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Espacio y Territorios

Ultrasonic Waves for Algae Control in dam Lake: A Comprehensive Study of Mamloo Dam

Ondas ultrasónicas para el control de algas en el lago de la presa: un estudio exhaustivo de la presa Mamloo

Ondas Ultrassônicas para Controle de Algas em Lago de Represa: Um Estudo Abrangente da Represa Mamloo

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Abstract

Dam reservoirs, which are crucial for managing river water quality (WQ), often face challenges from algal blooms caused by nutrient enrichment. This study investigates the use of ultrasonic waves (UWs) to control algal growth in Mamloo Dam. The objective is to assess the effectiveness of this technique and contribute to improved water management strategies.

The study was conducted at Mamloo Dam Reservoir, with sampling at five designated sites. WQ was assessed using a Conductivity Temperature Depth (CTD) device to measure temperature, dissolved oxygen, and chlorophyll A, as well as a DR 6000 spectrophotometer to test for Phosphorus and nitrate levels. Ultrasonic devices from LG Sonic were installed to evaluate their effect on algae control. Phytoplankton samples were collected from the surface to a depth of 2 meters, preserved with Lugol's solution and formalin, and then analyzed under a microscope. This approach aimed to determine the impact of UWs on algal growth and WQ.

The study found that the application of UWs in the Mamloo Dam Reservoir led to a significant reduction in phytoplankton populations, including green algae, diatoms, and cyanobacteria. Chlorophyll A levels showed considerable fluctuations, showing an overall decreasing trend. Additionally, the ultrasonic treatment improved WQ by reducing chemical oxygen demand (COD) and total phosphorus (TP), indicating the efficacy of ultrasonic technology in algae control and WQ improvement.

UWs significantly reduced phytoplankton in the pilot study, showing promise for algae control in small reservoirs. Further research is needed to assess its effectiveness on a larger scale.

Keywords: Ultrasonic waves; Algal control; Phytoplankton; Water quality; Mamloo Dam.

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Resumen

Los embalses de represas, fundamentales para la gestión de la calidad del agua (CA) de los ríos, a menudo enfrentan desafíos por floraciones algales causadas por el enriquecimiento de nutrientes. Este estudio investiga el uso de ondas ultrasónicas (OU) para controlar el crecimiento de algas en la Represa Mamloo. El objetivo es evaluar la efectividad de esta técnica y contribuir a mejorar las estrategias de gestión del agua.

El estudio se llevó a cabo en el embalse de la Represa Mamloo, con muestreos en cinco sitios designados. La CA se evaluó utilizando un dispositivo CTD (Conductividad, Temperatura y Profundidad) para medir la temperatura, oxígeno disuelto y clorofila A, y un espectrofotómetro DR 6000 para analizar niveles de fósforo y nitratos. Se instalaron dispositivos ultrasónicos de LG Sonic para evaluar su efecto en el control de algas. Se recolectaron muestras de fitoplancton desde la superficie hasta 2 metros de profundidad, se preservaron con solución de Lugol y formalina, y luego fueron analizadas al microscopio. Este enfoque buscó determinar el impacto de las OU en el crecimiento de algas y la CA.

El estudio encontró que la aplicación de OU en el embalse de Mamloo produjo una reducción significativa en las poblaciones de fitoplancton, incluidas algas verdes, diatomeas y cianobacterias. Los niveles de clorofila A mostraron fluctuaciones considerables, con una tendencia general a la disminución. Además, el tratamiento ultrasónico mejoró la CA al reducir la demanda química de oxígeno (DQO) y el fósforo total (PT), lo que indica la eficacia de la tecnología ultrasónica en el control de algas y la mejora de la CA.

Las OU redujeron significativamente el fitoplancton en el estudio piloto, lo que demuestra su potencial para el control de algas en pequeños embalses. Se necesita más investigación para evaluar su efectividad a mayor escala.

Palabras clave: Ondas ultrasónicas; Control de algas; Fitoplancton; Calidad del agua; Represa Mamloo.

Resumo

Reservatórios de barragens, fundamentais para o gerenciamento da qualidade da água (QA) dos rios, frequentemente enfrentam desafios devido a florescimento de algas causado pelo enriquecimento de nutrientes. Este estudo investiga o uso de ondas ultrassônicas (OU) para controlar o crescimento de algas na Represa de Mamloo. O objetivo é avaliar a eficácia dessa técnica e contribuir para estratégias aprimoradas de gestão da água.

O estudo foi realizado no reservatório da Represa de Mamloo, com amostragens em cinco pontos designados. A QA foi avaliada com o uso de um dispositivo CTD (Condutividade, Temperatura e Profundidade) para medir a temperatura, oxigênio dissolvido e clorofila A, além de um espectrofotômetro DR 6000 para analisar os níveis de fósforo e nitrato. Dispositivos ultrassônicos da LG Sonic foram instalados para avaliar seu efeito no controle de algas. Amostras de fitoplâncton foram coletadas da superfície até 2 metros de profundidade, preservadas com solução de Lugol e formalina, e analisadas ao microscópio. Essa abordagem teve como objetivo determinar o impacto das OU no crescimento de algas e na QA.

O estudo revelou que a aplicação de OU no reservatório de Mamloo resultou em uma redução significativa das populações de fitoplâncton, incluindo algas verdes, diatomáceas e cianobactérias. Os níveis de clorofila A apresentaram flutuações consideráveis, com tendência geral de queda. Além disso, o tratamento ultrassônico melhorou a QA ao reduzir a demanda química de oxigênio (DQO) e o fósforo total (PT), indicando a eficácia da tecnologia ultrassônica no controle de algas e na melhoria da QA.

As OU reduziram significativamente o fitoplâncton no estudo piloto, demonstrando potencial para o controle de algas em pequenos reservatórios. São necessárias pesquisas adicionais para avaliar sua eficácia em maior escala.

Palavras-chave: Ondas ultrassônicas; Controle de algas; Fitoplâncton; Qualidade da água; Represa de Mamloo.

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1. Introduction

The reservoirs of dams are typically constructed at the endpoints of catchment basins. They serve as collectors of both dissolved and undissolved materials from the basin, which are brought in by the movement of rivers. However, due to the large volume of water they hold, reservoirs also function as balancing tanks. This has a significant impact on the quality and quantity of water in the rivers (Jorgensen et al., 2013; Nazariha et al., 2009). The essential tool for determining the quality status of a reservoir is to examine a range of physical, chemical, and biological parameters. The most significant indicator of seasonal changes in the water quality (WQ) of a dam reservoir is the presence of algae in the lake, primarily due to the elevated levels of phosphorus and nitrogen (Lai et al., 2011; Wang et al., 2011). Algal blooms have a major effect on WQ in reservoirs, altering the water's color and causing various harmful consequences. They result in considerable changes in water characteristics, such as fluctuations in temperature and density, decreased levels of dissolved oxygen, and unpleasant tastes and odors. The growing prevalence and severity of these blooms present significant challenges to aquatic ecosystems, public health, and local economies (Zohdi & Abbaspour, 2019). Another harmful effect of algae growth in dams that supply drinking water is the increase in turbidity caused by the presence of phytoplankton and the inefficiency of water treatment plants in reducing it (Dokulil & Teubner, 2010; Ortenberg & Telsch, 2003). This lack of efficiency leads to a decrease in oxygen levels and creates anaerobic conditions that Anaerobic negatively affect many ecological and chemical processes in the reservoir (Hallegraeff et al., 2021).

The presence of heavier layers at the bottom of the reservoirs, intensified by mineral waste and organic material deposits causes significant changes in the WQ of the reservoirs. Therefore, WQ may decrease and deteriorate due to oxygen consumption and reduction, as well as an increase in the amount of algae under the layer (Rangel-Peraza et al., 2012; Wang et al., 2014). Considering that the growth and blooming of algae is one of the most important factors in decreasing the WQ of dam reservoirs, several solutions have been proposed for treatment (Ma et al., 2015; Sathe et al., 2016; Yang et al., 2020). The most important solution is reducing the entry of nutrients, especially nitrogen and phosphorus (Vongthanasunthorn et al., 2019). While this solution is simple in theory, its implementation requires extensive measures, significant costs, and the cooperation of stakeholders in the basin. This can be challenging and slow, making the use of intermediate methods a common approach to improve WQ in the short term (Schindler, 2006). On the other hand, the methods used also have requirements and sometimes very high costs. These costs vary depending on the type of dam, the climate, and the composition of phytoplankton. Therefore investigating these factors is of great importance, and it is necessary to carry out extensive research on it (Bibak & Hosseini, 2013). A range of techniques has been developed for algae management in natural water systems, such as using algaecides, sediment capping agents, barley straw, wetland islands, increased grazing pressure, and ultrasonication. Ultrasound has attracted interest for its straightforward application and low environmental impact. It operates by creating cavitation bubbles in the water, which generate intense heat and pressure. This process destroys algae gas vacuoles, damages cell membranes, and produces free radicals that further disrupt algae. These effects hinder the algae's buoyancy and photosynthesis, leading to a decrease in their biomass. While some vacuoles might regenerate, they do not fully recover, enhancing the effectiveness of ultrasound in controlling algae (Park et al., 2017).

Many studies have been conducted in the field of algae control and water quality improvement using the ultrasonic process. Chen et al. (2020) investigated the efficacy of ultrasonic technology in degrading Microcystis (MCs) and controlling algae in polluted water systems. Their research demonstrated that ultrasound at 1200 W could remove up to 99% of MCs within 15 minutes, effectively killing algae and inhibiting their growth. This method successfully prevented increases in MC levels and minimized secondary pollution (Chen et al., 2020). Duan et al. (2017) examined how ultrasound could be used to control cyanobacterial blooms by disrupting photosynthesis instead of destroying cells. Their research showed that ultrasound effectively impaired photosynthesis in Microcystis aeruginosa, leading to a notable decrease in cell numbers, while Chlorella pyrenoidosa was less impacted. This study suggests that ultrasound is a promising approach for targeting and managing Microcystis blooms by interfering with their photosynthetic activity (Duan et al., 2017). Honda et al. (2021) examined the effects of ultrasonic waves (UWs) on algae, microcapsules, and plankton, revealing that cavitation bubbles disrupt algae and microcapsules by matching their mechanical frequencies. In contrast, plankton experienced partial damage from localized shear stress. The study underscores the significance of ultrasonic frequency and shear stress in improving microbial control and water treatment technologies (Honda et al., 2021).

In this research, UWs are used as a method of controlling algae (Heng et al., 2009; Park et al., 2017). The primary objective of this research was to evaluate the effectiveness of UWs as a method for controlling algal growth in dam reservoirs, specifically focusing on their application in Mamloo Dam. By achieving these objectives, the research aimed to provide a comprehensive understanding of how UWs can be utilized as a viable alternative for algae control in dam reservoirs. This will contribute to the development of more effective and sustainable water management strategies, ultimately enhancing the quality of water in dam reservoirs and ensuring better performance of water treatment facilities.

2. Materials and methods

2.1. Study area

The Mamloo Dam reservoir is located on the Jajrood River, approximately 45 kilometers east of Tehran, between 32-35 degrees north latitude and 38-52 degrees east longitude. The dam was constructed to utilize the catchment area of the Jajrood River to provide irrigation water for Varamin and Pakdasht, as well as to help meet some of Tehran's drinking water needs (Sabeti et al., 2017). The Mamloo Dam Reservoir has a total capacity of 250 million cubic meters, with 202 million cubic meters being useful for its intended purposes. It can regulate up to 220 million cubic meters per year. Built in 2002, its goals include supplying 80–90 million cubic meters of potable water for Tehran, 110–130 million cubic meters for agricultural use in the Varamin Plains and Pakdasht, and 10–15 million cubic meters for industrial purposes (Naderi et al., 2022). The sampling stations along the Mamloo Dam reservoir are provided in (see Figure 1). In this study, sampling points were examined along the Dam Reservoir. The research encompassed 5 sampling sites. These sites were chosen after a thorough survey of the area.

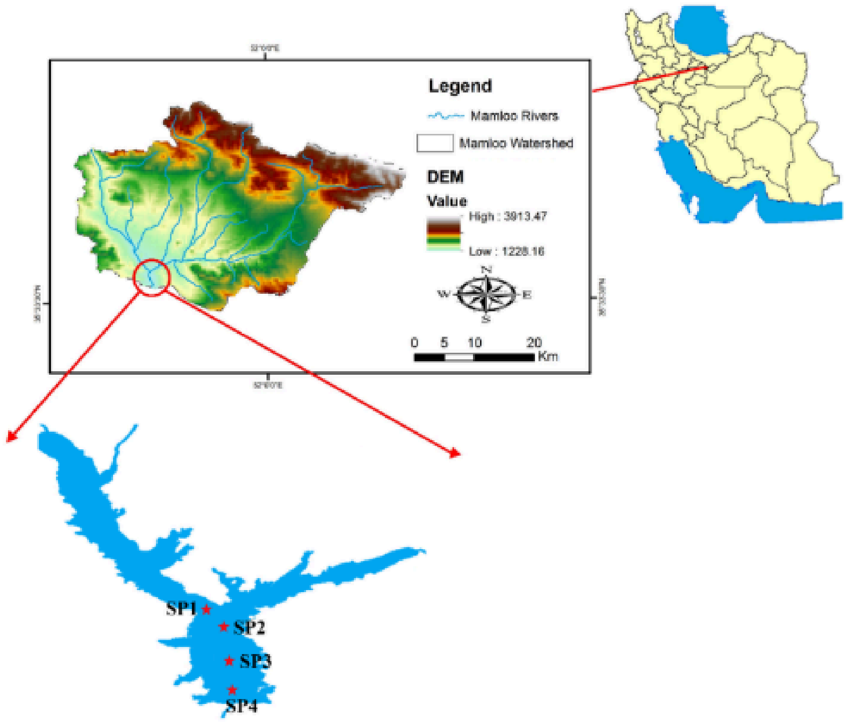

Figure 1. Mamloo dam reservior and location of sampling stations

Source: Elaborated by the authors

2.2. Physicochemical parameters analyses

A Conductivity Temperature Depth (CTD) device made by SEA & SUN Company was used to measure daily temperature, dissolved oxygen, and chlorophyll A. The DR 6000 spectrophotometric device from Hach Company was used to measure Phosphorus and nitrate. Phosphorus was measured using reagent code 2106069 and method 8048 provided by the company, while nitrate was analyzed using method 10049, without the need for any reagent (Hach, 2015; LG Sonic, 2025a). Also, UWs were produced and used from a device made by LG Sonic, customized to the specifications of the project. One device of this type was installed for the pilot, and three devices were installed on the appropriate buoy at an angle of 120 degrees to each other for the dam lake. The necessary electricity was supplied through solar panels.

2.3. Sample collection

To investigate the population structure of phytoplankton in various types of aquatic ecosystems (such as seas, lakes, rivers, etc.), samples were collected at each station from the surface down to a depth of half a meter.

Three ultrasonic wave-generating devices were installed on a prepared buoy to test their effectiveness in the Mamlo dam reservoir. Sampling was done at three points: 100 meters before the installation (toward the end of the lake), 20 meters after the installation (after the intersection of the other branch of the Tar River), and at the location of the water tower. Samples were taken from a depth of 2 meters.

For stabilization, samples were collected in opaque polyethylene containers that prevent light penetration. 0.7 cc of Lugol's solution was added to every cc of the sample. After one hour, the sample was fixed in a 4% formalin solution (4 cc of formalin per 100 cc) and transferred to the laboratory.

In the laboratory, one-liter samples were stored away from direct sunlight for a minimum of 72 hours without agitation to allow all phytoplankton to settle. After this period, the supernatant was removed using a siphon hose and a Pasteur pipette, leaving approximately 200 cc of the sample volume.

After homogenization, the samples were transferred to a 1 ml Sedgwick Rafter slide by the sampler. After a few minutes of phytoplankton settling in the slide, the samples were examined under a normal or inverted light microscope for identification and counting. It should be noted that this step was repeated three times for each sample.

2.4. Statistical analysis

Descriptive statistics, including means, standard deviations, and ranges, were calculated for chlorophyll A, nitrate, phosphorus levels, and phytoplankton counts at each sampling site and time point. Linear regression models were applied to analyze the relationships and trends between these parameters over the study period, using Excel and SPSS software (IBM SPSS Statistics for Windows, Version 24.0).

3. Result and discussion

3.1. Analysis of chlorophyll a, nitrate, and phosphorus levels during ultrasonic algae control experiment

Table 1 illustrates the sampling and monitoring program for the pilot tank over a five-week period, focusing on chlorophyll A, nitrate, and phosphorus levels, as well as phosphorus injection volumes and sampling dates. During the experiment, the effectiveness of UWs in controlling algae was assessed by monitoring these sampled parameters. This data included weekly measurements of phosphorus and nitrate concentrations, the number and types of water algae, and daily recordings of water temperature and total chlorophyll concentration. The use of Phosphorus injections helped isolate the impact of UWs by maintaining consistent nutrient levels within the tank.

In the first week, before any phosphorus injection, chlorophyll A measured 19.08 µg/l, nitrate was 29.3 mg/l, and phosphorus was 0.06 mg/l. After injecting 300 cc of 100 ppm Phosphorus, samples were taken. During the second week, chlorophyll A decreased to 11.01 µg/l, nitrate was slightly reduced to 29.1 mg/l, and phosphorus was 0.05 mg/l. An additional 300 cc of 100 ppm Phosphorus was injected. In the third week, chlorophyll A increased to 35.37 µg/l, nitrate remained at 29.1 mg/l, and phosphorus stayed at 0.06 mg/l after injecting another 300 cc of Phosphorus. Daily fluctuations in chlorophyll A levels were recorded, indicating varying algal growth patterns.

In the fourth week, chlorophyll A spiked to 44.22 µg/l, nitrate slightly decreased to 28 mg/l, and phosphorus increased to 0.11 mg/l. Another 300 cc injection of Phosphorus was administered. The spike in chlorophyll-a during Week 4 (from 35.37 µg/L to 44.22 µg/L) despite ultrasonic treatment can be attributed to:

Nutrient Injection Interference: The study injected 600 cc of phosphorus in Week 4, doubling previous doses. Phosphorus is a critical nutrient for algal growth, and sudden increases can temporarily override ultrasonic suppression, allowing residual algae to thrive (LG Sonic, 2025c; Wang et al., 2024).

Algal Adaptation: Cyanobacteria can regenerate gas vesicles within days if ultrasonic parameters remain static, enabling brief resurgences before sinking (LG Sonic, 2025c). LG

Sonic's adaptive systems avoid this by altering frequencies to prevent resistance, a feature not explicitly mentioned in the Mamloo setup (LG Sonic, 2025b).

Thermal Stratification: The thermocline observed in Mamloo (10–26 m depth) traps nutrients in deeper layers. Mixing events or incomplete stratification during treatment could have temporarily reintroduced nutrients to the surface, fueling algal growth (SONIC, 2025c; Wang et al., 2024).

The Mamloo Dam study validates ultrasonic technology's potential for algae control but highlights challenges in nutrient management and adaptive parameter tuning. Discrepancies with LG Sonic's trials stem from differences in scalability, real-time monitoring, and nutrient strategies. Chlorophyll-a spikes underscore the need for holistic approaches combining ultrasound with nutrient reduction and dynamic frequency adjustments, as exemplified by LG Sonic's systems (LG Sonic, 2025b, 2025c, 2025d).

By the fifth week, chlorophyll A was 12.87 µg/l, nitrate decreased to 27 mg/l, and phosphorus was 0.09 mg/l after further injections. Phytoplankton and chemical samples continued to be taken to monitor the effects. Overall, the data shows that while Phosphorus injections were aimed at controlling nutrient levels, chlorophyll A concentrations fluctuated significantly.

Table 1. Sampling and monitoring program of the pilot

Date		Sampling		Phosphorus injection	phosphorus)mg/l)	Nitrate (mg/l)	Chlorophyll A (µg/l)
		Phytoplankton	Chemical				
first week	23 November, 2021	√	√	√ 300 cc 100 ppm	0.06 (before injection)	29.3	19.08
	24 November, 2021						23.05
	25 November, 2021						20.16
	26 November, 2021						14.64
	27 November, 2021						30.6
second week	30 November, 2021	√	√	_	0.05	29.1	-
	1 December, 2021						11.01
	2 December, 2021	_	_	300 cc 100 ppm The device turned on	0.06	29.1	26.53
	3 December, 2021						27.68
	4 December, 2021						20.03

third week	7 December, 2021	√	√	300+300	0.06	29.1	35.37
	8 December, 2021						10.91
	9 December, 2021						10.42
	10 December, 2021						13.27
	11 December, 2021						5.38
forth week	14 December, 2021	√	√	300+300	0.11	28	44.22
	15 December, 2021						-
	16 December, 2021						11.01
	17 December, 2021						-
	18 December, 2021						30.95
fifth week	21 December, 2021	√	√	300+300	0.09	27	12.87
	22 December, 2021						-
	23 December, 2021						-

Source: Elaborated by authors

3.2. Changes in phytoplankton populations and total counts over time: late November to December 2021 and late February to March 2022

Figure 2 and Figure 3 illustrate the changes in the number of various phytoplankton types (green algae, diatoms, and cyanobacteria) over two distinct periods: late November to December 2021 and late February to March 2022. According to these results, three groups were identified: diatoms, cyanobacteria, and green algae. All three groups decreased in number during the monitoring period of the tank, which is explained in detail below. It is important to note that the increase in algae numbers in the fourth week compared to the third week was a result of an increase in phosphorus injection volume from 300 to 600 cc. Phosphorus is a key nutrient for phytoplankton growth (Jiang & Nakano, 2022); however, excessive levels can lead to nutrient imbalances and disrupt phytoplankton dynamics (Wang et al., 2021).

From late November to December 2021 (see Figure 2): the green algae population started at 300,000 NO./l on 23 November and significantly decreased to 22,489 NO./l by 30 November. However, it exhibited some recovery, peaking at 47,522 NO./l on 14 December before dropping to 6,628 NO./l by 21 December. Diatoms, initially recorded at 2,934,000 NO./l on 23 November, sharply decreased to 124,344 NO./l by 30 November and further declined to 6,473 NO./l on 7 December. There was a minor increase to 14,100 NO./l on 14

December, followed by a decrease to 9,157 NO./l by 21 December. Also, cyanobacteria starting at 60,000 NO./l on 23 November, dropped to 1,956 NO./l by 30 November and reached zero by 7 December. They briefly reappeared at 3,656 NO./l on 14 December but fell back to zero on 21 December. The total count of phytoplankton decreased significantly from 3,294,000 NO./l on 23 November to 148,789 NO./l by 30 November. This number further declined to 21,439 NO./l on 7 December but then showed some fluctuation, rising to 65,278 NO./l on 14 December before dropping to 15,785 NO./l by 21 December.

From late February to March 2022 (Figure 3): the green algae count began at 1,112,267 NO./l on 25 February, increased to 1,436,500 NO./l by 29 February, then decreased to 661,333 NO./l by 9 March, and finally to 493,000 NO./l by 15 March. Diatoms started at 2,258,933 NO./l on 25 February, decreased to 1,895,500 NO./l by 29 February, dropped further to 857,666 NO./l by 9 March, and significantly reduced to 42,500 NO./l by 15 March. Cyanobacteria were initially recorded at 22,933 NO./l on 25 February, dropped to 8,500 NO./l by 29 February, slightly increased to 10,333 NO./l by 9 March, and reverted to 8,500 NO./l by 15 March. The decline in diatom populations is particularly noteworthy, as diatoms are generally favored in cooler, nutrient-rich conditions, and their decline may reflect shifts in environmental conditions or nutrient availability (Kuefner et al. 2020). Also, the total phytoplankton count decreased from 3,394,133 NO./l on 25 February to 3,340,500 NO./l by 29 February, then dramatically dropped to 1,529,332 NO./l by 9 March, and further to 544,000 NO./l by 15 March.

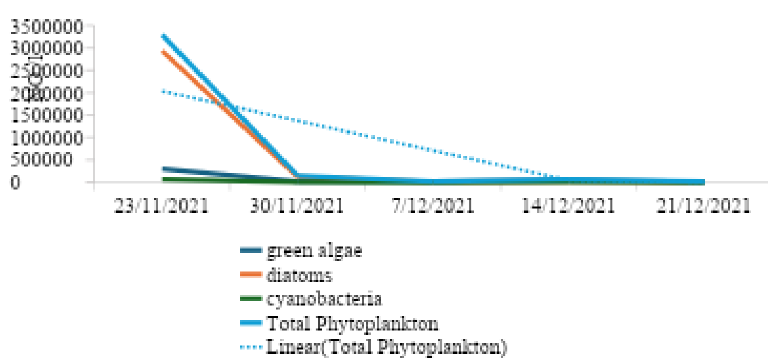

Figure 2. Changes in the number of phytoplankton during the monitoring of the pilot (the fist series of experiments)

Source: Elaborated by authors

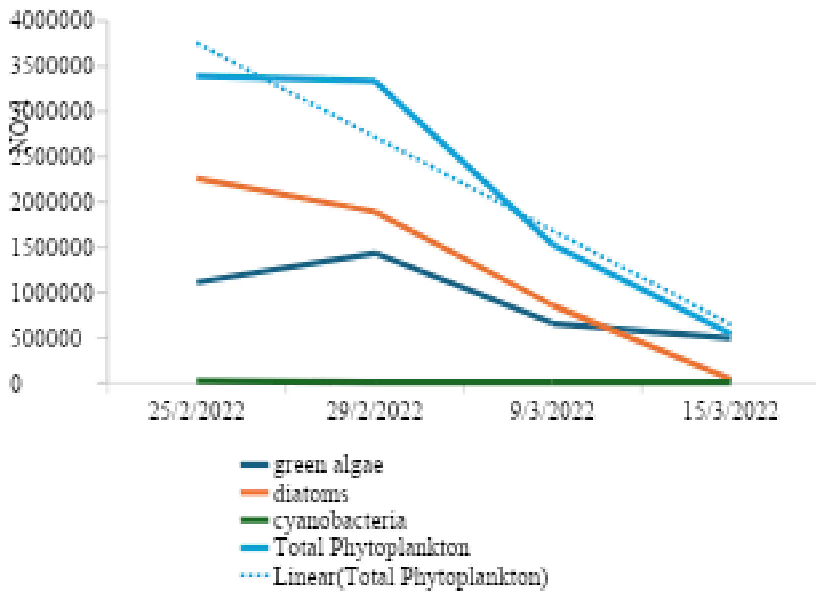

Figure 3. Changes in the number of phytoplankton during the monitoring of the pilot (the second series of experiments)

Source: Elaborated by authors

Comprehensive analysis of WQ, thermal stratification, and phytoplankton dynamics about ultrasonic algae control

The maximum wave propagation measured at the dam was about 100 meters, with the maximum impact observed up to 80 meters. The results of the samples collected from the specified points and depths are presented in the Figures below.

As observed on May 14, 2022 (Figure 4), a distinct thermal layering was established in the lake. The thermocline began at 10 meters and extended to approximately 26 meters. Below that, it gradually sloped towards the lake bed. Currently, the minimum temperature of the lake is 9 °C. According to thermal layering, a decrease in DO is expected under the thermocline layer. This is shown in Figure 5, which is entirely consistent with Figure 4. The highest amount of DO is 9.5 milligrams per liter at the surface of the lake. As the thermocline begins at 9 meters, the levels drop drastically, reaching 0.6 mg/liter at a depth of 14 meters. This phenomenon can be attributed to several factors. During thermal stratification, the upper mixed layer (epilimnion) is well-oxygenated due to wind mixing and photosynthetic activity by phytoplankton (MacKinnon & Herbert, 1996). However, the hypolimnion, or the deeper layer below the thermocline, experiences reduced oxygen levels because it is isolated from surface processes and is not replenished by atmospheric diffusion (Fukushima et al., 2017; Schwefel et al., 2016). The decrease in DO under the thermocline is further exacerbated by the decomposition of organic matter in these deeper layers, which consumes oxygen and leads to observed low levels (Zhang et al., 2015; Zhao et al., 2017). The observed DO gradient in the lake aligns with findings from recent studies on thermal stratification and its impact on lake oxygenation. For instance, Zhang et al. (2015) discuss how thermal stratification affects the distribution of oxygen in lakes, highlighting similar patterns of oxygen depletion in the hypolimnion (Zhang et al., 2015). To measure changes in chlorophyll A levels at different depths of the dam lake before installing the ultrasonic device, the CTD device was used. In stratified lakes, chlorophyll A concentrations often exhibit distinct vertical profiles due to variations in light availability and nutrient distribution (Mellard et al., 2011).

The results are shown in Figure 6. According to the Figure, the maximum amount of chlorophyll A is observed at a depth of 2 meters from the water surface at a rate of 12 µg/l. The high concentration of chlorophyll at a depth of 2 meters suggests that this depth is within the euphotic zone, where light penetration supports photosynthesis and thus higher algal growth (Kiefer et al., 1989). It decreases significantly upon entering the thermocline layer and continues to decrease noticeably up to a depth of 16 meters, where it is reduced to about 1 µg/l. The significant drop in chlorophyll A as the water column transitions into the thermocline (typically characterized by a rapid temperature gradient) aligns with the concept that the thermocline acts as a barrier to nutrient mixing and light penetration (Mignot et al., 2012). This same level of chlorophyll is maintained until the bottom of the lake. According to the Figure, sampling was conducted at a depth of 2 meters, where the highest amount of chlorophyll A was found. The sampling strategy focusing on a depth of 2 meters, where chlorophyll A concentrations are highest, is consistent with common practice in limnological studies aimed at assessing algal biomass and productivity and the significant impact of depth on chlorophyll concentrations in various studies like (Noges et al., 2010; Smith et al., 2024). This depth provides a representative measure of peak algal concentration, which is crucial for evaluating the impact of interventions, such as the installation of ultrasonic devices to manage algal populations and improve WQ (Huang et al., 2020).

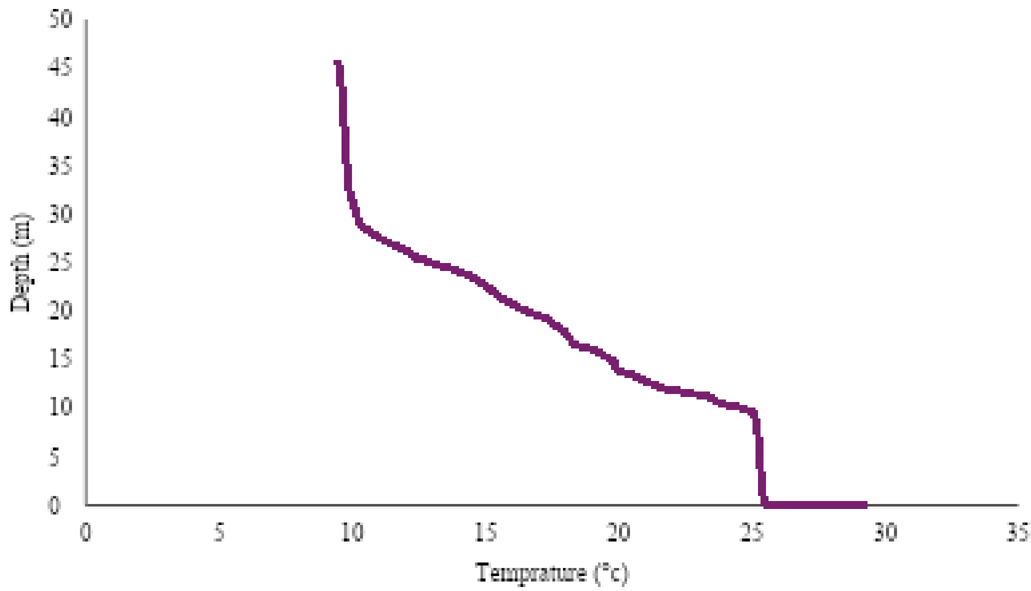

Figure 4. Distribution of the temperature profile in the pilot (14 May, 2022)

Source: Elaborated by authors

Figure 5. Changes in DO concentration in the pilot (14 May 2022)

Source: Elaborated by authors

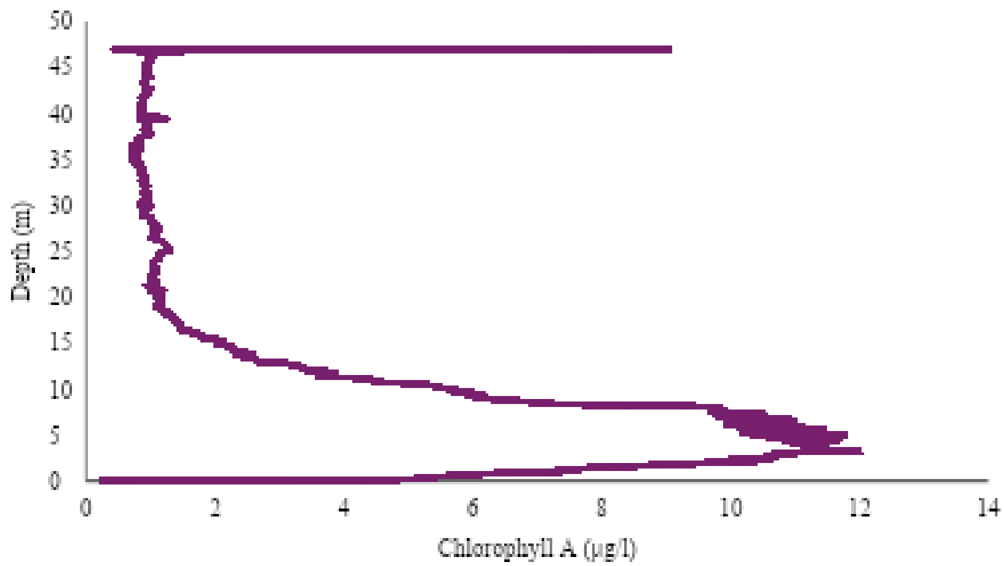

Figure 6. Changes in the chlorophyll A concentration in the pilot

Source: Elaborated by authors

The investigation into WQ at various monitoring sites, with an emphasis on the effect of UWs, uncovers important results concerning the concentrations of different pollutants. Notably, the presence of UWs appears to influence the levels of chemical oxygen demand (COD), biological oxygen demand (BOD), total phosphorus (TP), nitrite, and nitrate in the water. Ultrasonic technology has shown promise in improving WQ by reducing pollutant levels. Kim (2024) highlights the effectiveness of ultrasonic technology in degrading persistent organic pollutants (POPs) and other contaminants, such as methylene blue. This is achieved through the use of cavitation bubbles, which release energy to break chemical bonds (Kim et al., 2024).

According to Figure 7, the phytoplankton concentration is highest at the intake gate (2.668 /lit/1000000) and lowest 20 meters after the ultrasonic devices (1.98 /lit/1000000). This indicates that the UWs are effective in reducing the phytoplankton population. The COD level is highest at the Tar River crossing (13 mg/l) and 100 meters before the ultrasonic devices (9.6 mg/l). After the ultrasonic device, at a distance of 20 meters downstream, the COD shows a slight decrease (8.8 mg/l). This reduction may be due to the ultrasonic cavitation process, which facilitates the breakdown of complex organic molecules into simpler forms, making them more available for microbial degradation (Wang et al., 2019).

Also, The TP level is highest at 100 meters before the ultrasonic devices (1.09 mg/l), which is a critical factor in algae growth. This value decreases towards the intake gate (0.38 mg/l), indicating a reduction in nutrient levels as water moves through the system. The TP concentration at the intake gate is the lowest among the sampled locations, illustrating effective nutrient management. The presence of phytoplankton is closely associated with nutrient levels, particularly phosphorus. The highest concentration of phytoplankton was recorded at the intake gate and 100 meters before the ultrasonic device. This finding aligns with previous research indicating that UWs can disrupt the cellular structure of algae, reducing their growth and proliferation (Wu et al., 2011). However, the reduction in TP from 1.09 mg/l at 100 meters before the ultrasonic device to 0.38 mg/l at the intake gate suggests that ultrasound may aid in phosphorus removal by facilitating the coagulation and sedimentation processes, which can be enhanced by the cavitation effect, as noted by Li et al. (2013).

The nitrite concentration remains consistent at the intake gate and the Tar River crossing (0.25 mg/l) but shows a slight increase 20 meters after the ultrasonic devices and 100 meters before the ultrasonic devices (0.32 mg/l). This slight increase may be due to localized factors affecting nitrite levels. The nitrate concentration is relatively consistent across all locations, with a slight decrease observed 100 meters before the ultrasonic devices (6.6 mg/l). This indicates stable nitrogen levels throughout the monitored areas.

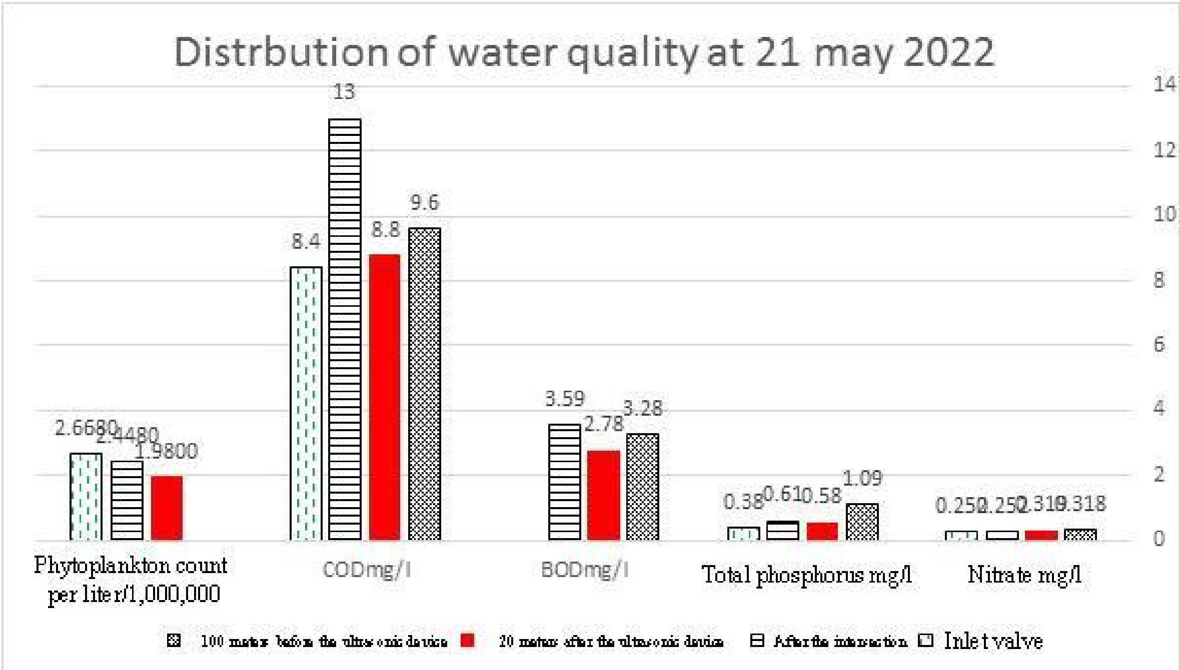

Figure 7. Variations in WQ parameters at different monitoring points (second series: 21 may, 2022)

Source: Elaborated by authors

4. Conclusion

Due to the small volume of the pilot study, the UWs have a significant impact on the number of phytoplankton. This method proves to be highly efficient for small areas of reservoirs and could be further explored in larger volume conditions, particularly in dam reservoirs. The dam where the devices were installed is shown to be highly nutritious. Before the devices were installed, the TP in terms of phosphorus exceeded 1 mg/l. Additionally, at the time of the device test, the lake has undergone thermal stratification, creating ideal conditions for algal growth and potential algal blooms. In this situation, it is essential to control algae growth by any possible method. The presented results clearly show a reduction in algae after the use of UWs. Despite the continuous injection of nutrients through the natural flow inside the tank, there has been a noticeable decrease in the number of phytoplankton in all measurements. However, due to the favorable conditions for their growth, an increase is observed again after moving away from the impacting waves. This increase is not as significant. However, once the water tower of the above devices is installed, it is expected that the amount of phytoplankton in the tank's outlet will be significantly reduced.

The Mamloo Dam study provides valuable insights into ultrasonic algae control but has key limitations that affect its broader applicability. Below, we address these limitations and propose solutions informed by global best practices (e.g., LG Sonic's methodologies) and research recommendations.

1. Short Study Duration

Limitation: The study spanned 5 weeks, capturing only short-term effects of ultrasonic treatment. Algal communities can adapt over time (e.g., regenerating gas vesicles), and seasonal factors (e.g., nutrient runoff, temperature shifts) were not assessed.

Chlorophyll-a fluctuations (e.g., Week 4 spike) suggest incomplete understanding of algal resilience and UW's long-term efficacy.

Solutions: Multi-Year Monitoring: Extend the study to 2–3 years to evaluate seasonal dynamics (e.g., summer blooms vs. winter stratification) and long-term algal adaptation.

Continuous Data Collection: Use real-time sensors (e.g., LG Sonic's MPC-Buoy with vertical profilers) to track chlorophyll-a, nutrients, and temperature hourly, enabling adaptive responses to sudden algal resurgences.

2. Single-Device Pilot Scale

Limitation: A single ultrasonic device was tested in a small area (max 100 m range), limiting scalability insights for large reservoirs like Mamloo (250 million m^3).

Overlapping ultrasonic coverage and hydrodynamic effects (e.g., currents, stratification) were not addressed.

Solutions: Grid-Based UW Deployment: Install multiple devices in a grid pattern to ensure overlapping coverage (e.g., LG Sonic's 50-buoy system in a 7 km^2 reservoir).

Site-Specific Calibration: Use adaptive ultrasonic frequencies tailored to dominant algal species (e.g., 20–40 kHz for cyanobacteria) and local conditions (e.g., depth, turbidity).

3. Fixed Ultrasonic Parameters

Limitation: The study used static frequency/power settings, which may allow algae to adapt over time (e.g., gas vesicle repair).

LG Sonic's trials show superior results with dynamic frequency adjustments based on real-time algal data.

Solutions: Algorithm-Driven Systems: Implement AI-powered systems (e.g., LG Sonic's MPC-Controller) to adjust UW parameters automatically in response to:

Algal species shifts (e.g., diatoms → cyanobacteria).

Nutrient spikes (e.g., phosphorus influx from rainfall).

Thermal stratification changes (e.g., thermocline depth).

4. Artificial Nutrient Injections

Limitation: Phosphorus injections (up to 600 cc) created an artificial nutrient-rich environment, masking real-world conditions where nutrient reduction is critical for sustained control.

Solutions: Integrated Nutrient Management: Pair UW with:

- Sediment capping (e.g., aluminum-modified clays) to immobilize internal phosphorus.
- Wetland buffers to reduce agricultural runoff.
- Naturalized Experiments: Conduct trials without artificial nutrient additions to mimic real reservoir conditions.

5. Limited Ecological Impact Assessment

Limitation: The study focused on phytoplankton and WQ parameters but did not assess impacts on zooplankton, fish, or benthic ecosystems.

Solutions: Ecological Monitoring: Include metrics like:

Zooplankton diversity (e.g., cladocerans as bioindicators).

Fish health (e.g., gill function, stress biomarkers).

Sediment oxygen demand (SOD) to evaluate hypolimnetic recovery.

Implementation Roadmap:

- Phase 1 (Year 1–2):

  Deploy 5–10 UW devices with adaptive frequencies in Mamloo.

  Integrate real-time sensors for chlorophyll-a, TP, and DO.

- Phase 2 (Year 3–4):

  Expand full reservoir coverage (20+ devices).

  Partner with agricultural stakeholders to reduce upstream nutrient loads.

- Phase 3 (Year 5+):

  Publish multi-year data to refine UW protocols for global dam reservoirs.

5. Closing Statements

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Contributions of each author:

Mehdi Vaezi: Formal Analysis, Investigation, Methodology, Writing– original draft, Writing– review & editing; Amirhossein Javid: Formal Analysis, Project Administration, Supervision; Seyed Mustafa Khezri: Formal Analysis, Project Administration, Supervision; Mohsen Eslamizadeh: Formal Analysis, Project Administration, Supervision.

Conflict of Interest:

The authors declare no conflicts of interest in the writing or publication of this article.

Ethical Implications:

The authors have no ethical implications that should be declared in the writing or publication of this article.

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