphasized that, despite their timeliness in obtaining meteorological information and their frequency of water sample collection, traditional monitoring programs cannot fully characterize the spatiotemporal trends in water quality. To obtain data for water quality indices and to understand the degradation process of water environments, relatively high-frequency monitoring of water sources is required. Therefore, we can only have a true image of the development of this phenomenon in the aquatic ecosystems of Romania by developing extensive measurement campaigns and by improving the national monitoring strategies.

Some aspects related to this subject can be highlighted in the analyzed works, namely the following: (i) unfavorable conditions can develop in lake/reservoir systems, due to the reduction of the flood plain and its filtering role along the river and its tributaries [40,74]; (ii) some analyses carried out are correlated with the effects of climate change, so the authors investigate the effects that decreasing water levels, rising temperatures, and changing the residence time of water have on the ecosystems studied [36,37,41]; and (iii) the available database of limnological parameters is relatively small and should therefore be expanded during future monitoring campaigns—almost 80% of the investigated papers propose more frequent measurements.

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Appendix A

Table A1. Water quality indices. Results of mapping of literature review on Romanian eutrophic lakes and reservoirs.

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[13]	Stânca–Costești	12	The research findings show that the trophic state of the lake is directly influenced by hydrological variability, namely evolving to a hypertrophic status due to concentrations of nutrients. This study proposed that the water quality should be verified monthly, and this should be carried out using a more reliable method, such as a multiparameter index or multicriteria analysis.	n	y	n

Table A1. *Cont.*

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[28]	National level		The quality of lacustrine waters was studied for each region, river basin, and the aquatic surface of Romania, for use in different fields of activity and regarding the capability of life support for the biological component. Ten-year seasonal campaigns had as their main purpose the complex characterization of the quality of the lacustrine water, which was undertaken by interpreting the results of field measurements concerning their classification into quality classes.	y	n	n
[37]	Danube Delta	1	Based on a comparative analysis of the spatial changes, over five years, in dissolved nutrient concentrations along the Danube Delta, it was found that the retention of nutrients in the delta decreases significantly during periods of low and medium water levels.	y	n	n
[44]	Danube Delta	1	This study reports mean values of inorganic constituents and global organic pollution in correlation with measured biological parameters (primary production).	y	n	n
[45]	Danube Delta	1	The process of eutrophication is found to be stronger in the waters close to the agricultural areas and the urban localities on the Romanian shore of the Black Sea.	n	y	n
[46]	Danube Delta	1	A limnological investigation proved that Lake Tașaul has a highly eutrophic level. Cyanophytes dominate phytoplankton by 67–94% and form frequent algal blooms. Based on the chemical and biological analysis and fishery investigations, recommendations are provided for Lake Tașaul rehabilitation.	y	n	n
[50]	Danube Delta	1	The interpretation of the data resulting from the grain size analysis highlighted the deposition of the sediments by suspensions in calm water with poor circulation, a different and poor sorting, and an excess of fine clastic material.	y	n	n
[55]	Bucharest	2	The assessment of water quality of the four small artificial lakes in the Bucharest–Ilfov metropolitan area is based on the determination of ecological status by assessing chemical and physicochemical characteristics.	y	n	n
[56]	Bucharest	2	This study shows the results of the monitoring of the quality of water and sediments together with the dynamics of phosphorous from Plumbuita Lake (Bucharest, Romania). The physicochemical indicators of water quality fall in the first and second water quality classes, as regulated by the Romanian legislation, with few exceptions.	y	n	n
[57]	Bucharest	2	This study shows the results of the monitoring of the quality of water and sediments together with the dynamics of nitrogen from Plumbuita Lake (Bucharest, Romania). The concentrations of nitrogen species in water showed higher values during the summer and at the beginning of autumn, when hypoxic conditions emerged. Up to 99% of the nitrogen is represented by organic nitrogen, while the ionic nitrogen species are represented by 62–95% ammonium and 5–38% nitrates.	y	n	n
[58]	Snagov	18	The trophic stage of Snagov Lake from April 2010 to October 2014 and in all the points of sampling is eutrophic–hypereutrophic for all the parameters used for assessment, except several short periods (the fall of 2010, and the spring and fall of 2011) when the lake was mesotrophic.	n	y	n

Table A1. *Cont.*

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[59]	Bucharest	2	In 2017, a database was developed with fluorescence spectra of samples collected from Morii Lake over 6 months. Fluorescence indices were used to provide a complex characterization of the organic matter and to develop a prediction model for Morii Lake water quality.	y	n	n
[60]	Bucharest	2	The evaluation of the trophic status of three lakes riparian to the Colentina River using water and sediment samples which were taken from the inlet and outlet areas of each lake in two sampling campaigns in July 2016 and September 2016.	y	n	n
[61]	Bucharest	2	The total concentration of organochlorine pesticides in the water of the closed lakes in the Bucharest area was measured and these concentrations were compared with the consensus-based sediment quality guidelines to evaluate the ecological risk of the sediments. The highest potential adverse effects were associated with gamma- Hexachlorocyclohexane exposure. The periodical draining and dredging of lakes lead to the resuspension of contaminants, increasing pesticide bioavailability and accumulation in sediments. In addition, it was observed that fluorescent dissolved organic matter (DOM) might influence the OCP cycle.	y	n	n
[63]	Amara	3	The evolution of some parameters responsible for the eutrophication process of Amara Lake, which have an insignificant variation during the study period, suggests that the lake is in a self-regulation stage of biological and physicochemical processes.	y	n	n
[64]	Amara	3	A SWOT analysis of the Amara Lake ecosystem was performed to find the most adequate management solution. The proposed management solution considers the forestation of the southern shore of the lake with *Acer campestre*.	y	n	n
[65]	Izvorul Muntelui	4	An evaluation of the trophic degree in the year 2005 for the Izvorul Muntelui/Bicaz reservoir. The calculation of the trophic degree shows that this reservoir may be integrated into the oligotrophic category.	y	n	n
[66]	Moldavia	20	A review of the main methods and techniques for modelling the processes regarding the evolution of main hilly lakes from Moldavia for the period 2016–2020.	y	n	n
[67]	Izvorul Muntelui	4	Ecological modeling of the reservoir, determination of its trophic state, and an inventory of solutions for reservoir ecological rehabilitation.	n	y	n
[69]	Gozna and Secu	5	A study of the eutrophication evolution of the Gozna and Secu storage reservoirs on the river Bârzava during 2006–2010. As a result of physicochemical and biological analyses, some conclusions and imposed measures are drawn.	y	n	n
[75]	Valea Mare	8	Based on the analyses performed, the ecological potential was assessed and the water quality characterization of lakes was monitored in terms of eutrophication parameters. According to the results obtained, it was concluded that both storage lakes have moderate ecological potential.	y	n	n
	Turceni	9				

* No. of lake according to Figure 4; ** OM—own measurements, NARW—NARW measurements, WM—without measurements, y—yes, and n—no.

Table A2. Water quality modelling. Results of mapping of literature review on Romanian eutrophic lakes and reservoirs.

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[53]	Danube Delta	1	For each water quality variable (dissolved oxygen, nitrate–nitrogen, and orthophosphates), a multi-layer feed-forward artificial neural network model (ANN) was constructed using the macrophytes as explanatory variables.	y	n	n
[70]	Gozna and Secu	5	A mathematical model based on multiple correlations between the most important eutrophication parameters was developed. From a trophic point of view, the two reservoirs fall into a mesotrophic category with a eutrophication tendency, because of human activity in the area.	n	y	n
[71]	Roşu	6	A forecast of the phenomenon of eutrophication found in Roşu Lake was undertaken by considering the ecosystem dynamic. The model output indicated differential effects of nitrogen and phosphorus nutrient loading on concentrations, and major in-lake fluxes of total nitrogen and total phosphorus, dynamics, and algal community structure. The modeling results, expressed in terms of water quality, allowed for establishing the critical/threshold values for the nutrient loads.	n	y	n
[72]	Golești	7	It is proposing a eutrophication model that describes the thermal and biochemical behavior of a eutrophic reservoir, the Golești reservoir. The model, calibrated and validated using the data collected over two years (2008 and 2009), reproduces spatial and temporal concentration distributions of water quality constituents.	n	y	n
[73]	Bahlui	16	The purpose was to evaluate the viability of using a reservoir for recreational purposes. This kind of action changes the river hydrodynamics, with ecological implications regarding the modification of water quality parameters.	n	y	n
[74]	Tisza	15	Using the unregulated, eutrophic Someș River (Romania/Hungary), a tributary of the Upper Tisza River as a model system, phytoplankton growth was related to the structure of the river network modified by human intervention. The TAPIR model realistically reproduced the observed mean biomass profiles of phytoplankton in the Someș River. According to modeling results, the P-determined biomass capacity prevented further growth of algae along the lower two-thirds of the river.	Hungarian Water Quality Database		
[76]	Stiucii	10	A eutrophication model that describes the ecological behavior of a eutrophic closed ecosystem (the shallow lake Stiucii). The conceptual model analyzes a simple food chain and reproduces the spatial and temporal concentration of water quality constituents. The results provided by the model show a good correlation with the measured values.	n	y	n
[84]	Colibița	14	The evolution of Lake Colibița's water quality by application of software; the calibration and validation of the software were based on experimental data.	y	n	n

* No. of lake according to Figure 4; ** OM—own measurements, NARW—NARW measurements, WM—without measurements, y—yes, and n—no.

Table A3. Aquatic organisms. Results of mapping of literature review on Romanian eutrophic lakes and reservoirs.

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[35]	National level		The lake trophic ranking method was tested in some individual lakes with a relatively long time series of monitoring data. The relationship between total P and light extinction is often very good in the Northern European lake types compared to the Central European lake types. This can be one of the reasons for a better agreement between the indices and eutrophication pressure in the Northern European lake types.	n	y	n
[36]	Danube Delta	1	The aquatic vegetation present in lakes in the delta of the River Danube was studied using field survey data and satellite images. Based on the spectral information from satellite images three categories of lakes were distinguished: clear/macrophyte-dominated, intermediate, and turbid/poorly vegetated. The satellite-based classification was consistent with vegetation cover and water transparency measured in the field.	y	n	n
[40]	Danube Delta	1	The increase in the nutrient loads, as well as in the P–N ratio, in the Danube waters were the main factors that induced the upward development of the trophic state in the Danube Delta lakes. So, from 1980 to 1989, the total reactive phosphorus concentration (TRP) in the lower part of the Danube river grew by about 5.7 times, while the atomic N–P ratio lowered by 25–85 times. This unfavorable development was enhanced by the reduction of the flood plain with its filtering role along the river and its tributaries in recent years.	y	n	n
[41]	Danube Delta	1	The main changes in the submerged vegetation dynamics throughout two successive decades included changes in spatial distribution, mainly by diminishing areas, as well as qualitative and quantitative changes in species richness, species dominance, and biomass production. These changes induced important alteration of both the energy entering the aquatic system through the trophodynamic modules of primary producers and the phytophagous and detritophagous transfer of energy towards the successive trophodynamic modules.	y	n	n
[42]	Danube Delta	1	A study which aimed to verify whether diatomic assemblies have the potential to reconstruct the history of eutrophication of the Danube Delta lakes.	y	n	n
[43]	Danube Delta	1	In the Danube Delta lakes, the ratios of average excreted inorganic nitrogen by tubificids to sedimented organic nitrogen were 1.32% for the first category of lakes and 1.02% for the second category of lakes. The ratios of the release rate of inorganic nitrogen by tubificids to sedimentation rate of organic nitrogen were 8.26 and 6.39%.	y	n	n
[47]	Danube Delta	1	Spectral analysis of specific phytoplankton pigments was applied as a diagnostic marker to establish the distribution and composition of phytoplankton taxonomic groups. Fluorescence spectroscopy was used to quantify changes in dissolved organic matter (DOM). The relative contribution of the main phytoplankton groups to the total phytoplankton biomass and the trend of development during successive seasons showed that cyanobacteria could raise potential ecological or human health problems.	y	n	n

Table A3. *Cont.*

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[48]	Danube Delta	1	Within the framework of a pilot study, the potential of sedimentary diatom assemblages for the reconstruction of the eutrophication history was studied in short sediment cores from five shallow lakes located in the Romanian Danube Delta. The delta lakes likely became meso- to eutrophic long before 1950, possibly during late Holocene times.	y	n	n
[49]	Danube Delta	1	The Lower Danube River Basin lentic ecosystems area was identified as a significant hot spot regarding the major hazard of the fish fauna's ecological status, in a possible climate change sequence of potential future events.	y	n	n
[51]	Danube Delta	1	Based on a comparative analysis of the spatial changes, over five years, in dissolved nutrient concentrations along the Danube Delta, it was found that the retention of nutrients in the delta decreased significantly during periods of low and medium water levels.	y	n	n
[52]	Iron Gates	13	Study regarding the modifications of the Danube biocenosis structures due to the construction of the Iron Gates dam. The presence of the reservoir led to fundamental changes: certain populations of invertebrates disappeared while others appeared, and the structure of ichthyofauna was modified, as well. At present, the structure of the zoobenthos, as well as of the phytoplankton and zooplankton, is characteristic of the limnic–rheophilic ecosystems.	n	y	n
[54]	Danube Delta	1	The remarkable role of the Iron Gates was uncovered by this study, which also demonstrated how phytoplankton can serve as a sign of hydromorphological degradation. The Iron Gates significantly slows down the river and interferes with the processes outlined by the River Continuum Concept, affecting the river in numerous ways both upstream and downstream.	y	n	n
[52]	Danube Delta	1	With the FluoroProbe, the highest chlorophyll densities were measured in the Roșu–Puiu complex, suggesting that this is the most productive complex with plenty of food to sustain a *Daphnia* population. Food conditions in the other complexes seemed to be suboptimal for *Daphnia*.	y	n	n
[68]	Izvorul Muntelui	4	Examining the content of organic substance, organic nitrogen, and total phosphorus in sediments, in an aquaculture area, and the concentration of the main nutritive elements in the interstitial water of the same sediment samples, respectively, it was observed that the influence of the material emission from the fishing farms upon chemical characteristics of the sediments is evident, as well as the differences in chemical composition do not correspond to the high quantities of organic and mineral material additionally introduced in the ecosystem through the aquaculture activity.	y	n	n

* No. of lake according to Figure 4; ** OM—own measurements, NARW—NARW measurements, WM—without measurements, y—yes, and n—no.

Table A4. Equipment to rehabilitate eutrophic ecosystems. Results of mapping of literature review on Romanian eutrophic lakes and reservoirs.

Study	Lake/Reservoir		Results	Measurements **		
	Name	No. *		OM	NARW	WM
[77]	Pângărați	11	A new solution using renewable resources to collect and dry the collected vegetation is presented. It can be permanently used as a biomass resource in a power plant placed on the lakeshore. The obtained results compare the prototype efficiency after a few months and after one year of utilization.	n	n	y
[78]	Pângărați	11	A prototype was developed and implemented in silted lakes at a rate of more than 80% to restore the ecological balance, without disturbing the environment. It is environmentally friendly and can be used in the hydroelectric reservoirs used also for water supply.	n	n	y
[79]	Techirghiol	19	The solution presented in [65] is used for collecting and drying the sludge without therapeutic efficiency and is the only solution adapted and efficient in the local conditions: Natural Reservations and Lakes Techirghiol and Mangalia.	y	n	n
[80]	Izbiceni	17	The wastewater from the unit, although it passed through a water treatment plant, still contains large amounts of ammonium nitrate, phosphorus, and organic substances. After being mixed with the water coming from upstream, there is a certain reduction in the amounts of nutrients, as a result of dilution, but the contribution from this industrial effluent remains substantially a continuous process of additional nutrients for the downstream sector.	y	y	n
[81]	Pângărați	11	The realized prototype represents a challenge concerning the design, execution, automation, control, and compacting of systems for the environmental conditions.	n	n	y
[82]	-		A device for ozonizing lake water was made to avoid the occurrence of eutrophication and to improve the quality of water. The device uses two conventional sources of energy: a micro-central baffle solar photovoltaic and a vertical axis wind group, with the energy being accumulated in batteries with accumulators via a regulating relay, then supplying a module that contains the mini-installations for obtaining the air pressure: a turbine, a compressor, and the ozone generation device.	n	n	y
[83]	Danube Delta	1	An efficient and sustainable method of harnessing the energy potential of the aquatic biomass collected from the reservoirs and/or from the coastal areas is presented. Apart from the direct benefits that harnessing aquatic biomass may bring to producing renewable biogas, this practice can avoid inefficiency or malfunctions of the hydropower plants caused by clogging hydro-equipment and components.	y	n	n

* No. of lake according to Figure 4; ** OM—own measurements, NARW—NARW measurements, WM—without measurements, y—yes, and n—no.

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