Sustainable Wastewater Treatment Using Microorganisms: A Low-Cost Biological Approach

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ABSTRACT

There are significant environmental and public health risks associated with the growing discharge of untreated wastewater. This study uses native microbial consortia isolated from raw wastewater to investigate a low-cost and sustainable biological wastewater treatment approach. An aerobic bioreactor system built with low-cost materials was used to enrich and apply microorganisms. Over the course of 14 days, physicochemical and biological parameters such as pH, turbidity, total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen (DO) were monitored in order to assess treatment efficiency. With BOD and COD removal efficiency ranging from 50 to 80 percent, the results showed notable decreases in organic and suspended contaminants. Improved water quality was proven by lower turbidity and higher DO levels. The study concludes that microbial-based wastewater treatment is an environmentally sustainable and economically viable alternative for decentralized and small-scale wastewater management systems.

KEYWORDS: Wastewater treatment, microbial consortium, low-cost bioreactor, BOD, COD, sustainability

1. INTRODUCTION

The treatment of water contamination has grown to be a serious worldwide concern. The production of fertilizer, mining, and pesticides, as well as household effluents, are the main industrial processes that emit contaminants. Hazardous waste releases disrupt aquatic ecosystems and have an impact on human health. An estimated 80% of wastewater released into the environment has been sufficiently cleaned, according to the UN World Water Development Report of 2024 [UNESCO WWDR,2024]. This is especially true in low- and middle-income nations. According to a 2024 World Health Organization (WHO) research, over 2 billion people consume water tainted with excrement, which results in around 485,000 diarrheal deaths annually (WHO,2024). More than 60% of freshwater bodies worldwide are either moderately or severely contaminated, according to the UNEP Global Environment Outlook (2024). These contaminants range from nutrient overloads (eutrophication) to emerging pollutants like pharmaceuticals, microplastics, and personal care products (Tiwari,2022). The development of effective and sustainable wastewater treatment (WWT) systems is urgently needed in light of these concerning figures. In order to guarantee the availability of cleaned water, recent advancements in biological WWT motivate researchers to enhance microbial bioremediation methods (Coelho, 2015; Ferrera, 2016).

In line with global initiatives, such as Sustainable Development Goal (SDG) 6.3, which aims to reduce the concentration of untreated wastewater by half and greatly improve its recycling and safe reuse via nature-based solutions (NbS), microbial bioremediation provides an economical and environmentally friendly alternative (Crowther,2024). Microbial species including bacteria, fungus, and yeast are used in the bioremediation process to remediate contaminated soil and water. The use of biological processes to eliminate, reduce, or change contaminants is known as bioremediation. Whether pollution comes from a single source or from several sources, aquatic ecosystems are the first and most severely affected in every country. The main principal sources are discharged straight into the stream.

Effluents from municipal and industrial operations, runoff and leachate from solid waste disposal sites, industrial drainage, and vessel discharges are common sources of environmental contamination. Other secondary sources of water pollution include agricultural runoff from fields and orchards and urban runoff from undeveloped areas. Birds and land animals, in addition to aquatic life, suffer greatly from contaminated water. Aquatic life is killed by contaminated water, which also prevents them from reproducing. As a result, water is no longer fit for human or domestic use, and in severe cases, it may even be harmful to human health. The financial and environmental expenses of waste disposal can be reduced by using bioremediation [Pillay, 1992]. Many treatments typically involve seeding polluted water with competent microflora that can degrade hazardous materials to hasten the bioremediation process (Divya,2025).

Microorganisms may break down pesticides, chemical waste from agriculture, fuel leftovers, and imperishable substances like chlorofluorocarbons, chlorinated solvents, and various organic ingredients in addition to processing wastewater and urban detritus. Microorganisms may be isolated and endemic in the contaminated area, or they may be brought in from their home country throughout the procedure. Contaminants are transformed by microbial populations through metabolic processes. The biodegradation of a pollutant is also significantly influenced by the behavior of various bacteria species (Zouboulis, 2019; Ojha, 2021).

Figure:1. Graphical abstract of microbial-based wastewater treatment

2. METHODOLOGY

Physiological and biological processes are the main techniques used to remediate wastewater. Precipitation and evaporation are two common physicochemical techniques used. sorption, ion exchange, osmosis, and electrochemical treatment. They are neither economical nor ecologically sustainable. Because biological approaches are effective at eliminating trace amounts of metal ions and other pollutants, they are recommended. Biological WWT is economical and environmentally friendly. A microbial consortium with a high metal binding potential can efficiently remove heavy metals from a contaminated site. It has no negative impacts on aquatic environments and is quite effective even at low doses. Because the microbial population readily adjusts to the environment, biological therapy is quite effective (Kadirvelu, 2002).

2.1. Sample Collection

Samples of raw wastewater were taken from domestic sewage outlets in Tamil Nadu's Coimbatore district. India. use sterilized containers. After being collected, samples were sent to the lab in four hours. To reduce microbial alterations, samples were kept at 4°C.

2.2. Isolation and Enrichment of Microorganisms

Sterile distilled water was used to serially dilute wastewater samples. On nutrient agar, the proper dilutions were plated and incubated for 24 to 48 hours at 30 to 37°C. Based on their physical traits, Bacillus microbe colonies were chosen and moved to nutritional broth for enrichment. A mixed microbial consortium was created by combining enriched cultures to remediate wastewater.

2.3. Preparation of Biological Treatment Unit

A cheap glass or plastic Bacillus bioreactor with a 5–10 L capacity was properly cleaned and disinfected. Up to 80% of the reactor's volume was filled with raw wastewater, and 10–20% (v/v) of an enriched microbial consortium was added. An air pump with a diffuser was used to maintain aerobic conditions. The reactor was run at a pH of 6.5 to 8.0 and a temperature of 30 to 35°C. A 14-day treatment duration was continued.

2.4. Experimental Design and Control Setup

The same environmental conditions were maintained in a control reactor that contained raw wastewater without microbial inoculation. To assess the effectiveness of the treatment, treated and control samples were compared.

2.5. Monitoring Parameters

Samples were collected on Day 0, Day 3, Day 7, and Day 14 and analyzed for:

2.5.1. Physicochemical parameters:

- pH
- Turbidity
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)

2.5.2. Biological parameters:

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Dissolved Oxygen (DO)
- Microbial count (CFU/mL)

Standard APHA methods were followed for all analyses.

2.6. Data Analysis

The % reduction of BOD, COD, and TSS was used to determine treatment efficiency. The mean ± standard deviation was used to express the results. Wastewater quality changes over time were depicted using graphs.

Figure:2. Raw wastewater samples were collected domestic sewage outlet from at Coimbatore district, TamilNadu. India

Figure:3. A control reactor and Treated samples

Table 1. Characteristics of Raw Wastewater (Day 0)

Parameter	Unit	Value
pH	–	7.4
Turbidity	NTU	120
TSS	mg/L	220
TDS	mg/L	650
BOD	mg/L	240
COD	mg/L	480
DO	mg/L	1.8

Table 2. Operational Conditions of the Bioreactor

Parameter	Condition
Reactor volume	5–10 L
Inoculum concentration	10–20%
Temperature	30–35°C
pH range	6.5–8.0
Aeration	Continuous
Treatment duration	14 days

Table 3. Changes in Wastewater Quality During Treatment

Parameter	Day 0	Day 3	Day 7	Day 14
pH	7.4	7.3	7.2	7.1
Turbidity (NTU)	120	85	45	25
TSS (mg/L)	220	160	90	55
BOD (mg/L)	240	180	100	60
COD (mg/L)	480	350	220	140
DO (mg/L)	1.8	3.2	4.6	5.6

Table 4. Comparison Between Control and Treated Wastewater (Day 14)

Parameter	Control	Treated
pH	7.5	7.1
Turbidity (NTU)	110	25
TSS (mg/L)	210	55
BOD (mg/L)	230	60
COD (mg/L)	460	140
DO (mg/L)	2.0	5.6

Table 5. Removal Efficiency of Pollutants

Parameter	Removal Efficiency (%)
BOD	75.0
COD	70.8
TSS	75.0
Turbidity	79.2

3. RESULT

Over the course of a 14-day treatment period, the effectiveness of the inexpensive aerobic bioreactor inoculated with a native Bacillus-based microbial consortium was assessed by tracking important physicochemical and biological parameters. When compared to the untreated control, the results show a significant improvement in effluent quality.

3.1. Characteristics of Raw Wastewater

Table 1 summarizes the baseline parameters of the raw residential wastewater collected from the Coimbatore district. With BOD and COD levels of 240 mg/L and 480 mg/L, respectively, the wastewater showed high levels of organic matter and suspended solids. A considerable degree of organic pollution was indicated by the low dissolved oxygen (DO) concentration (1.8 mg/L). TSS (220 mg/L) and turbidity (120 NTU) results further demonstrated that the influent wastewater was contaminated.

3.2. Changes in Physicochemical Parameters During Treatment

Over the course of the treatment, turbidity and suspended particles gradually decreased (Table 3). By Day 14, turbidity has dropped from 120 NTU on Day 0 to 25 NTU, a decrease of around 79%. In a similar vein, TSS levels decreased from 220 mg/L to 55 mg/L, suggesting a 75% clearance effectiveness. Throughout the treatment procedure, the wastewater's pH stayed close to neutral, dropping from 7.4 to 7.1 by Day 14. This stability points to ideal circumstances for microbial activity in the bioreactor.

3.3. Reduction in Organic Load (BOD and COD)

Over the course of the 14-day treatment period, there were notable decreases in both BOD and COD (Table 3). The BOD concentration dropped from 240 mg/L to 60 mg/L, indicating a 75% removal efficiency. COD levels were lowered from 480 mg/L to 140 mg/L, representing a reduction of almost 71%. The microbial consortium's efficient biodegradation of organic waste under aerobic conditions is indicated by the steady decrease in BOD and COD levels over time.

3.4. Dissolved Oxygen Improvement

Over the course of treatment, dissolved oxygen levels increased significantly, from 1.8 mg/L at the beginning to 5.6 mg/L by Day 14 (Table 3). A decrease in organic pollutants that require oxygen and efficient aeration in the bioreactor system are reflected in the rise in DO.

3.5. Comparison Between Control and Treated Wastewater

Table 4 shows a comparison of the treated reactor at Day 14 with the control reactor (without microbial inoculation). With high turbidity (110 NTU), TSS (210 mg/L), BOD (230 mg/L), COD (460 mg/L), and low DO (2.0 mg/L), the control sample's wastewater quality exhibited no improvement. Turbidity (25 NTU), TSS (55 mg/L), BOD (60 mg/L), COD (140 mg/L), and DO (5.6 mg/L) were all significantly reduced in the treated wastewater. These outcomes unequivocally show how well the microbial consortium improves wastewater treatment efficiency.

4. DISCUSSION

The probiotic or bioremediation qualities of Bacillus bacteria are especially noteworthy. Bacillus species that are aerobic, gram-poor, and non-pathogenic are common in the environment. They may improve overall performance, colonize fish gastrointestinal tracts, strengthen defenses against illnesses, and enhance the water quality of fish ponds (Nunes et al., 2020).

Just 3% of the water resources on Earth are freshwater. However, freshwater availability has been interrupted by increased agricultural production, population development, and climate variability. Water scarcity is expected to rise as population expansion is outpaced by water demand. Wastewater from cities and industries further deteriorates water quality, endangering human health and the environment (Smith et al., 2021).

Despite being a problem, wastewater can be a useful resource, particularly in arid areas. It promotes agriculture and is rich in nutrients, but pollutants like heavy metals and viruses are dangerous. Untreated use damages crops, deteriorates soil, and puts human health at risk. Wastewater is a sustainable choice since advanced treatment can lessen these risks (Johnson et al., 2020). Water resources for industry and agriculture are increased by wastewater treatment, which includes at least secondary-level disinfection (Taylor et al., 2019). Because treated wastewater contains nutrients, it lessens the need for chemical fertilizers and freshwater (Martinez et al., 2022). But maintaining chemical and microbiological safety is still a major problem that calls for ongoing study and creativity (Anderson et al., 2021).

Physical, chemical, and biological procedures are the three categories of methods used to minimize pollutants in wastewater. Regarding cost, efficiency, environmental effect, pre-treatment requirements, and byproduct creation, each strategy has benefits and drawbacks. Among these, biological treatment has lower capital expenditures, consumes less land, and is more environmentally friendly (Luo et al., 2014; Verma et al., 2017). By using microorganisms to break down organic materials, biological wastewater treatment lowers the biochemical oxygen demand (BOD). Under the right circumstances, this mechanism uses natural microbial metabolism to oxidize and eliminate soluble organic materials (Hedaoo et al., 2012; Wang et al., 2019). Additionally, biological treatment eliminates total nitrogen and phosphorus while also removing suspended and dissolved substances, including organic matter and inorganic ions such as calcium, potassium, sulfate, nitrate, and phosphate (Metcalf & Eddy, 2003; Sharma et al., 2021).

Biological treatment has benefits, but it is a gradual procedure that may encourage the growth of undesirable microbes that reduce treatment effectiveness (Gupta & Yadav, 2020). Physical, biological, and chemical procedures are examined critically in light of the importance of wastewater management in order to identify the most efficient and sustainable approaches. In order to direct future research toward creative and economical solutions, this study attempts to look at opportunities and problems in wastewater treatment while offering a comparative analysis (Zhou et al., 2022).

CONCLUSION

This work shows the efficacy of a low-cost, sustainable biological wastewater treatment system using an aerobic native Bacillus-based microbial consortia. Turbidity, total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) all significantly decreased throughout the 14-day treatment period. The microbial consortium's considerable biodegradation capacity is demonstrated by removal efficiencies of roughly 70–75% for organic and suspended contaminants. Favorable operational stability and increased aerobic microbial activity are indicated by the steady rise in dissolved oxygen levels and the preservation of nearly neutral pH throughout the treatment process. In comparison to the untreated control, the treated wastewater showed markedly superior performance across all monitored parameters, confirming the critical role of microbial inoculation in pollutant removal.

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