

Advancing Water Quality Management Using Hybrid Ecotechnological Approaches

Siddharth Srimali, Dr. Divya Srivastava

Department of Civil Engineering, Amity University Uttar Pradesh Lucknow Campus

Abstract:

Making sure our water is good quality is really important, especially since we need different ways to improve it.. One way to do this is by using artificial floating wetlands (AFW). The importance of aquatic plants, animals, and microbes in AFW for cleaning and disinfecting water is also discussed. Constructed wetlands are increasingly recognized as sustainable systems that combine natural ecological processes with engineered design. Their long-term performance depends on adapting the setup to local environmental conditions, maintaining the structures regularly, and ensuring they work in harmony with wider water management practices. While not a universal substitute for conventional treatment, they represent a strategic, long-term solution for improving water quality, enhancing ecosystems, and supporting community-level environmental goals. In conclusion, more viewpoints regarding artificial float islands were identified in order to improve their performance. This research emphasizes how important it is to comprehend the mechanisms in AFW that drive the removal of various contaminants to improve water quality. Ultrasonic therapy is an eco-friendly method that could help control algal blooms. It works by breaking apart the cells without needing any chemicals.. Its greatest potential lies in targeted, small-to-medium scale applications or in combination with other treatment methods, rather than as a universal replacement for conventional algal management strategies. On the other hand, a hybrid system, combining ultrasonic algal disruption with artificial wetlands, offers a complementary, eco-technological solution to water quality management. Blooms can be quickly and precisely controlled with ultrasound. This integration positions it as a strategic method for eutrophic water bodies dealing with recurrent algal bloom issues because it not only improves treatment efficiency but also guarantees increased sustainability, resilience, and safety. According to the research in the present work, a hybrid system of combining Artificial floating wetland models with Ultrasonic algal bloom treatment modules is shown. The efficient layout to combine these systems is to use a ratio of ultrasonic modules to AFW modules of 1:21.

Keywords: *Ultrasonic therapy; algal disruption; artificial wetlands; toxin attenuation; algal bloom*

Water pollution is caused by different parameters; some of the major contributors are algal blooms and nutrient overload (N, P). Algal blooms reduce dissolved oxygen (DO) and also release toxins, while the dissolved nutrients, such as nitrogen, increase the growth of algal blooms. In current times, many chemical treatments are being used, but they are short-term solutions and have harmful side effects on aquatic life. On the other hand, mechanical removal is found to be expensive and not scalable. We need sustainable, non-chemical solutions which is also eco-friendly and long-term. Some alternate methods also show some good effects, like Artificial floating wetlands and ultrasonic algal bloom treatment units, but they also have their vulnerabilities. The artificial floating wetlands (AFWs) are found to be very efficient in absorbing nutrients like nitrogen and phosphorus, and also increasing DO simultaneously. They are very cost-friendly and they cause no harm to aquatic life. But the presence of an algal bloom inhibits the efficiency of wetlands.

On the other hand, the ultrasonic algal bloom remover is a short-term solution, as the algal bloom recurs due to the presence of dissolved nutrients like nitrogen present in the water body. Current research is based on combining these two models, as these two models complement each other so perfectly for improving the quality of water.

Water quality measures include many parameters, like Algal blooms and dissolved nutrients (nitrogen and phosphorus), which ultimately lead to lowering dissolved oxygen (DO). Algal blooms often arise when cyanobacteria thrive in nutrient-rich waters, especially under warm conditions where nitrogen and phosphorus are more (Lee et al., 2001). These blooms reduce dissolved oxygen (DO), which can suffocate fish and other aquatic organisms. Additionally, some cyanobacteria release harmful toxins that pose risks to both human and animal health if ingested. Conventional chemical treatments can temporarily suppress blooms, but they often harm aquatic forlife and are not sustainable solutions (Mahvi & Dehghani, 2005). Some existing techniques, such as the release of Chemicals, are examples of techniques that are usually used, but they are not a permanent solution as they also damage aquatic life and are not cost-friendly and economical. (Mahvi & Dehghano, 2005). Our research comes with a solution: to use Artificial Floating Wetlands (AFWs), also called floating treatment wetlands (FTWs) or constructed wetlands. AFWs are platforms that float on the surface of the water and support plants whose roots hang freely in the water. These roots not only provide surface area for microbial biofilms to grow but also absorb nutrients directly from the water. In this

way, AFW does a dialysis that continuously filters and cleans the water, Research shows that artificial floating wetlands (AFWs) are capable of reducing nutrient levels in water systems. Depending on plant species and coverage, AFWs can cut phosphorus and nitrogen concentrations by a considerable margin (Shutes, 2001; Chang et al., 2017). For example, phosphorus removal in stormwater ponds has been measured at around 25–45% (McAndrew et al., 2017), while studies in subtropical environments with emergent plants like *Juncus effusus* observed even higher reductions (Chang et al., 2013). Such findings highlight the value of AFWs as a nature-based solution to nutrient pollution. Studies have shown that floating wetlands can substantially lower nutrient loads in water bodies. For instance, McAndrew et al. (2017) observed that phosphorus concentrations in stormwater ponds were reduced by roughly one-quarter to nearly half. In subtropical environments, systems containing emergent species like *Juncus effusus* achieved even stronger reductions, close to 50% (Chang et al., 2013).

These findings demonstrate the efficacy of AFWs in eliminating the nutrients that support the growth of algae. Also, continuous harvesting of plant biomass creates a long-term nutrient sink by permanently removing the nutrients that are locked inside the plants from the water system (Robert et al., 1997).

However, Ultrasonic Algal Control, another cutting-edge technique, provides an additional means of directly lowering algal bloom concentration. A thin layer of pressure is created on the water's surface by transmitting low-power ultrasonic vibrations into it. Tiny internal gas vesicles are essential for many buoyant cyanobacteria to float up and reach sunlight. Ultrasonic waves disrupt the tiny gas vesicles inside buoyant cyanobacteria, preventing them from floating near the surface. Once they sink deeper into the water, they receive less light and are unable to photosynthesize, eventually leading to their decline. This process has been mathematically described using a first-order decay model, where the reduction in algal concentration over time follows an exponential decline (Zhou et al., 2006; Zhang et al., 2020).

Crucially, sub-cavitation levels, or low-power ultrasound, do not result in dangerous cavitation, which can create excessive pressures and injure other aquatic life. According to controlled research, these lower intensities have little effect on other aquatic life (Shenoy et al., 2025).

Ultrasonic Algal Bloom

The ultrasonic unit transmits low-frequency ultrasonic waves that destroy gas vesicles created by cyanobacteria. These gas vesicles are responsible for creating a buoyancy force for the algal bloom to float on the surface and do photosynthesis. The dispersion of algae in the water column is impacted by low-intensity ultrasound. It is an eco-friendly technique that poses no danger to humans, fish, plants, or other water life. A sound layer is formed on the water body's uppermost layer when low-power ultrasonic waves are released into it, creating a pressure differential with the water's lower layers. As a result, new algae cells are unable to come to the surface to take up light for photosynthesis. The primary metric used to quantify this effect is the decrease in chlorophyll-a concentrations.

For planktonic algae to be at the water's surface and receive sunlight, they need buoyancy. By adjusting the amount of intercellular gas vesicles they produce, cyanobacteria control their buoyancy.

All algae that depend on buoyancy are directly harmed by ultrasound waves. Over time, the algae cells degrade after sinking to the bottom of the body of water and dying from a lack of light. Ultrasonic technology is a tried-and-true technique that has been used for decades to control the growth of algae. Below (Fig. 1) is the demonstration of the rise of algae by buoyancy force produced by gas vesicles.

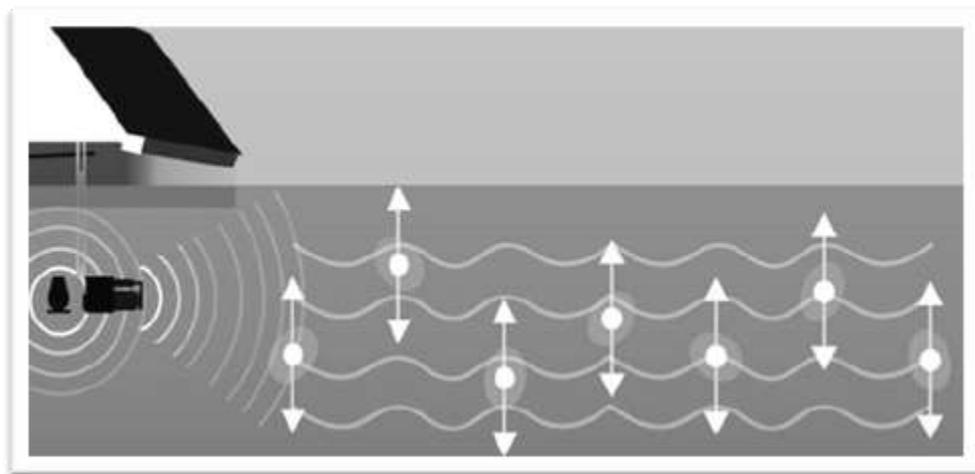


Fig 1 . Algae (In Green) Buoyancy In The Water Column

Modern field applications of ultrasound include systems such as the MPC-Buoy developed by LG Sonic, which use low-intensity sound waves to manage algal populations in lakes and reservoirs (Shenoy et al., 2025). These devices operate continuously, creating pressure conditions that interfere with the buoyancy of algae without causing harm to fish or other non-target organisms.

The ultrasound lessens the buoyancy of the algae by raising the hydrostatic pressure surrounding the algal cell. For algae to stay at the top water layer and receive enough light to develop and flourish quickly, they need cell buoyancy. The idea that algal buoyancy depends on the formation and collapse of gas vesicles is only partially accurate. It is irreversible for gas vesicles to collapse. Because of the size and structure of the vesicle, this is not feasible for certain algae species.

High-power ultrasound can not be used as it can undergo cavitation. At very high ultrasonic intensities, cavitation can occur — a process where microscopic bubbles form and collapse violently within the water. This collapse generates extreme local conditions, including intense heat, high pressure, and reactive radicals, which can break down algal cells but also risk damaging other aquatic organisms (Shenoy et al., 2025). Significant gas-phase chemical processes are fueled by this extreme heat and pressure, which happen on a millisecond scale. The pressure and heat destroy algal cells. Both plant filaments and red blood cells may sustain harm from it. Furthermore, highly reactive hydroxyl radicals produced by unstable cavitation can disrupt organic materials. Using this technique to treat lakes has not yet proven to be practical.

Artificial Floating Wetlands

In simple terms, AFWs are floating rafts with plants and roots hanging into the water. The roots have microbial biofilm support to take Nutrient uptake (N, P) and also perform Oxygenation & filtration. Below (Fig. 2) is an example of an AFW plant. They are kept in water by a 3-point mooring with plastic wires. The 3-point mooring is done in case of stormwater flow.



Fig 2. Canna indica

These systems' area, length-to-width ratio, water depth, wastewater loading rate, and transit time through the wetland all affect how well they work. Constructed wetlands generally perform very well in treating contaminated water. Research reports suggest that they can eliminate up to nine out of ten harmful microorganisms, while also removing around 80% of organic matter and suspended solids. Their effectiveness for nutrient removal, however, is usually lower, often falling below 60% (Shutes, 2001; Robert, 1997). Constructed wetlands are a useful and appropriate technique that can be used either alone or in conjunction with other systems to treat wastewater and other water pollution sources. Small communities in developing nations, where the potential health advantages of pathogen eradication are significant, are ideally suited for it. Below (Fig. 3) is the layout of AFW.

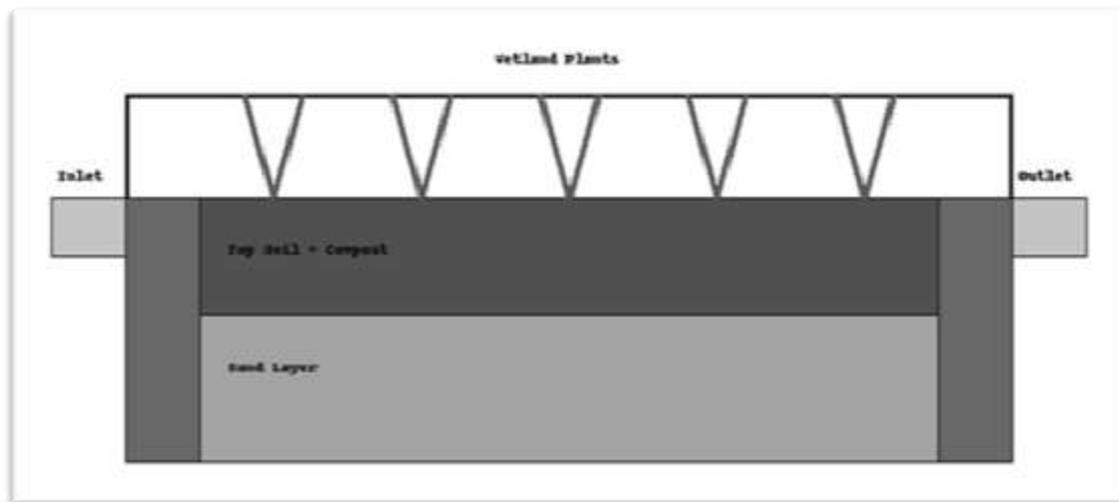


Fig 3. Layout of an artificial floating wetland

These two models have their own vulnerabilities when working alone, but in the current paper, the effects (decrease in nitrogen and algal bloom concentration) of the proposed model, BioSonic Hybrid Floating Wetlands (both ultrasonic algal bloom unit and artificial floating wetlands), are studied. In the current paper, the simulation of the working model of our proposed layout, considering real-life situations (using MATLAB simulations), has been done.

Methodology

Study Area

Consider a one-hectare body of water, which is equivalent to a 100 m by 100 m square plot of land, with depths between 3 and 4 m and a moderate nutrient load (Total Phosphorus between 0.1 and 0.3 mg/L). We intend to establish Artificial Floating Wetlands (AFWs), which are floating rafts with plants that purify the water as they develop, to improve water quality organically.

Assumptions and Design Basis

Experts advise that floating wetlands should make up to 10–25% of a pond's surface and not

more than that to significantly improve water quality by maintaining the level of DO, according to ecological design principles (Arivukkarasu & Rangarajan et al.,2022). The target coverage is 7.5%, which is small but effective—supported by Alfonso et al. (2014)—as it is environmentally benign without overtaxing the waterbody or running the risk of low oxygen zones (anoxia).

The area of each floating module is 3 m * 3 m, or 9 m². It is estimated that roughly 750 m² of AFW will be required to fill 7.5% of the 10,000 m² water body. This comes to 83.3 modules when divided by 9 m² each module, rounded up to 84 modules for convenience.

Quick calculations

10,000 m² * 0.075 = 750 m² of floating wetland is needed for AFW coverage.

The total number of modules is 84, which is equal to 750 m² ÷ 9 m²/module ≈ 83.3.

According to Shutes et al. (2001), the average number of plant plugs needed is 6 per m² * 750 m² = 4,500.

Context and Scientific Support

These systems of floating wetlands are well-known. For example, during the growing season, MDPI, a small-scale AFW of only 90 m² on the Chicago River, decreased phosphate by 6.0% and nitrate by 6.9%. This demonstrates that even small-scale systems can significantly enhance the quality of the water.

Current cautious 7.5% choice balances treatment advantages without running the danger of oxygen depletion in deeper waters, even though a 10–25% surface covering is optimal for increased effectiveness (Robert H. Kadlec,1997). Even in situations when wider coverage is not practical, this careful design helps to retain good performance.

Ultrasonic Algal Control + Power Setup

To manage algae naturally, ultrasonic transducers are used, devices that emit sound waves disrupting algal cells. These operate non-chemically and are considered environmentally safe.

Four units are used, each with a practical ~40 m radius of influence, positioned at the centre and three corners (NW, NE, SE). This arrangement ensures overlapping coverage, shown below (Fig. 4), across the entire hectare to account for water movement and shadowing from wind or currents.

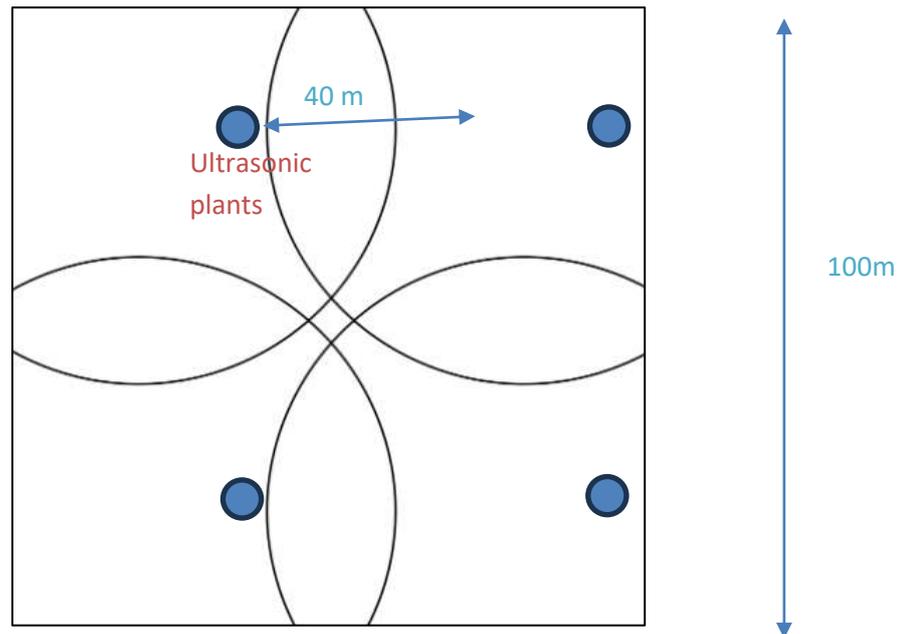


Fig 4. Overlapping of the area coverage of ultrasonic units of radius 40m each in area of 10000m²

Each ultrasonic unit consumes around 30 W, leading to 720 Wh per day (30 W * 24 h). Under average sunlight conditions (~5 peak sun hours) and a derating factor (a factor of safety) of 1.5 (typical in PV design), the required solar panel capacity is calculated as:
 $(720 \text{ Wh/day} \div 5 \text{ h/day}) * 1.5 \approx 216 \text{ Wp}$

For simplicity and a safety margin, it is rounded up to a 250 Wp panel per unit.

Summary

Floating Wetlands on a 1-hectare pond with depths of 3–4 m and moderate nutrient levels have been installed. To treat the water without causing oxygen-related issues, it was chosen to cover just 7.5% of the surface with AFWs about **750 m²**, requiring **84 modules** of **9 m²** each. **4,500 plugs** (about six per square meter) is planted. Research shows even smaller installations (e.g., 90 m² in Chicago) can reduce nutrients significantly. To control algae naturally, four ultrasonic units each with a 40 m coverage radius will be deployed across the pond to ensure full coverage. Powered by solar panels (250 Wp each) and backed with 1.2 kWh batteries, each unit draws about 30 W continuously, yielding around **720 Wh/day**, with enough storage for **1.5 days** of operation under low sunlight scenarios. This design relies on proven science while being accessible and intuitive to understand.

Below (Fig. 5) is the flowchart of the hybrid Artificial Floating Wetlands and Ultrasonic Algal Bloom Treatment for the better treatment of water bodies.

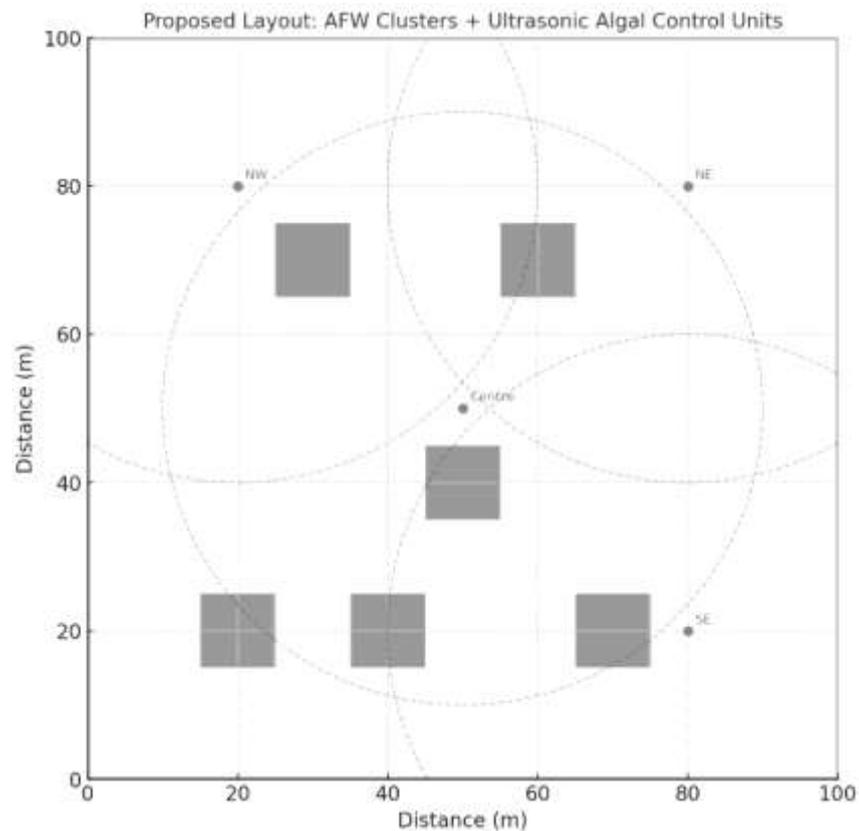


Fig. 5 the proposed schematic layout showing:

- Ultrasonic units (centre, NW, NE, SE) with ~40 m coverage radius.
- AFW clusters (6 groups of 14 modules each) distributed strategically.
- Boundary represents the 1-hectare (100 * 100 m) waterbody.

4 units at approximate positions: NW corner (near inflow if), NE corner, SE corner, and one central service raft. Ensure overlap zones between effective radii.

MONITORING AND PERFORMANCE

In the current study, it has been simulated how pollution in the Yamuna river (nutrients, like nitrogen) affects the growth of algae, and how floating wetland plants and ultrasonic treatment can control that algae. To do this, we used a mathematical model (MATLAB, with three equations), one for nutrients (N), one for algae (A), and one for plants (P). Each equation tells us how the concentration changes every day.

The nutrient values (initial dissolved nitrogen is taken as 3 mg/L) on real measurements are taken from Sharma et al. (2017), who studied nutrient chemistry in the Yamuna. Seasonal

temperatures (summer -30 °C, monsoon -26–27 °C, winter -14 °C) from Yamuna studies in Delhi are used. These values let us make the model more realistic for the river.

Nutrients (N) Dynamics

Nutrients decrease when algae eat them and when plants absorb them for growth. $\mu(T)$ is the algal growth rate depending on temperature. $(N / (K_N + N))$ is Michaelis–Menten uptake (Monod kinetics). $I(A) = 1 / (1 + \alpha A)$ is light limitation. $k_{\text{uptake}} \cdot P \cdot N$ is nutrient removal by plants. (Reynolds, 2006; Sharma et al., 2017)

$$dN/dt = - \mu(T) \cdot A \cdot (N / (K_N + N)) \cdot I(A) - k_{\text{uptake}} \cdot P \cdot N \quad (1)$$

$\mu(T)$ = algal growth rate, which depends on temperature.

Nutrient uptake by algae follows a saturation-type relationship: when nutrients are scarce, uptake is slow, but as concentrations increase, the uptake rate approaches a maximum limit. This principle is expressed mathematically by the Michaelis–Menten (or Monod) model, which is widely used in ecology to represent nutrient limitation (Reynolds, 2006)

$I(A) = 1 / (1 + \alpha A) =$ **light limitation factor**; if algae are dense, they block light for themselves.

$k_{\text{uptake}} P N =$ nutrient removal by plants, which increases when there are more plants and more nutrients.

In short, **nutrients go down when algae and plants take them up.**

Below (Fig.6) is the stimulated result of proposed model:

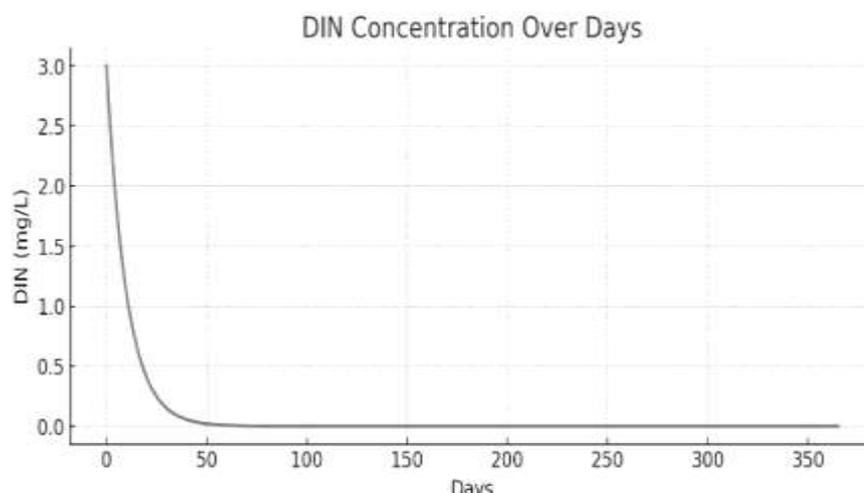


Fig 6. Dissolved inorganic conc. Decrease with passing days

Final DIN (t=365 d): 0.041 mg/L

Algae (A) Bloom Dynamics

Algae grow if there are enough nutrients and light, but ultrasound kills them. (Reynolds, 2006; Varma et al., 2024)

$$dA/dt = \mu(T) \cdot A \cdot (N / (K_N + N)) \cdot I(A) - k_{\text{lysis}}(T) \cdot A \quad (2)$$

First part = **growth** (depends on nutrients, light, temperature).

Second part = **loss** due to ultrasonic lysis (breaking cells apart).

So algae can bloom if nutrients are high, but ultrasound and competition from plants keep them in check.

Below (Fig.7) is the stimulated result of proposed model:

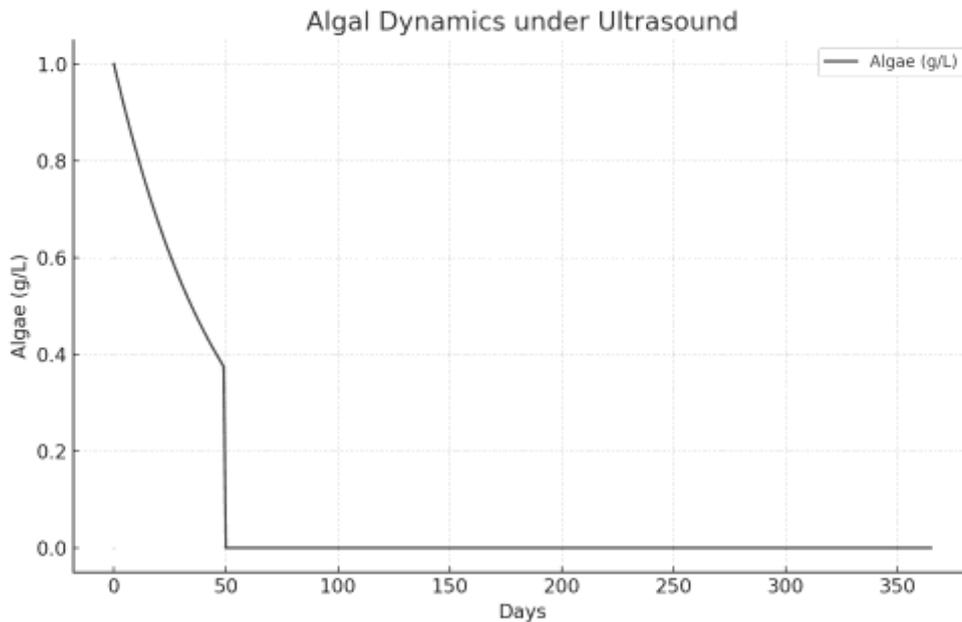


Fig 7. Algal bloom conc. With passing days

Final Algae (t=365 d): 0.000 mg/L

Plants (P) Growth Dynamics

Plants grow by taking nutrients from the water, but they cannot grow forever — they have a carrying capacity and also decay. (Reynolds, 2006)

$$dP/dt = Y_p \cdot (k_{uptake} \cdot P \cdot N) \cdot (1 - P / P_{max}) - k_{decay} \cdot P \quad (3)$$

Y_p = yield (how efficiently plants convert nutrients into biomass).

Logistic term $(1 - (P/P_{max}))$ = prevents infinite growth, since plants are limited by space on the floating wetland.

$k_{decay}P$ = natural plant death and biomass loss.

So plants grow when nutrients are available, but level off near their maximum capacity.

Below (Fig.8) is the stimulated result of proposed model:

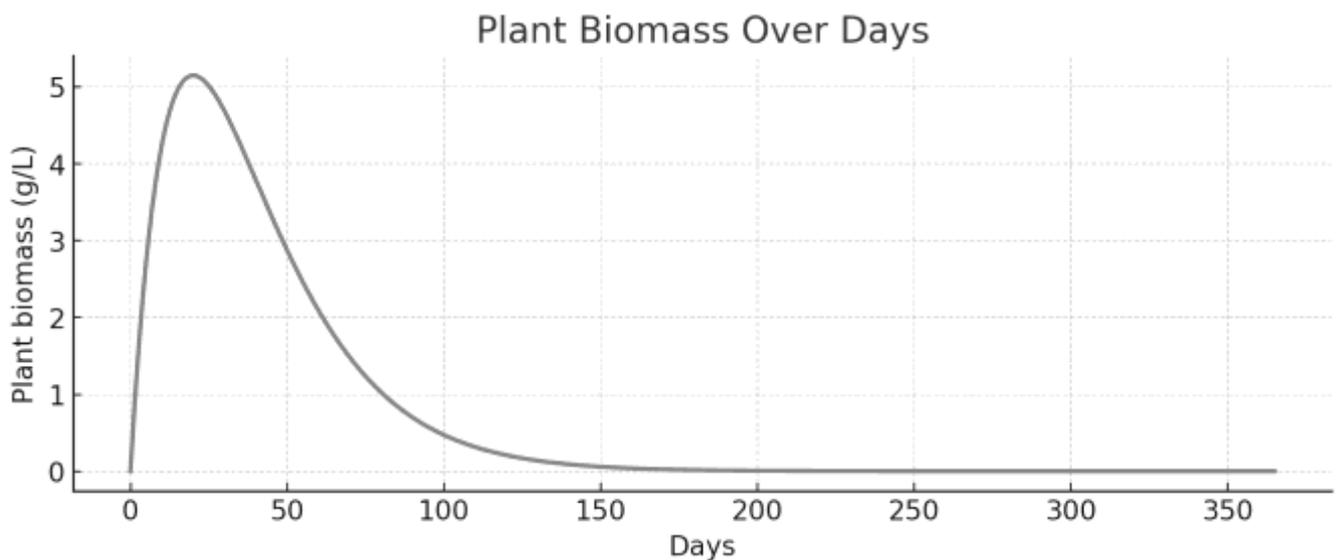


Fig 8. Decrease of plant biomass With passing days

Final Plant biomass (t=365 d): 0.001 g/L

Temperature Forcing

In real rivers, seasons matter a lot. For example, algae grow faster in warm summer months and slower in winter, because temperature strongly influences biological activity, the algal growth rate and ultrasound-induced lysis were adjusted using the Q10 rule. This ecological principle states that for many biological processes, the rate approximately doubles for every 10 °C rise in temperature, unless limited by other factors (Reynolds, 2006).

$$\mu(T) = \mu_{ref} \cdot Q10_{\mu}^{(T - T_{ref})/10} \quad (4)$$

$$k_{lysis}(T) = k_{lysis,ref} \cdot Q10_{lysis}^{(T - T_{ref})/10} \quad (5)$$

At reference temperature ($T_{ref}=20^{\circ}\text{C}$), the base values μ_{ref} and $k_{lysis,ref}$ apply.

For every **10 °C rise**, rates roughly **double** (if $Q10 = 2$).

Temperature changes with season as a sine wave (Varma et al., 2024)

$$T(t) = T_{mean} + T_{amp} \cdot \sin((2\pi/365)(t - \phi)) \quad (6)$$

- $T_{mean} \approx 23^{\circ}\text{C}$,
- $T_{amp} \approx 7.8^{\circ}\text{C}$,
- giving peaks $\sim 30^{\circ}\text{C}$ (summer) and lows $\sim 15^{\circ}\text{C}$ (winter), consistent with Yamuna seasonal data.

Nutrients slowly decline as plants and algae take them up. Algae may bloom in warmer months if nutrients are high, but ultrasound + plants suppress them. Plants grow steadily until they reach maximum biomass. Seasonal temperature causes ups and downs in algae and plant dynamics.

Below (Fig.9) is the stimulated result of proposed model:

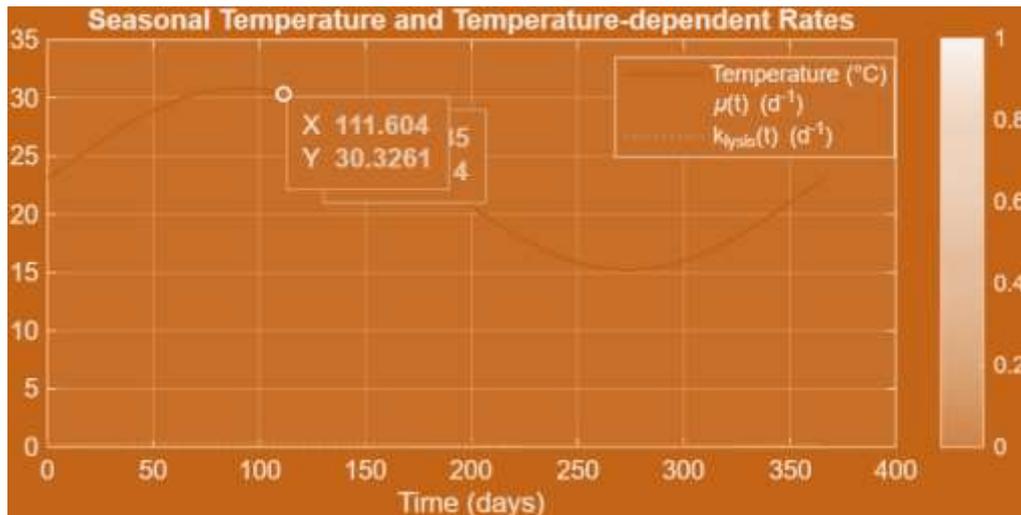


Fig 9. Temperature variation in an year and it's effect on proposed model

FIELD PROTOCOL

Phase 0: Baseline (2–4 weeks): baseline water quality (phycocyanin, nutrients), map site, and current patterns.

Phase 1: Install AFW modules (1-2 weeks): plant plugs, assemble, and anchor modules.

Phase 2: Ultrasound and solar installation (one week): install transducers, PV, batteries, and telemetry.

Phase 3: Tuning (four weeks): adjust duty cycles, frequency bands, and transducer depth; confirm using a fluorometer and chlorophyll sample.

Phase 4: Operation & Optimization (Continuous): monthly transducer cleaning, planned plant maintenance (pruning, harvesting), and DO monitoring, particularly at night.

RISK AND MITIGATION

Night time and shading DO stress: monitor DO, offer mixing pauses, and keep AFW \leq 10% (we're at 7.5%).

Use vendor-safe frequency bands and pay attention to fish behaviour before commissioning to avoid non-target consequences.

Biofouling & maintenance: Plan on cleaning the transducer faces and performing visual inspections once a month.

Storm damage prevention measures include elastic mooring, backup anchors, and a fast-

disconnect strategy for the strongest storms.

RESULT AND CONCLUSION

By combining **Artificial Floating Wetlands (AFWs)** and **Ultrasonic Algal Control**, the system cleans the pond in two ways: the wetlands utilize plants to absorb nutrients such as nitrogen and phosphorus, while the ultrasound prevents algae from floating and growing. According to our simulation (MATLAB), our model in real-time situations with all parameters considered (like self-shading of algae and temperature forcing) shows a reduction of dissolved inorganic nitrogen (DIN) from 3 mg/l to 0.04mg/l and a reduction in algae from more than 1g/l to 0g/l in a year (Table 1)

Table 1

Simulated nutrient and algae concentrations before and after treatment

parameters	Original conc. before treatment	Simulated conc. after treatment	% reduction
nitrogen	3mg/l	0.041mg/l	98.633
algal	1000mg/l	0.0 mg/l	100
Plant biomass	0.5	0.001 mg/l	98.0

After 50 days, it is seen that the nitrogen becomes significantly low(Fig.6) and becomes constant, due to which a sudden fall of algae concentration is seen(Fig. 7), as now, after 50 days, the algae can not reproduce again due to a lack of nitrogen.

This significant loss in these parameters is achieved only in a span of 50 days and maintained throughout the year.

REFERENCES

- [1] Lee, T. J., Nakano, K., & Matsumara, M. (2001). Ultrasonic Irradiation for Blue-Green Algae Bloom Control. *Environmental Technology*, 22(4), 383–390.
- [2] Mahvi, A. H., & Dehghani, M. H. (2005). Evaluation of ultrasonic technology in removal of algae from surface waters. *Pakistan Journal of Biological Sciences*, 8(10), 1457–1459.
- [3] Gaskill, J. A., Harris, T. D., & North, R. L. (2020). Phytoplankton Community Response to Changes in Light: Can Glacial Rock Flour Be Used to Control Cyanobacterial Blooms? *Frontiers in Environmental Science*, 8, 180. <https://doi.org/10.3389/fenvs.2020.540607>
- [4] Brand, L. M., & Shenoy, R. (2025). *Harmful algal bloom control using ultrasound: A sustainable approach for medium and large water bodies*. LG Sonic.
- [5] Shutes, R. B. E. (2001). Artificial wetlands and water quality improvement. *Environment International*, 26, 441–447. [https://doi.org/10.1016/S0160-4120\(01\)00025-3](https://doi.org/10.1016/S0160-4120(01)00025-3)
- [6] Vymazal, J., Zhao, Y., & Mander, Ü. (2021). Recent research challenges in constructed wetlands for wastewater treatment: A review. *Ecological Engineering*, 169, 106318. ISSN 0925-8574.
- [7] Kong, Y., Zhang, Z., & Peng, Y. (2022). Multi-objective optimization of ultrasonic algae removal technology by using response surface method and non-dominated sorting genetic algorithm-II. *Ecotoxicology and Environmental Safety*, 230, 113151. ISSN 0147-6513.
- [8] Rodriguez-Molares, A., Dickson, S., Hobson, P., Howard, C., Zander, A., & Burch, M. (2014). Quantification of the ultrasound-induced sedimentation of *Microcystis aeruginosa*. *Ultrasonics Sonochemistry*, 21(4), 1299–1304. ISSN 1350-4177.
- [9] Lehmann, H., & Jost, M. (1971). Kinetics of the assembly of gas vacuoles in the blue-green alga *Microcystis aeruginosa* Kuetz. emend. Elekin. *Archiv für Mikrobiologie*, 79, 59–68.
- [10] Zhang, G., Zhang, P., Wang, B., & Liu, H. (2006). Ultrasonic frequency effects on the removal of *Microcystis aeruginosa*. *Ultrasonics Sonochemistry*, 13(5), 446–450.
- [11] Kadlec, R. H. (1997). An autotrophic wetland phosphorus model. *Ecological Engineering*, 8(2), 145–172. ISSN 0925-8574.

- [12] Chang, Y., Cui, H., Huang, M., & He, Y. (2017). Artificial floating islands for water quality improvement. *Environmental Reviews*, 25, 350–357. <https://doi.org/10.1139/er-2016-0038>
- [13] McAndrew, B., & Ahn, C. (2017). Developing an ecosystem model of a floating wetland for water quality improvement on a stormwater pond. *Journal of Environmental Management*, 202, 198–207. <https://doi.org/10.1016/j.jenvman.2017.07.035>
- [14] Arivukkarasu, D., & Rangarajan, S. (2022). Floating wetland treatment: An ecological approach for the treatment of water and wastewater – A review. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2022.11.191>
- [15] Chen, G., Ding, X., & Zhou, W. (2019). Study on ultrasonic treatment for degradation of Microcystins (MCs). *Ultrasonics Sonochemistry*, 63, 104900. <https://doi.org/10.1016/j.ultsonch.2019.104900>
- [16] Klemenčič, P., & Krivograd Klemenčič, A. (2021). Effect of ultrasonic algae control devices on non-target organisms: A review. *Acta Biologica Slovenica*, 64, 5–17. <https://doi.org/10.14720/abs.64.1.15758>
- [17] Sharma, S., et al. (2017). Nutrient chemistry of River Yamuna, India. Mean $\text{NH}_4\text{-N} = 2.43$, $\text{NO}_3\text{-N} = 0.48$, $\text{NO}_2\text{-N} = 0.14$ mg/L ($\text{DIN} \approx 3.05$ mg/L used as initial condition). <https://doi.org/10.3233/AJW-170016>
- [18] Hassan, T., Parveen, S., Bhat, B. N., & Ahmad, U. (2017). Seasonal variations in water quality parameters of River Yamuna, India. *International Journal of Current Microbiology and Applied Sciences*, 6(5), 694–712.
- [19] Bhat, B. N., et al. (2018). Seasonal assessment of physicochemical parameters and evaluation of water quality of River Yamuna, India. *Advances in Environmental Technology*.
- [20] Varma, K., et al. (2024). Phosphorus distribution in the water and sediments of the Ganga and Yamuna Rivers (Uttar Pradesh, India): Insights into pollution sources, bioavailability and eutrophication implications.
- [21] Reynolds, C. S. (2006). *Ecology of Phytoplankton*. Cambridge University Press.