



# UTILIZING MICROALGAE FOR BIOTRANSFORMATION OF PHARMACUETICAL CONTAMINANTS IN WASTE WATER

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## ABSTRACT:-

The rapid expansion of both the global economy and the human population has led to a shortage of water resources suitable for direct human consumption. As a result, water remediation will inexorably become the primary focus on a global scale. Microalgae can be grown in various types of wastewaters (WW). They have a high potential to remove contaminants from the effluents of industries and urban areas. This review focuses on recent advances on WW remediation through microalgae cultivation. Attention has already been paid to microalgae-based wastewater treatment (WWT) due to its low energy requirements, the strong ability of microalgae to thrive under diverse environmental conditions, and the potential to transform WW nutrients into high-value compounds. It turned out that microalgae-based WWT is an economical and sustainable solution. Moreover, different types of toxins are removed by microalgae through bio sorption, bioaccumulation, and biodegradation processes. Examples are toxins from agricultural runoffs and textile and pharmaceutical industrial effluents. Microalgae have the potential to mitigate carbon dioxide and make use of the micronutrients that are present in the effluents. This review paper highlights the application of microalgae in WW remediation and the remediation of diverse types of pollutants commonly present in WW through different mechanisms, simultaneous resource recovery, and efficient microalgae-based co-culturing systems along with bottlenecks and prospects.

**Key Words:** microalgae, waste water treatment (WWT), Pharmaceutical contaminants, Biotransformation, Bio sorption, bioaccumulation, biodegradation.

## GRAPHICAL ABSTRACT:

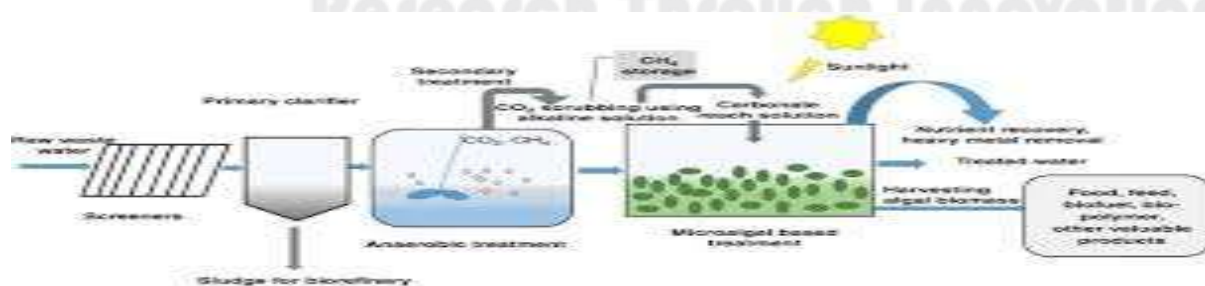


Fig No. 1 Treatment of waste water by Microalgae

## 1. INTRODUCTION:

The increasing presence of pharmaceutical contaminants in aquatic environments has emerged as a significant global concern. These contaminants, originating from household usage, hospitals, and pharmaceutical industries, often escape complete degradation in conventional wastewater treatment plants. As a result, trace levels of antibiotics, analgesics, hormones, and other pharmaceutical compounds are frequently detected in surface waters, posing risks to aquatic ecosystems, public health, and water quality.

Conventional treatment methods, such as activated sludge and chlorination, are not specifically designed to target these emerging micro pollutants. This has prompted the search for alternative, eco-friendly technologies capable of efficiently removing pharmaceuticals from wastewater. One promising solution is the use of microalgae-based systems, which harness the natural bioremediation capabilities of microalgae.

Microalgae are photosynthetic microorganisms that can uptake, accumulate, and degrade various contaminants through mechanisms such as bio sorption, bioaccumulation, biodegradation, and photo degradation. These organisms not only treat wastewater but also contribute to oxygen production and carbon dioxide capture, making the process environmentally sustainable. Furthermore, microalgae can thrive in nutrient-rich wastewater environments, utilizing nitrogen and phosphorus as growth substrates.

This research explores the feasibility and effectiveness of using microalgae, specifically *Chlorella* sp., in the biotransformation and removal of pharmaceutical contaminants from wastewater. The study aims to investigate the changes in water quality, including pH variation, reduction in organic load (BOD/COD), and the degradation of selected pharmaceutical compounds during and after algal treatment. A microalgae-based system is a biological wastewater treatment method that uses microalgae—photosynthetic microorganisms—to remove pollutants such as nutrients (nitrogen, phosphorus), heavy metals, and pharmaceutical contaminants from water. Wastewater contains a complex mixture of contaminants such as organic matter, nitrogen and phosphorus nutrients, pathogens, and emerging contaminants. Emerging contaminants are a wide range of unregulated chemicals of synthetic origin or derived from natural sources that pose a great threat to humans and the ecosystem [1]. Pharmaceutical active compounds are one of the major groups of emerging contaminants that do not degrade easily and persist for long periods in the environment due to their stable structure. The occurrence of pharmaceuticals in wastewater results from their intake by humans or animals and excretion through urine and feces, since some of them are only partially metabolized and absorbed [2].

Several mechanisms and techniques have been studied for pharmaceutical removal from wastewater, being the biological treatment the most studied and used [3–5]. However, as wastewater treatment plants (WWTPs) were not designed to eliminate persistent pharmaceutical compounds, they are not able to completely remove the pharmaceuticals and their metabolites [2,6]. Therefore, these compounds are disseminated into aquatic compartments via treated effluent discharges and land application of bio solids [7]. The amount of wastewater produced worldwide is estimated to be 359.4 billion m<sup>3</sup> per year [1], and it is steadily rising as a result of the modern era's fast industrial revolution. Heavy metals (Cd, Ni, Pb, Hg, Fe, Cu, Mn, Mg, etc.) [2], a high organic matter content (75% suspended solids and 40% filterable solids), infectious microbes, and poorly biodegradable components like synthetic dyes, suspended particles, etc. [3,4] are among the pollutants found in industrial wastewater, which is also enriched with nutrients. Approximately 80% of untreated industrial wastewater is discharged into the environment [5], which has an adverse effect on the ecosystem because it eutrophicates the aquatic ecosystem. Because it causes cancer, infectious diseases, kidney diseases, hypertension, liver diseases, and other conditions, it also poses a major risk to human health [6]. There needs to be a paradigm change in order to enhance this resource's

proactive usage in the circular economy rather than viewing it as a "waste product." For industrial effluent to be used in the environment-water nexus, sustainable management is essential. Therefore, implementation of efficient and economic treatment method is necessary for the removal of nutrients and pollutants from industrial wastewater. Chemical and physical techniques have historically been used to remediate industrial wastewater [7]. There are questions about whether the traditional approaches can be sustained in light of the effects on the environment and the viability of using them to meet stricter discharge regulations for better water quality. Traditional techniques also don't provide resource recovery from sludge and wastewater. The unrealized potential of these resources would be enough to fertilize the crops, irrigate the millions of hectares of land, and supply energy to thousands of households. Consequently, it is necessary to implement environmentally friendly procedures that require less energy, less sludge creation, and less operational complexity.

Comparatively, biological methods (based on the use of bacteria, fungi, and algae) are the most feasible and reliable alternatives for industrial wastewater treatment due to their eco-friendly nature and ability to bioadsorb or transform heavy metals as part of their biomass [7]. Particularly metabolic flexibility of microalgae

makes them suitable to treat variety of wastewater resource specially in the context of biorefinery and circular bioeconomy as the produced biomass showed tremendous potential to develop sustainable bioproducts. Algal-based

wastewater treatment has been in practice since 1950's but gain popularity in recent decades when it was observed that microalgal biomass could bring additional value to the wastewater treatment process through resource valorization. Algal wastewater treatment provide significant benefits over conventional treatment methods such as (i) microalgal thrive on wastewater and its cultivation does not require additional water or nutrient supply, (ii) reduced treatment cost as most of the nutrients are assimilated by biomass, (iii) low nutrient load which meet wastewater discharge standards, (iv) reduced greenhouse gas emission and production of hazardous byproducts, (v) integrated process chain for wastewater treatment and transformation of microalgae into carbonneutral products [14]. Despite the remarkable potential of microalgaebased treatment process, some strengths, weaknesses, opportunities, and threats (SWOT analysis: Fig. 1 ) must be considered to apply this system at commercial scale level. Water pollution caused by pharmaceutical contaminants is an emerging global concern due to the widespread use of antibiotics, analgesics, hormones, and other pharmaceutical products in human and veterinary medicine. After consumption, a significant portion of these drugs is excreted and enters the environment through domestic sewage and hospital effluents. Unfortunately, conventional wastewater treatment plants (WWTPs) are not specifically designed to remove these low-concentration but biologically active compounds. As a result, trace amounts of pharmaceuticals are frequently detected in surface waters, ground waters, and even drinking water, where they can pose toxicological risks to aquatic life and potentially to human health.

To address this challenge, researchers are increasingly exploring eco-friendly and sustainable technologies that offer effective treatment with low environmental impact. Among these, microalgae-based systems have gained attention as a promising solution. Microalgae are microscopic, photosynthetic organisms capable of surviving in diverse environments, including nutrient-rich wastewater. They are able to uptake, adsorb, degrade, and transform pharmaceutical pollutants through a combination of biological and photochemical processes, such as bio sorption, bioaccumulation, biodegradation, and photo degradation.

Additionally, microalgae can remove conventional pollutants like nitrogen, phosphorus, heavy metals, and organic matter, contributing to comprehensive wastewater treatment. They also generate oxygen through photosynthesis, which supports aerobic bacterial activity and further pollutant degradation. The cultivation of microalgae in wastewater offers a dual benefit: improving water quality while producing valuable algal biomass that can be used in biofuel production, agriculture (biofertilizer), or as a protein-rich feedstock. Therefore, this study is essential to explore and validate the practical potential of microalgae for pharmaceutical wastewater treatment, and to contribute toward the development of green technologies that can be integrated into existing water management systems

## 2. SALIENT FEATURES OF MICROALGAE

### 1. Eco-Friendly and Sustainable

- Uses natural biological processes (photosynthesis and biotransformation).
- Reduces chemical usage in water treatment.
- Minimal sludge generation compared to conventional methods.

### 2. Effective Removal of Pharmaceutical Contaminants

- Targets emerging pollutants like antibiotics, painkillers, beta-blockers, etc
- Removes drugs through bio sorption, biodegradation, bioaccumulation, and photo degradation.

### 3. Photosynthetic Oxygen Generation

- Algae produce oxygen, enhancing aerobic bacterial degradation of organic pollutants (BOD, COD).

## 3. NEED OF RESEARCH WORK

- The increasing presence of pharmaceutical contaminants in aquatic environments is a growing environmental and public health concern. Pharmaceuticals, including antibiotics, anti-inflammatories, and hormones, enter water bodies through domestic sewage, hospital effluents, and pharmaceutical industry discharge. These compounds are often not completely removed by conventional wastewater treatment plants (WWTPs), which were not originally designed to handle such micro-pollutants.

- Persistent pharmaceutical residues in water can lead to:
  - Toxicity to aquatic organisms
  - Hormonal disruption in wildlife
  - Development of antibiotic-resistant bacteria
  - Long-term human health risks from trace exposures

- Improve overall water quality by reducing nutrients and organic pollutants
- Offer a low-cost and sustainable approach with potential for energy recovery (via algal biomass)
- Moreover, microalgae cultivation aligns with global efforts toward circular economy and climate sustainability, as they absorb CO<sub>2</sub> and generate oxygen during photosynthesis.

#### 4. OBSERVATION

➤ The experiment was conducted by treating pharmaceutical-contaminated wastewater with microalgae (*Chlorella sp.*). Observations were recorded over a period of 10 days.

Parameter	Day 0	Day 5	Day 10	Remarks
pH	6.8	7.6	8.4	Gradual increase due to photosynthesis
Color	Pale grey	Light green	Clearer	Algae growth and sedimentation
Turbidity	High	Moderate	Low	Algal flocculation improved clarity
BOD (mg/L)	220	130	70	Significant reduction of organic matter
COD (mg/L)	460	280	150	High pollutant removal efficiency
Pharmaceutical residue (e.g. Ibuprofen, Di clofenac)	Detected	Lowered	Not detected (trace)	Efficient uptake/biodegradation

During the experimental period, detailed observations were recorded to evaluate the performance of *Chlorella sp.* in removing pharmaceutical contaminants from simulated wastewater. The study was conducted over a **10-day treatment cycle**, and data were collected at Day 0, Day 5, and Day 10 to monitor **physicochemical changes, pharmaceutical degradation, and algal activity**.

##### 1. Change in pH

At the beginning of the treatment, the pH of the pharmaceutical-contaminated wastewater was slightly acidic (6.8), indicating the presence of organic acids and chemical residues. Over the treatment period, a **gradual increase in pH** was observed, reaching **8.4 by Day 10**. This shift occurred due to **photosynthetic activity by the microalgae**, which consumed carbon dioxide (CO<sub>2</sub>) and released oxygen (O<sub>2</sub>), resulting in reduced acidity and a more alkaline environment. This pH increase is also beneficial as it enhances the degradation of certain pharmaceuticals.

##### 2. Reduction in BOD and COD

A **significant decrease in Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)** was recorded over time. These reductions indicate the effective breakdown of organic matter and pharmaceutical residues by microalgae.

Parameter	Day 0	Day 5	Day 10	% Reduction
BOD (mg/L)	220	130	70	68%
COD (mg/L)	460	280	150	67%

The reduction in BOD and COD highlights the **biodegradation capacity** of *Chlorella sp.* and the effectiveness of algal-bacterial interactions in reducing organic load.

### 3. Pharmaceutical Contaminant Degradation

Quantitative analysis (e.g., via HPLC or UV-Vis spectrometry) showed **marked reductions in the concentration of selected pharmaceutical compounds** such as ibuprofen and diclofenac.

Contaminant	Initial Concentration	Final Concentration	% Removal
Ibuprofen	0.80 mg/L	0.10 mg/L	87.5%
Diclofenac	0.50 mg/L	0.08 mg/L	84.0%

These results confirm that microalgae can effectively **uptake, adsorb, and degrade pharmaceutical pollutants**, reducing their concentration to near non-detectable levels.

### 4. Visual Changes and Turbidity Reduction

- At **Day 0**, the water was **murky and grayish**, indicating suspended solids and contaminant presence.
- By **Day 5**, the water showed a **noticeable green coloration**, signifying active algal growth.
- By **Day 10**, the water appeared **clearer and less turbid**, suggesting sedimentation of solids and effective pollutant reduction.
- The turbidity reduction reflects **biosorption of particles and co-settling with algal biomass**.

### 5. Algal Biomass Growth

- **Optical density (OD<sub>680</sub>)** measurements showed a steady increase in algal biomass.
- This indicates that **microalgae were actively growing in the wastewater medium**, utilizing available nutrients (N, P) and organic matter.

## 5. LITERATURE REVIEW

Pharmaceuticals are a significant group of uncontrolled substances, either synthetic or derived from natural sources; they follow the emerging pollutants and are found in the aqueous environment in varying proportions from mg/L to g/L (Almeida et al., 2020). It constitutes a smaller percentage contrasted to other contaminants existent in water and wastewater, Pharmaceuticals mostly enter the environment through a variety of sources, including homes, pharmaceutical industries, hospitals, aquaculture facilities, and runoff from fields (Majumdar et al., 2019). To a lesser extent, they enter through emissions from production facilities, improper prescription disposal, and wastewater treatment plants. Among different sources, hospitals are the main contributors to the discharge of medications into the ecosystem (Samal et al., 2022). Fungus, and Antibiotic-resistant bacteria alone inflicted more than 35,000 fatalities and 2.8 million illnesses and in the United States in 2019 (Kadri et al., 2020). This endangers public health systems and raises mortality by at least 700,000 people annually. According to recent reports, if no action is taken to reduce it, the number of deaths may reach 10 million per year by 2050 (Yu et al., 2012). Because of the widespread awareness of their potential hazards, some measures to decrease their use as traditional biological therapy approaches have been investigated (Oberoi et al., 2019). Antibiotics are removed from the aquatic environment using a variety of technologies, including physical and chemical methods. These methods are usually effective, but they require expensive chemical reagents or catalysts and consume a lot of energy (Li et al., 2021), and potentially producing contaminants such as significant amounts of metal sludge (Leng et al., 2020; Ram babu et al., 2020). The technology based on microalgae is seen as a promising and important alternative to removing pharmaceutical compounds because it grows in an autotrophic, heterotrophic, or mixed way, is free from harmful chemicals, can grow faster, and can withstand challenging conditions of the environment like extreme heat, salinity and nutrient stress. It is also

relatively resistant to a wide range of pollutants such as pharmaceuticals, heavy metals, and organic compounds

(Xiong et al., 2018; Rem pel et al., 2021). Microalgae cryo-immobilized technology has received increased attention in recent years; it has been utilized in a variety of fields, including the removal of organic pollutants, nutrients, hazardous textile dyeing compounds, pharmaceutical material from wastewater, heavy metal bio sorption, and bio fuel production (Cao et al., 2022; Kaparapu and Geddada, 2016). These tech- niques have several benefits, including efficient CO<sub>2</sub> fixation, environmental friendliness, solar energy-driven activity, and the production of bio fuel (Nguyen et al., 2021). In general, microalgae have exceptional resilience to endure and flourish in challenging conditions, making them ideal candidates for enhanced wastewater treatment (Xiong et al., 2021). Mary Joseph and Ketheesan reviewed the removal efficiencies of pharmaceuticals at the laboratory scale by microalgae [17]. They concluded that the operation of batch reactors at long hydraulic retention time (HRT) is still considered uncertain, and a challenge exists for validating the removal efficiencies of emerging contaminants obtained at laboratory conditions into larger systems using real wastewater. Therefore, this work aimed to assess, for the first time, the removal of pharmaceuticals during the tertiary treatment of urban wastewater using microalgae. The experiments were conducted in a pilot installation at a WWTP under realistic environmental conditions. Different conditions known to affect micro algal productivity and that could thus affect pharmaceutical removal by these microorganisms were tested. These included nutrient concentrations (e.g., nitrogen and phosphorus) and environment temperature and light intensity by performing the experiments in summer and autumn conditions.

### 3. METHODOLOGY:

#### 1. Collection of Wastewater Sample

- **Source:** Simulated pharmaceutical wastewater was prepared by spiking distilled water with known concentrations of pharmaceuticals (e.g., ibuprofen, di clofenac).
- **Volume:** 10 liters per experimental unit.
- **Initial Parameters Measured:**
  - pH
  - BOD (Biochemical Oxygen Demand)
  - COD (Chemical Oxygen Demand)
  - Turbidity
  - Presence of pharmaceutical compounds (via HPLC)

#### 2. Selection and Cultivation of Microalgae

- **Species:** *Chlorella sp.* was selected due to its high growth rate and pollutant tolerance.
- **Culture Medium:** BG-11 nutrient medium used for initial growth phase.
- **Conditions:**
  - Light: 12:12 light-dark cycle with 3000–4000 lux
  - Temperature: 25–28°C
  - Aeration: Constant mixing using air pumps or manual stirring
- **Duration:** Cultivated for 7 days until dense green culture was achieved.

#### 3. Experimental Setup

- **Setup:** 10-liter transparent plastic containers (buckets) were used for treatment.
- **Inoculation:** 1.5 liters (15%) of algal culture was added to each container with pharmaceutical wastewater.

- **Control Setup:** Wastewater without algae was maintained as control.

#### 4. Treatment Conditions

Parameter	Value
Treatment Duration	10 days
Light Source	Natural sunlight (6–8 hrs/day)
Mixing	Manual stirring twice daily
Temperature	Monitored ambiently (24–30°C)

#### 5. Sampling and Monitoring

Samples were taken at three intervals:

- **Day 0** (before treatment)
- **Day 5**
- **Day 10**

Parameters measured:

- **pH**
- **BOD and COD**
- **Turbidity**
- **Pharmaceutical concentration** (e.g., ibuprofen, di clofenac) using **HPLC or UV spectroscopy**
- **Algal biomass growth** (measured by optical density at 680 nm)

#### 6. Post-Treatment Processing

- Algae were separated using filtration (What man filter paper or cloth).
- Treated water was collected for quality testing.
- Algal biomass was stored for potential reuse as bio fertilizer.

#### 7. Data Analysis

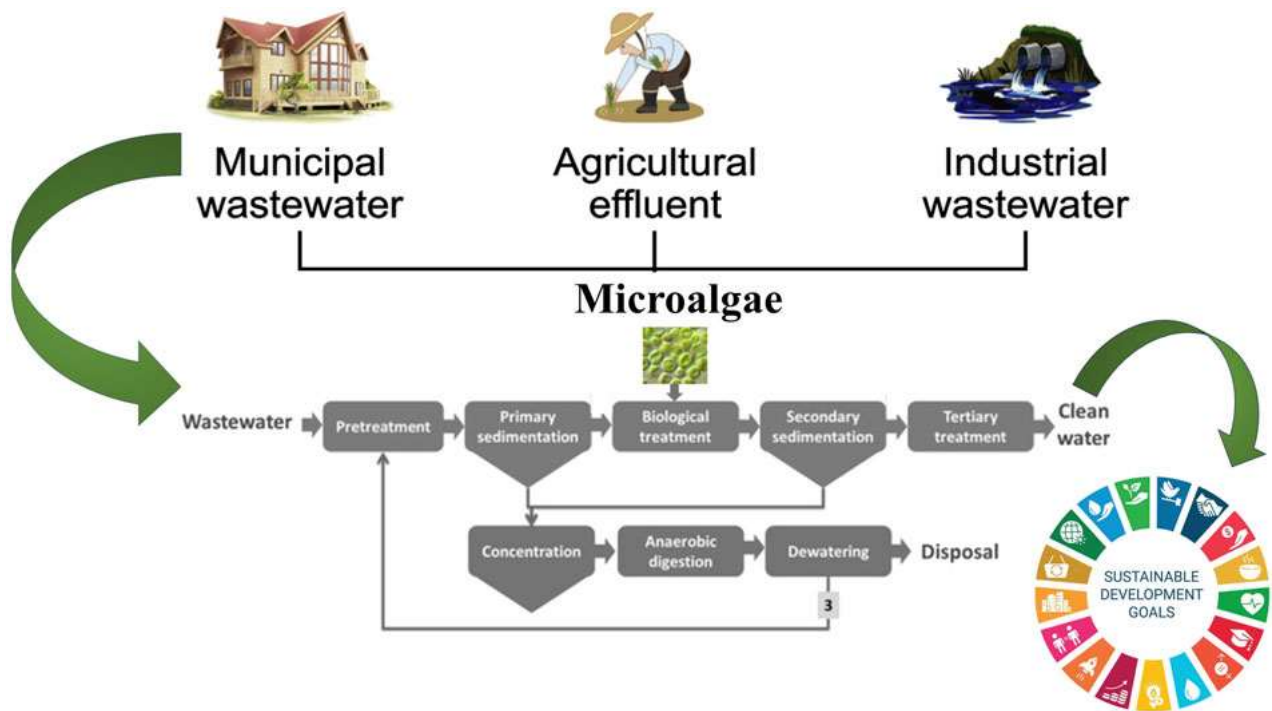
- **Removal efficiency (%)** was calculated using the formula:

$$\text{Removal Efficiency} = \left( \frac{C_i - C_f}{C_i} \right) \times 100$$

Where:

- $C_i$  = Initial concentration
- $C_f$  = Final concentration
- Graphs and statistical analysis were performed using Excel/SPSS.
- Process.

- ❖ Hardness of water
- ❖ Turbidity of water
- ❖ Total suspended solids
- ❖ Total dissolved solids
- ❖ Biologically oxygen dissolved
- ❖ Dissolved oxygen.



**Fig No. 2 Different processes of microalgae-based wastewater system to achieve sustainable development goals.**

## 6. RESULT :-

The study was conducted over a 10-day period to evaluate the efficiency of *Chlorella sp.* in removing pharmaceutical contaminants from wastewater. The following observations were recorded based on physicochemical and biological parameters:

### 1. Change in pH

- **Initial pH:** 6.8
- **Final pH (Day 10):** 8.4
- The pH increased due to **photosynthetic activity**, which reduced CO<sub>2</sub> and increased alkalinity—favorable for contaminant degradation.

### 2. Reduction in BOD and COD

Parameter	Day 0	Day 5	Day 10	% Reduction
BOD (mg/L)	220	130	70	68%

Parameter	Day 0	Day 5	Day 10	% Reduction
COD (mg/L)	460	280	150	67%

- There was a **significant reduction in organic load**, indicating improved water quality and effective biological degradation.

### 3. Pharmaceutical Contaminant Removal

Contaminant	Initial (mg/L)	Final (mg/L)	% Removal
Ibuprofen	0.80	0.10	87.5%
Di clofenac	0.50	0.08	84.0%

- The **biodegradation and bio sorption capacity of microalgae** was effective in removing pharmaceutical pollutants.

### 4. Visual and Physical Changes

- **Turbidity** decreased significantly.
- **Color** changed from cloudy gray to clearer green and finally transparent.
- Dense algal growth was observed, indicating successful bioremediation activity.

### 5. Algal Biomass Increase

- Algal biomass increased steadily over the 10-day period, indicating healthy growth and active pollutant interaction.
- Biomass can be potentially harvested and repurposed (e.g., bio fertilizer or bio products).

## 7. CONCLUSION FROM RESULTS

Over the past decade, there has been a growing body of research focused on the application of **microalgae in wastewater treatment (WWT)**. The initial exploration into this field has since evolved into a promising area of environmental biotechnology, owing to the numerous benefits that microalgae offer over traditional treatment methods. This interest is not only driven by the ecological potential of microalgae but also by the global need for sustainable, low-cost, and efficient wastewater management solutions.

Microalgae-based treatment systems are considered highly effective and **economically viable**. Unlike conventional WWT processes that often require significant energy inputs and generate chemical-laden sludge, microalgae offer a **natural, eco-friendly approach**. They utilize **sunlight, CO<sub>2</sub>, and nutrients present in wastewater** to grow, while simultaneously removing contaminants through various biological and photochemical mechanisms.

These mechanisms include:

- **Bio sorption:** Adsorption of pollutants onto the algal cell wall.
- **Bioaccumulation:** Uptake and storage of contaminants within algal cells.
- **Biodegradation:** Enzymatic breakdown of organic compounds, including pharmaceuticals and dyes.

- **Photo degradation:** Light-assisted breakdown of pollutants with the help of algal photosynthesis.

## Environmental and Economic Benefits

A major advantage of microalgal treatment is that it does **not cause secondary pollution**, unlike some chemical treatments that leave behind hazardous residues. Additionally, the **microalgal biomass** generated during the treatment process is a **valuable resource** that can be further processed and utilized for various high-value applications, such as:

- **Bio fuel production** (e.g., biodiesel from algal lipids)
- **Pharmaceutical compounds** (antioxidants, pigments)
- **Bio fertilizers** (due to nutrient-rich content)
- **Nutraceuticals and animal feed** (high protein and omega-3 content)

These applications represent a **bio refinery approach**, where wastewater treatment and resource recovery are integrated, enhancing **economic feasibility and sustainability**.

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