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Impact of Diversified Water Sources and Effluents on the Photosynthetic Efficiency of Chlorella sp

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Abstract
This study aimed to investigate the effects of water from Mandulog River, a nearby creek, and piggery effluent on the photosynthetic rate of *Chlorella* sp. An improvised manometer, constructed using U-shaped tubes, colored water, cardboard, and mm-ruled graphing paper, were used to measure the photosynthetic rate of *Chlorella* sp. Measurements were taken by recording the rise of colored water in the left arm of the U-tube at 6-hour intervals over a 48-hour period. The rate of photosynthesis was calculated as the total photosynthetic activity divided by the observation time. The results revealed that piggery effluent produced the highest photosynthetic rate, averaging 14.82 mm/hr, while water from the creek resulted in the lowest rate at 0.11 mm/hr. A significant increase in the number of *Chlorella* cells was observed in piggery effluent after 48 hours. No significant difference (P value >0.05) was found between the photosynthetic rates of the water sourced from Mandulog River and the control (mineral water). This suggests similar photosynthetic activity in these two water conditions. However, the photosynthetic rate of *Chlorella* sp. in piggery effluent was significantly higher compared to the control. Hence, it is recommended that a detailed analysis of the nutrient composition of piggery effluent will be conducted to identify the specific factors contributing to the increased photosynthetic rate.

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INTRODUCTION

Phytoplankton, which includes photosynthetic unicellular algae such as *Chlorella* sp., plays a vital role in aquatic ecosystems. These organisms float near the surface of the water and serve as a primary food source for many aquatic animals. Additionally, they contribute significantly to the production of dissolved oxygen in the water through photosynthesis, which is essential for the survival of other aquatic life (Raven & Falkowski, 1999).

Chlorella species are predominantly found in freshwater habitats and thrive in nutrient-rich environments (Eberly et al., 1957). As a genus of green algae, *Chlorella* has been extensively utilized as a model organism for studying photosynthesis and carbon assimilation processes due to its simple cellular structure and efficiency in converting sunlight into energy (Becker, 2007). It has also been a key subject in research on mass cultivation techniques, wastewater treatment, and biofuel production, as well as its potential in purifying sewage and mitigating environmental pollution (Borowitzka, 1999).

However, *Chlorella* and other phytoplankton are highly sensitive to water pollution caused by industrial, agricultural, and domestic effluents. These pollutants, often discharged into rivers and creeks without proper treatment, alter water quality, making it less habitable for photosynthetic organisms. Polluted waters can contain excessive nutrients (e.g., nitrogen and phosphorus), heavy metals, or toxic chemicals that negatively impact the growth and photosynthetic efficiency of *Chlorella* and other phytoplankton (Guo et al., 2014). Consequently, the degradation of phytoplankton populations not only disrupts aquatic food chains but also reduces oxygen production, exacerbating the overall health of aquatic ecosystems.

With modern industrialization, pollution of water, air, and land has become one of the most pressing ecological problems of our time. Efforts to protect *Chlorella* and other phytoplankton species from the deleterious effects of pollution are essential. These efforts include improving wastewater management practices, enforcing stricter environmental regulations, and raising awareness about the importance of maintaining clean water bodies for the benefit of aquatic life and human populations alike (UNEP, 2019).

Masojídek and Torzillo (2014) emphasized that *Chlorella* is one of the most widely cultivated eukaryotic algae due to its versatility and broad applications. It is extensively used as a health food and feed supplement, owing to its high nutritional value and safety for consumption. Additionally, *Chlorella* plays a significant role in the pharmaceutical and cosmetics industries, where it is utilized for its bioactive compounds and skin-enhancing properties.

Chlorella belongs to the green algae group (Chlorophyta) and thrives in a variety of habitats, including both aquatic and terrestrial environments. Remarkably, some strains of *Chlorella* exhibit high-temperature tolerance, with the ability to grow in a range between 15 °C and 40 °C, making it adaptable to diverse climatic conditions. This adaptability enhances its potential for large-scale cultivation in different geographical regions.

The importance of *Chlorella* as a model organism in scientific research dates back to the pioneering studies by Beijerinck (1890) and Warburg (1919), as cited by Borowitzka (2018). It was the first alga successfully isolated in culture and became instrumental in studying photosynthesis. Photosynthesis, as described by Kirk (2011), is a fundamental energy conversion process wherein light energy is transformed into chemical energy, sustaining phototrophic organisms like *Chlorella*. This process not only supports *Chlorella's* rapid growth but also contributes to oxygen production, benefiting aquatic ecosystems.

Research on *Chlorella* extends to its response to pollutants, with studies varying in scope and objectivity. According to Klamczynska and Mooney (2017), *Chlorella* has been a part of the human food supply for centuries and is recognized as safe for consumption. These algae are commonly found floating or drifting in freshwater bodies such as ponds, lakes, and rivers. They also inhabit terrestrial environments, living in soil and on the bark of trees. *Chlorella* plays a vital ecological role, serving as a food source for aquatic animals and producing dissolved oxygen that supports aquatic life.

What sets *Chlorella* apart is its remarkable photosynthetic efficiency. As Ibrahim (2020) noted, *Chlorella* can grow under diverse conditions, including heterotrophic (utilizing organic carbon) and mixotrophic (combining photosynthesis and organic carbon consumption) environments. This versatility enables it to thrive in nutrient-rich and nutrient-poor conditions alike. Through efficient photosynthesis, *Chlorella* is capable of reproducing itself in just a few hours, requiring only sunlight, water, carbon dioxide, and minimal nutrients (Liu and Chen, 2014). These characteristics make *Chlorella* an ideal candidate for applications such as biofuel production, wastewater treatment, and large-scale cultivation for nutritional and industrial purposes.

This study aimed to evaluate the effects of water from Mandulog River, Baslayan Creek, and piggery effluent on the photosynthetic rate of *Chlorella* sp. using an improvised manometer. Specifically, the objectives were to: (1) determine the photosynthetic rates and levels of *Chlorella* sp. in different water and effluent samples at various observation intervals; (2) identify which water and effluent samples negatively affect the photosynthetic rate of *Chlorella* sp.; and (3) identify the sample that promotes the fastest photosynthetic rate of *Chlorella* sp. The results of this study provide valuable insights into how *Chlorella* sp. responds to different water and effluent conditions, highlighting the relationship between pollutants and biological systems. This information may guide authorities in developing strategies to effectively manage wastewater from irrigation, agriculture, and feedlots through biological treatment systems using *Chlorella* sp. Furthermore, the findings contribute to the growing body of scientific knowledge and may inspire further research in this area.

The study on the impact of diversified water sources and effluents on the photosynthetic efficiency of Chlorella sp. holds contemporary importance in the context of environmental science and ecosystem studies. The ability of Chlorella sp. to adapt to various water conditions and effluents can provide valuable insights into the resilience of aquatic organisms in changing environments. Such research not only aids in understanding the broader implications of water quality on photosynthetic organisms but also contributes to sustainability practices, especially in aquatic ecosystem management. As noted by Hussain and Farea (2022), the evolving research on environmental factors impacting biological systems aligns with the growing focus on the metaverse ecosystem's influence on various industries, including environmental science. In a similar vein, Hussain (2025) emphasizes the importance of ethics in technological advancements, such as AI-enabled neuromarketing, which resonates with the ethical considerations in environmental research and sustainable practices. This body of research, including Farea's (2025) exploration of consumer behavior and its links to digital marketing, highlights the increasing convergence of technological, ecological, and social science domains. Furthermore, as Hussain (2025) discusses in his work on the fabric of the mind, incorporating psychology and Eastern wisdom into modern studies is essential, and this can be applied to environmental science for a deeper understanding of human interaction with nature. The interdisciplinary nature of the research presented here underscores the value of integrating diverse perspectives to address contemporary challenges in environmental sustainability.

The study specifically focused on assessing the direct effects of water from Mandulog

River, Baslayan Creek, and piggery effluent on the photosynthetic activity of *Chlorella* sp., with mineral water serving as the control. Due to resource constraints, nutrient analyses, such as nitrate and phosphate levels, were excluded from the study. The number of *Chlorella* sp. cells was counted before and after the experiment using an improvised counting chamber. To ensure consistency, the temperature was maintained at 27 °C in all experimental setups by conducting the experiments in an air-conditioned room. As a standard instrument was unavailable, hence, an improvised manometer was used to measure the photosynthetic rates of the test organism. This approach allowed for the reliable collection of data within the study's constraints.

METHODOLOGY

Research Design and Subject of the Study

This research utilized a quantitative descriptive method to evaluate the effects of different water and effluent samples on the photosynthetic rate of *Chlorella* sp. The study involved two groups: an experimental group and a control group, with experiments conducted in three trials. The experimental group consisted of three setups, each containing water from Mandulog River, Baslayan Creek, and piggery effluent, respectively. The water and effluent samples were collected from the following sources: (1) Mandulog River: Characterized by its wide expanse and muddy waters, primarily due to extensive sand and gravel quarrying activities; (2) Baslayan Creek: A drainage system managed by the city government; and (3) Piggery Effluent: Liquid wastewater collected from a piggery disposal system, containing waste products such as pig manure, spilled feed, and urine. This effluent is rich in ammonia and contributes to elevated chemical and biological oxygen demand (COD/BOD). *Chlorella* sp. was chosen as the test organism for its availability and suitability for the study. Its use as a model organism in photosynthetic research makes it an ideal candidate to assess the effects of various water and effluent samples on biological processes.

Sampling and Data Gathering Procedure

Before data collection and experimentation, preliminary protocols were conducted to ensure the study adhered to ethical principles, particularly the principle of consent. A formal letter requesting permission to conduct the study was submitted to the Office of the Barangay Captain. Additionally, all necessary environmental and health protocols were carefully considered and implemented throughout the study.

Water samples were manually collected from the surface of each sampling site. The process involved immersing a labeled screw-capped plastic container to the desired water depth, unscrewing the cap slowly to allow the container to fill completely, and then securely tightening the cap before retrieving it. Effluent samples were collected from a piggery disposal system and placed in separate containers. All collected water and effluent samples were transported to the laboratory for experimentation. The test organism, *Chlorella* sp., was cultured freshwater algae sourced from MSU-IFRD in Naawan, Misamis Oriental. The study spanned three days, with sampling conducted in the morning under favorable weather conditions (no rain within 24 hours prior to collection).

Fifteen 1000 mL Erlenmeyer flasks were prepared for the experiment. Each flask was filled with 200 mL of *Chlorella* culture, and 800 mL of the respective sampled water was added to create test solutions. A blank solution was used as a control to assess the photosynthetic activity of microorganisms in water from Mandulog River, Baslayan Creek, and the piggery effluent. Each flask was sealed tightly with a rubber stopper, into which a 3-inch glass tube was inserted. The flasks were connected to an improvised manometer using rubber tubing, with one end of the U-tube of the manometer inserted into the tubing. During nighttime, fluorescent lamps were used to illuminate the flasks to maintain consistent light conditions. This setup allowed the researchers to measure the photosynthetic activity of *Chlorella* sp. under different water conditions.

The photosynthetic activity in each flask of *Chlorella sp*. was measured using the improvised manometer. This was done by measuring the rise of the colored water to the left of the U-tube sense the rise toward the right means there is no photosynthesis taking place. The manometer reading was taken at a 6-hour-interval for 48 hours. Obtaining the photosynthetic rate was determined using the formula:

$$\text{Rate of Photosynthesis} = \frac{\text{sum of photosynthesis}}{\text{no. of hours observed}}$$

The number of cells of *Chlorella sp.* was determined before and after observation (48 hrs.). One ml of *Chlorella sp.* was placed in the improvised counter chamber and the cells were counted under the microscope. The number of cells were then multiplied by 200 ml to get the total number of cells per 200 ml of *Chlorella sp.* This research used one-way Analysis of Variance (ANOVA) to determine the significant difference among the different water samples and effluents on the photosynthetic activity of *Chlorella sp.*

RESULTS AND DISCUSSION

The photosynthetic rates of *Chlorella* sp. were measured in different water and effluent samples, and the results revealed distinct variations across the samples. Notably, the highest photosynthetic rate was observed in piggery effluent, with a value of 14.82 mm/hr. This elevated rate can likely be attributed to the presence of organic, nutrient-rich materials in the effluent. These nutrients, such as nitrogen and phosphorus, promote the growth of bacteria, which in turn release carbon dioxide as a byproduct of their respiration. This carbon dioxide is essential for photosynthesis in *Chlorella* sp. and other photosynthetic organisms. Priestley (1772) described how plants and animals mutually "restore" the air for each other, underscoring the importance of the carbon cycle in supporting photosynthetic processes. The interaction between bacteria and *Chlorella* sp. within nutrient-rich environments such as effluent may create a synergistic effect, where the bacteria supply carbon dioxide, facilitating enhanced photosynthetic rates for the microalgae.

In contrast, the photosynthetic rate of *Chlorella* sp. in water from Baslayan Creek was slower. This reduced photosynthetic activity could be attributed to the presence of chemical pollutants commonly found in urban water bodies. The creek water is often contaminated with a variety of pollutants such as phosphates, nitrates, sulfides, chlorinated hydrocarbons, and other organic compounds from domestic and industrial waste discharge. These pollutants can adversely affect the photosynthetic efficiency of aquatic plants and microalgae. Ashenden (1978) emphasized that exposure to pollutants over extended periods can lead to a significant reduction in the rate of photosynthesis in plants. In this case, the presence of chemical contaminants in the creek water likely hindered the photosynthetic activity of *Chlorella* sp., resulting in a slower rate compared to the piggery effluent.

Statistical analysis using Analysis of Variance (ANOVA) revealed that there was no significant difference in the photosynthetic rates between the control group (mineral water) and the water samples from Mandulog River and Baslayan Creek. This suggests that the water quality from these sources did not differ significantly from that of the control in terms of its impact on the photosynthetic activity of *Chlorella* sp. However, a significant difference was observed in the photosynthetic rate of *Chlorella* sp. in piggery effluent compared to both the control and the river and creek water samples. This significant difference can be attributed to the high bacterial content in piggery effluent, which contributes to increased carbon dioxide levels, facilitating more efficient photosynthesis in the microalgae. The symbiotic relationship between the bacteria and *Chlorella* sp. in nutrient-rich effluent likely played a key role in enhancing the photosynthetic rate in this sample.

These findings align with previous research that suggests nutrient enrichment from organic waste, such as effluent, can boost the photosynthetic activity of certain algae species (Borowitzka, 2018). However, the presence of pollutants, particularly in the creek water, demonstrates how water contamination can have detrimental effects on photosynthetic processes in aquatic ecosystems (Ashenden, 1978; Klamczynska & Mooney, 2017). Further studies exploring the interaction between microbial communities and algae in polluted environments could provide deeper insights into the complex dynamics of aquatic photosynthesis and its response to environmental stressors.

Table 1. Photosynthetic Rate (mm/hr.) of *Chlorella sp.* in different water and effluent samples.

	Photosynthetic Rate (mm/hr)			
Water and Effluent Samples Photosynthetic rate	Total	Mean	Blank Solution	Final Rate
Control (mineral water)	0.490	0.245	0.490	0.245
Mandulog river	0.905	0.450	0.125	1.350
Creek	1.765	0.588	0.480	0.110
Piggery effluent	46.640	15.550	0.730	14.820

The average photosynthetic activity of *Chlorella* sp. in various water and effluent samples over time is presented in Table 2. The photosynthetic activity in the control group consistently showed an increasing trend, which can be attributed to the presence of sufficient nutrients and the absence of pollutants in the water. Mineral water, used as the control, provided an optimal environment for *Chlorella* sp. as it lacked contaminants that could hinder photosynthesis. The stable supply of nutrients in the control water ensured the algae's continuous growth, resulting in progressively higher photosynthetic rates.

For the water samples from Mandulog River, the photosynthetic rate of *Chlorella* sp. showed an increase between 12 to 18 hours. This increase can be attributed to the availability of nutrients in the river water, which supported the algae's growth. However, after 24 to 30 hours, the photosynthetic rate dropped, likely due to the depletion of these favorable nutrients. As the nutrients in the water were consumed, the algae experienced a reduced rate of photosynthesis. Interestingly, after 42 hours, the photosynthetic rate began to rise again. This increase can be explained by the growth in the number of *Chlorella* cells, which provided more biomass to carry out photosynthesis. However, after 48 hours, the photosynthetic rate dropped again, possibly due to nutrient exhaustion or other limiting factors. This fluctuation suggests that while river water supports *Chlorella* growth for a limited period, it cannot sustain continuous photosynthetic activity without replenishing nutrient levels.

The photosynthetic activity of *Chlorella* sp. in creek water was generally low throughout the study. This can be attributed to the chemical pollutants and organic waste that are commonly dumped into the creek, which severely affects water quality. According to Daral (1984), who conducted a nutrient analysis of Baslayan Creek and Mandulog River in Iligan City, the phosphate concentration in Baslayan Creek was 2.34 mg/L, higher than at other sampling stations. The elevated levels of phosphates, largely from laundry water and other domestic waste, contribute to nutrient imbalances in the creek. These imbalances can increase the water's acidity or alkalinity, which may inhibit the growth of aquatic organisms, including *Chlorella* sp. Phosphates, in particular, are known to alter the pH of water, which can negatively impact the photosynthetic efficiency of algae (Daral, 1984).

Cayne (1987) also emphasized that the introduction of effluents with high concentrations of nitrates and phosphates into water bodies leads to significant changes in the microflora. These changes affect both the quantity and composition of the microbial communities, which can directly influence the ecological dynamics of aquatic ecosystems. In the case of *Chlorella* sp., the presence of high levels of pollutants such as nitrates and phosphates likely disrupted its normal photosynthetic processes. These pollutants can create an environment where only certain species of algae or bacteria thrive, potentially outcompeting *Chlorella* sp. and limiting its growth and photosynthetic activity.

The findings of this study align with previous research that has shown how pollutants, such as nitrates and phosphates, can disrupt the photosynthetic activities of microalgae (Cayne, 1987). In particular, *Chlorella* sp. and other algae species are highly sensitive to water quality changes, and the presence of chemical pollutants often leads to reduced photosynthetic rates and overall growth. This emphasizes the importance of maintaining water quality and minimizing the discharge of pollutants into natural water bodies to ensure the health and productivity of aquatic ecosystems.

Table 2. Average Photosynthetic Activity (mm/hr.) of *Chlorella sp.* in different water and effluent samples by time.

	Photosynthetic Activity (*mm at 6 hrs. interval*)						
Water and Effluent Samples	6	12	18	24	30	36	42
Control (mineral water)	0	0	1.5	1.2	3	3	3
Mandulog river	0	6	6.67	2	1.5	2	11.3
Creek	0	3	4	6.5	2	2	5
Piggery effluent	20	76.6	100	111	114	112	108

Table 3 presents a significant increase in the number of *Chlorella* sp. cells across all water and effluent samples, with the highest cell multiplication observed in the piggery effluent. This rapid increase in cell count is likely due to the presence of organic nutrients in the effluent, which provide a favorable environment for *Chlorella* sp. to grow. Piggery effluent is typically rich in organic matter such as manure, urine, and spilled feed, which can supply essential nutrients like carbon, nitrogen, and phosphorus, promoting the growth of microorganisms (Mabury & Breen, 1999). These organic nutrients can enhance cellular multiplication in *Chlorella* by providing readily available resources for metabolism and photosynthesis.

Similarly, the water sample from Mandulog River also showed a notable increase in the number of *Chlorella* cells. The favorable conditions for cell multiplication in this water source can be attributed to the presence of adequate amounts of nitrates and other minerals derived from soil and agricultural runoff, often treated with nitrogenous and phosphate-rich fertilizers (Sharpley & Smith, 1994). These fertilizers, while intended to boost agricultural productivity, often find their way into nearby water bodies through runoff, providing additional nutrients that support the growth of aquatic organisms, including *Chlorella* sp.

In contrast, the water sample from Baslayan Creek showed the lowest cell count, which could be linked to the presence of pollutants such as phosphates, nitrates, phenols, and other chemical substances that can have detrimental effects on *Chlorella* sp. While *Chlorella* can still survive in polluted environments, the presence of these chemicals likely inhibits optimal growth and photosynthetic efficiency. Phosphates and nitrates, though essential in moderate concentrations, can lead to imbalances in the ecosystem at higher levels, contributing to eutrophication and the growth of harmful algal blooms (Cayne, 1987).

Another key factor influencing cell multiplication in these water samples could be the pH and turbidity of the water. As highlighted by Cutanda (1999), Baslayan Creek is characterized by high turbidity and low pH (6.5). The pH of water plays a crucial role in the survival and activity of aquatic organisms, including microalgae like *Chlorella* sp. According to Odum (1971), extreme pH values, whether too acidic or too basic, can inhibit the activity of essential microorganisms, rendering the ecosystem less conducive to the growth of plants and animals. In highly acidic environments, the metabolic processes of aquatic organisms may be disrupted, leading to reduced biological activity.

Studies have also shown that high phosphate concentrations in water bodies can lead to eutrophication and algal blooms, which may either promote or inhibit the growth of certain species depending on environmental conditions (Kenady, 1998). The increased nutrient availability, particularly phosphorus, often fuels the rapid growth of algae in surface waters, but this can also lead to oxygen depletion in the water as algal decomposition consumes oxygen, harming aquatic life. In Baslayan Creek, the presence of high phosphate levels likely contributed to an imbalance in the ecosystem, preventing optimal cell multiplication in *Chlorella* sp.

In short, while *Chlorella* sp. can adapt to various environmental conditions, factors such as nutrient availability, pollutants, pH, and turbidity significantly influence its growth and multiplication. The presence of organic nutrients in piggery effluent and the minerals in Mandulog River water provided favorable conditions for cell growth, while the high pollution levels and low pH in Baslayan Creek created a less supportive environment for *Chlorella* sp. despite its ability to survive.

Table 3. Average Photosynthetic Activity (mm/hr.) of *Chlorella* cell per 200ml in the different water and effluent samples.

	Photosynthetic Activity (*mm/hr interval per 200ml*)	
Water and Effluent Samples	Mean Initial Rate	Mean Final Rate

Control (mineral water)	533	6000
Mandulog river	667	5866
Creek	733	4533
Piggery effluent	600	6400

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, the conclusions are drawn:

1. The highest cell multiplication of *Chlorella sp.* observed in piggery effluent demonstrates its suitability as a growth medium due to the abundance of organic nutrients, including carbon, nitrogen, and phosphorus, which promote robust cellular metabolism and photosynthesis.
2. Water samples from Mandulog River supported notable cell multiplication, likely due to nutrients from agricultural runoff containing nitrates and phosphates, although these concentrations were lower compared to piggery effluent.
3. The lowest cell multiplication observed in Baslayan Creek highlights the detrimental effects of pollutants such as phenols, high phosphate concentrations, and chemical substances. High turbidity and low pH (6.5) further inhibited the optimal growth of *Chlorella sp.*, emphasizing the adverse impact of water quality degradation on microalgal productivity.
4. Key factors such as pH, turbidity, and the concentration of nutrients and pollutants significantly influence the growth and photosynthetic activity of *Chlorella sp.*, with polluted environments showing inhibitory effects even on resilient microalgal species.
5. While moderate levels of nutrients like phosphates and nitrates promote algal growth, excessive concentrations may lead to eutrophication and ecological imbalance, as seen in the case of Baslayan Creek.

Based on the findings of this study, the following are highly recommended:

1. Given its nutrient-rich composition, piggery effluent can be optimized as a growth medium for cultivating *Chlorella sp.* in controlled conditions for applications in biofuel production, feed, or wastewater treatment. Pre-treatment processes should be explored to ensure its safe and efficient use.
2. To maintain the productivity of aquatic ecosystems like Mandulog River, authorities should regulate and monitor agricultural runoff to prevent excessive nutrient enrichment that could lead to eutrophication.
3. Measures should be implemented to reduce chemical pollution and manage domestic and industrial wastewater discharged into Baslayan Creek. Strategies such as constructing proper drainage systems and enforcing stricter regulations on pollutant disposal are recommended.
4. Continuous monitoring of water quality parameters, including pH, turbidity, and pollutant levels, should be prioritized to assess the suitability of water sources for aquatic life and microalgal growth.

5. Further studies are recommended to understand the tolerance mechanisms of *Chlorella sp.* in polluted environments, focusing on its survival and potential applications in bioremediation.
6. Raising public awareness about the effects of pollutants on aquatic ecosystems and microalgae is critical. Policymakers should create guidelines to manage water pollution and promote the use of biological treatment systems to address wastewater issues.
7. Since *Chlorella sp.* showed adaptability to various water conditions, its potential in bioremediation should be explored to mitigate pollution in water bodies, particularly in areas with high levels of nitrates, phosphates, and organic matter.
8. Encourage sustainable practices in agriculture and livestock management to minimize nutrient runoff and promote ecosystem health. Collaboration between local government units, industries, and environmental agencies is crucial to achieving these goals.

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Conflicts of Interest

The authors have disclosed no conflicts of interest.

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