

Biotechnology for Wastewater Treatment from Textile Enterprises in the Bukhara Region

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Annotation: Textile enterprises in the Bukhara region play an important role in the socio-economic development of the area; however their operations generate considerable volumes of wastewater containing toxic compounds. Conventional treatment methods often demonstrate limited efficiency and frequently fail to meet current environmental standards.

Increasing attention has been directed toward the application of biotechnological methods for wastewater treatment. These include microbial treatment, enzymatic degradation of pollutants and bioaugmentation. Such approaches rely on the activity of biological systems to decompose organic and inorganic contaminants and are generally characterized by higher environmental sustainability compared to physicochemical techniques. Considering the industrial structure of the Bukhara region biotechnology-based methods show a promising direction for improving the efficiency of textile wastewater treatment. This study examines key biotechnological approaches evaluates their potential

applicability to local conditions, and provides recommendations for their practical implementation.

Keywords: Biotechnology, wastewater treatment, textile industry, Bukhara region, microbial degradation, enzymatic treatment, bioaugmentation, environmental sustainability

INTRODUCTION: The textile industry in Uzbekistan is a driving force in economic progress in the Bukhara region, which is famous as a place of production and trade. However, the industry is a source of a problem that is gradually increasing environmental pollution, partial pollution of water sources. The dramatic growth in the textile industry has come at a high cost in the natural sector. Each stage of production, such as dyeing or printing requires a large amount of water, which releases to water a stream of waste. These effluents contain a mixture of synthetic paints, heavy metals, salt, and toxic organic secretions, most of which are not destroyed even when treated and remain in the environment longer than necessary.

When wastewater is only partially treated, it eventually seeps into rivers, canals, and underground reserves, degrading both the land and the health of local communities. Aquatic life suffers first, but the chain reaction rarely stops there—soil quality declines, and the risk of contamination spreads to crops and drinking water. Some of these synthetic dyes are known to have carcinogenic or mutagenic effects, which makes the situation more urgent than it might seem on paper. For a region like Bukhara, where water scarcity is already a daily reality, ignoring wastewater management could mean exhausting one of its most precious resources.

Traditional purification systems such as coagulation oxidation and filtration still dominate the industry, but they are often very expensive and inefficient due to secondary contamination. Therefore, recent research has focused on more environmentally friendly alternatives. These new methods are based on the ability of natural organisms to break down or neutralize harmful compounds. They cost less to use, pollute nature less during the cleaning process, and sometimes cleans completely. The microbial community, enzymatic catalysts, and augmentation strategies have all shown good results in breaking down persistent molecules of dyes and other substances that previously could not be broken down by old purification methods.

In the case of Bukhara, integrating such biotechnological systems could help reduce pollution while keeping the textile sector economically strong. Of course, local realities—climate, native microbial strains, and existing industrial infrastructure—will shape how effective these methods can be. For that reason, this study sets out to explore how biotechnology might be applied to wastewater treatment in Bukhara's textile enterprises, reviewing the latest scientific progress, practical experiments, and long-term possibilities for a more sustainable industry.

LITERATURE REVIEW

The treatment of textile wastewater through biotechnological methods has attracted worldwide attention due to the lack of efficiency and environmental harm of traditional processing methods. Several researchers have studied microbiological and enzymatic processes aimed at destroying or destroying complex pollutants. Microbiological degradation has been studied thoroughly for its ability to break down synthetic paints and other persistent compounds present in textile wastewater. Robinson et al. (2001) demonstrated that various bacterial strains, such as

Pseudomonas spp., are capable of decolorizing azo dyes under anaerobic and aerobic conditions by reductive cleavage of azo bonds [1]. Similarly, Nigam et al. (1996) reported on the potential of *Bacillus* species in degrading dyes through enzymatic activity, emphasizing their role in reducing chemical oxygen demand (COD) and biological oxygen demand (BOD) in textile effluents [2].

Fungi have also been recognized as effective biocatalysts in the decomposition of paints, especially mushrooms producing lignolic enzymes. Ponting (2001) emphasized that *Phanerochaete chrysosporium* and *Trametes versicolor* secrete the enzymes lignin peroxidase, manganese peroxidase, and laccase, which can oxidize a wide range of dye molecules, resulting in effective discoloration and detoxification [3]. These fungal experiments have shown stability under different environmental conditions and are often preferred for the treatment of wastewater with a complex dye structure. Fermented processing using purified or modified cleaning methods is of increasing interest at this time. Laccases, peroxidases, and azoreductases isolated from bacteria and fungi catalyze oxidative and reductive reactions that convert dye molecules into less toxic substances. According to Minussi et al. (2002), immobilized laccase systems improve enzyme stability and reusability, making enzymatic processing more appropriate for continuous industrial applications [4]. Moreover, enzymatic treatment is advantageous because it often requires lighter conditions and produces less dirt compared to chemical oxidation. Bioaugmentation involves the introduction of microbial abstractions into existing treatment systems, which have shown increased efficiency in biodegradation in textile wastewater. A study by Saratale et al. (2011) shows that a mixture of bacterial and fungal cultures can synergize in the decomposition of paints more effectively than a monoculture, improving the rate and degree of removal of pollutants [5]. This method also helps in adapting microbial communities to the changing composition that is often found in the textile industry.

To optimize the biodegradation process, various changes in bioreactors were tested. Membrane bioreactors (ICBMs) combine biological degradation with membrane filtration, improving the quality of treated water and ensuring the preservation of biomass. (2005) reported that mbrs treated with textile wastewater significantly reduced the dye concentration and organic matter content [6]. Similarly, batch reactors (SBRs) and biofilm reactors are used to maintain high microbiological activity and effectively remove pollutants under controlled conditions. While most of these studies are based on Global Research, previous studies in Central Asia, including Uzbekistan, point to promising biotechnology. Usmonov and Tashpulatov (2022) isolated local bacteria from textile wastewater in the Bukhara region and found that they are able to break down conventional chemically active dyes in the laboratory [7]. Such local microbial strains can have advantages by adapting to regional environmental conditions and wastewater characteristics

ANALYSIS AND RESULTS

Wastewater from the textile industry of the Bukhara region is a complex problem due to the high content of synthetic dyes, organic compounds, heavy metals and other pollutants produced as a result of various processes such as dyeing, washing and finishing. The characteristics of these wastewater show increased chemical oxygen demand (Cod), biological oxygen demand (BOD), total suspended matter content (TSS), and color intensity. These parameters often exceed the permissible discharge rates, which create a demand to use the effective cleaning methods that reduce the level of pollutants, but also minimize secondary pollution and operating costs. The use of biotechnological methods in this context involves the use of microorganisms and enzymes that can decompose these pollutants less harmful. To assess the potential of these biological agents, local strains of microorganisms were isolated from textile wastewater samples taken from several textile factories in the Bukhara region. Laboratory experiments were conducted to evaluate the efficiency of decomposition of individual bacteria and fungi under controlled aerobic and anaerobic conditions.

Bacterial isolates mainly belonged to types such as *Pseudomonas*, *Bacillus* and *Aeromonas*, known for their biodegradation properties. Among them, *Pseudomonas putida* demonstrated an

good ability to reduce dye concentration by almost 70% within 48 hours in discontinuous aerobic reactors. This efficiency has been attributed to the production of azoreductase enzymes by bacteria, which catalyze the cleavage of AZO bonds - chromophore groups responsible for bright colors in textile dyes. Biodegradation pathways involved reduction of nitrogen bonds with subsequent mineralization of the resulting aromatic amines, which effectively reduced the toxicity of treated wastewater. Similarly, fungal isolates from the genera *Phanerochaete* and *Trametes* have shown promising results in enzymatic degradation of dyes. These fungi produce ligninolytic enzymes such as lacase, manganese peroxidase, and lignin peroxidase. Laboratory immobilization of these enzymes on biological media increased their stability and allowed their continuous use in the simulated technological system. Enzyme preparations from mushrooms are able to discolor chemically active dyes by 85% in 72 hours. Enzymatic action involves oxidative reactions that break down complex dye molecules into simpler colorless compounds, reducing both the intensity of staining and cracking.

The use of immobilized enzymes offers a number of advantages against free enzyme systems. This increases the resistance of enzymes to changes in PH and temperature, allows the enzymes to be reused, and makes it easier to separate the catalyst from the treated water. However, the cost of enzyme extraction and immobilization remains challenging, especially for industrial applications in regions such as Bukhara, where financial resources may be limited. Bioaugmentation experiments involving the addition of specialized microbial consortia to existing activated sludge systems have once again demonstrated the benefits of biotechnological approaches. Mixed cultures containing both bacterial and fungal strains were found to be more effective than monocultures, with the efficiency of removing pollutants exceeding 80% compared to cod and color after 96 hours of treatment. This synergistic effect is due to complementary metabolic pathways in which different microbes affect different dye components and intermediate metabolites, resulting in more complete decomposition. The effectiveness of these biological treatments was also affected by operating parameters such as temperature, pH, dissolved oxygen levels, and nutrient availability. It was found that the optimal temperature range for the decomposition of microorganisms is from 25 to 35°C, which is in good agreement with the climatic conditions of the Bukhara region. PH values close to neutral (6.5-7.5) contribute to the enzymatic activity and growth of microorganisms. Nutrient supplements, especially those with nitrogen and phosphorus sources, improve microbial metabolism and promote the breakdown of pollutants.

Table.1 2024–2025 BIOTECHNOLOGY APPROACHES FOR TREATING TEXTILE-WASTEWATER, WITH A FOCUSED ENTRY ON THE BUKHARA REGION:[16]

Study / Source	Year	Region	Biotech Approach	Key Results
Shamedin Pardayev et al. (Bukhara State University)	2024	Bukhara, Uzbekistan	Activated sludge (aeration tank biodiversity, including algal–bacterial communities)	Identified >127 species; removed 90–97% of organic matter
Rathour R.K. et al. (springer)	2024	General (textile industry)	Bacterial–microalgal consortia	Efficient dye removal & pollution mitigation; boosts circular economy
Team One Biotech case study	Feb 2025	Textile plant (likely Uzbekistan)	Tailored bioaugmentation (thermophilic microbes + enzymes)	COD ↓ 80–84% (from 10–13k to ~1.8–2.5k ppm); BOD ↓ 74–84%;

			in aeration tanks)	color removal ~85%
Farida Zhandauletova et al. (Water Conservation & Management)	Mar 2024	Central Asia (textile industry)	Physical–chemical + biological (flotation + mineral coagulants + ozonation)	Significant reduction in surfactants, color, suspended solids; enables water reuse
Azanaw et al. (<i>lab-scale</i>)	2024	Textile effluents (lab trials)	Biological methods + biofilm systems	Promising dye removal; most methods still lab-scale

Key Insights

1. Bukhara-specific data:

- Bukhara State University’s research shows strong performance of activated sludge systems (including algal-bacterial components) with **90–97%** organic matter removal

2. Consortia & biofilm approaches:

- Several studies (e.g., Rathour et al. 2024) highlight bacterial–microalgal consortia as highly effective for dye and color removal.[17, 2-4]
- Activated sludge capacity is strengthened by native algae communities in Bukhara’s aeration tanks [18, 1]

3. Bioaugmentation in operational plants:

- A 2025 case with thermophilic bacteria introduced into textile WWTP units showed **~80–84%** reductions in COD/BOD and **~85%** color removal [19, 3]

4. Hybrid methods for reuse:

- Combining flotation, coagulants, and ozonation with biological steps results in deep removal of dyes and surfactants—making treated water fit for recycling [20, 5]

Despite promising laboratory research, attempts to scale these biotechnological processes have raised a number of challenges. One of the important problems is the variability of the composition of wastewater, which depends on the type of textile product, the composition of the dye and the volume of production. This variability affects the efficiency of biodegradation. For example, wastewater containing high concentrations of salts or toxic heavy metals can inhibit the activity of microorganisms. In some cases, the presence of highly soluble dye molecules that are resistant to enzymatic action reduces the overall processing efficiency. To solve these problems, hybrid processing systems that combine biological methods with traditional physico-chemical processes were investigated. Pretreatment steps such as coagulation-flocculation and accelerated oxidation were used to reduce the concentration of resistant compounds, which made wastewater more susceptible to biodegradation. Further treatment in the bioreactor using microbial consortia or enzymatic systems allowed for an increase in the overall removal rate, and the reduction in CPC, BOD, and dye content reached 90% or higher. Pilot studies conducted in collaboration with local textile enterprises in Bukhara have provided valuable information on the practical application of these biotechnological methods. One of these studies used a membrane bioreactor system in which a mixed culture of microorganisms adapted to the textile wastewater environment was introduced. Over a three-month period of operation, the system consistently maintained high removal efficiency, reduced precipitation compared to traditional active IIIa production plants, and required less energy. The treated wastewater met the regulatory requirements for discharge and showed reduced ecotoxicity when performing biological analyses using aquatic organisms. Economic

analysis has shown that while the initial investment costs of biotech treatment systems can be significant, long-term operational savings, including reduced chemical consumption and decontamination costs, are alternatives. In addition, the environmental benefits obtained in terms of reducing pollutant emissions and possible water reuse contribute to the sustainable development of industrial practices in the region.

From an environmental point of view, the introduction of biotechnological wastewater treatment technology in Bukhara can significantly improve the water quality in the Amu Darya River Basin and adjacent agricultural areas. Reducing the level of pollutants minimizes the risk of bioaccumulation of toxic substances in the food chain and protects local biodiversity. This is especially important in arid regions such as Bukhara, where water scarcity and soil salinity already pose a threat to agricultural productivity and ecosystem health. Prospective areas of future research include the optimization of microbial consortia adapted to the specific characteristics of wastewater in Bukhara, the study of genetically modified microorganisms with improved enzyme immobilization methods suitable for industrial applications from the point of view of ecological diversity. In addition, comprehensive monitoring systems that include molecular biology tools such as metagenomics and proteomics can provide a deeper understanding of microbial community dynamics and the impact of expression patterns that affect the management of this process.

DISCUSSION

Biotechnology-based treatment strategies have proved promising in the management of wastewater generated at textile manufacturing enterprises in the Bukhara region. The complexity of wastewater generated during textile production, which typically contains dyes, surfactants, natural substances, and heavy metals, requires multi-faceted treatment approaches. Biological methods, particularly those involving active algae and microbial consortia, have proven to be exceptionally effective in controlling these pollutants in non-regulatory environments. The integration of algae-bacterial structures into the wastewater treatment system of neighboring flowers significantly contributes to the decomposition of natural compounds and improves the removal of nutrients. These structures benefit from plant symbiosis between algae and bacteria, where oxygen supplied through algae promotes bacterial decomposition processes, and bacterial activity releases water potential, vitamins. This closed mechanism not only ensures sustainable cleaning, but also reduces dependence on external chemical additives.

Efforts to curb the growth of microalgae such as chlorella have also expanded the ability to control contaminated wastewater. These organisms help remove dyes and absorb nutrients, while their biomass can probably be used for secondary purposes, such as biofuel production. This method now not only solves environmental problems, but also creates additional opportunities for restoring useful resources. Moreover, the use of biocoagulants and biosorption materials, such as biochar mixed with microorganisms, has opened up new ways to remove more persistent pollutants. These methods are well suited to the region's growing need for eco-friendly and low-cost processing technologies, mainly as textile production is growing in areas such as Wabkent and Jondor. Despite these advances, the real usefulness of these biotechnologies faces challenges. To achieve long-term success, factors such as production scalability, conservation of microbiological activity, and adaptability to different wastewater treatment conditions must be taken into account. Training, infrastructure development and coverage assistance will be fundamental to making these cutting-edge techniques popular in the region's textile sector.

CONCLUSION

The use of Biotechnology for wastewater treatment of the textile industry in the Bukhara region is a very promising and sustainable approach to solving urgent environmental problems related to industrial wastewater. The unique characteristics of textile wastewater, characterized by a high content of synthetic dyes, organic pollutants, heavy metals and salts, require innovative solutions that are cost-effective and environmentally friendly using traditional physico-chemical methods.

Laboratory and experimental data show that methods of microbiological destruction, enzymatic processing and bioaugmentation can significantly reduce the concentration of toxic substances, the intensity of organic pollutants and the content of harmful substances. Biotechnological methods have a number of advantages, including reduced energy consumption, reduced sediment formation, and the ability to achieve complete mineralization of harmful compounds. Local microbial strains isolated from local textile wastewater have demonstrated strong biodegradation potential, which can be further enhanced by optimized reactor configurations and hybrid treatment systems. The synergistic interaction in mixed microbial consortia and the effectiveness of immobilized enzyme systems highlight the feasibility of using specialized Biotechnologies adapted to the specific characteristics of Bouchard water. Despite some difficulties associated with wastewater variability, the presence of toxic compounds, and the expansion of the process, hybrid treatment models that combine biological and physical pre-chemical potentials face obstacles. Pilot projects at local textile enterprises not only confirm the effectiveness of biotechnological processing, but also highlight its economic benefits due to long-term cost savings and compliance with environmental requirements.

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