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Physicochemical and Microbial Insights into Metallotolerance in Textile Effluents of ETP of Amravati (M.S.)

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ABSTRACT

Textile industry effluents are a major environmental concern due to their high organic load, salinity, and heavy metal contamination. This study investigated the physicochemical characteristics and microbial resistance of effluents from a textile Effluent Treatment Plant (ETP) in Amravati, Maharashtra. The effluent exhibited brown coloration with near-neutral pH (6.9), but several parameters exceeded CPCB permissible limits, including oil & grease (72.8 mg/L), TSS (400 mg/L), TDS (2280 mg/L), BOD (420 mg/L), COD (1920 mg/L), and cadmium (0.06 ppm). Dissolved oxygen (3.1 mg/L) was below desirable levels, indicating oxygen depletion. Metallotolerant bacterial strains resistant to chromium, cadmium, and lead were isolated and characterized. Morphological and Gram staining analyses revealed distinct pigmentation and colony features, with cadmium-resistant strains showing greater diversity and predominance of Gram-negative forms. Minimum Inhibitory Concentration (MIC) assays demonstrated higher tolerance in cadmium-resistant isolates, sustaining growth up to 600 ppm, while chromium- and lead-resistant strains were inhibited beyond 300 ppm. The findings confirm non-compliance of textile effluents with CPCB standards and highlight the potential of cadmium-resistant bacteria for bioremediation, offering eco-friendly solutions for improved effluent management.

Keywords:- Textile effluents; Physicochemical parameters; Heavy metal resistance, Metallotolerant bacteria; Bioremediation

1. INTRODUCTION

The textile industry is recognized as one of the largest generators of industrial wastewater worldwide, contributing significantly to environmental pollution [1], [2]. Textile effluents are complex mixtures containing dyes, salts, surfactants, suspended solids, organic matter, and heavy metals, which pose serious ecological and health hazards [3], [4]. Conventional treatment methods such as coagulation, flocculation, activated sludge, and chemical oxidation often fail to completely remove recalcitrant compounds, leading to non-compliance with regulatory standards [5]– [7]. In India, the Central Pollution Control Board (CPCB) prescribes stringent discharge limits for effluents [8]; however, many textiles effluent treatment plants (ETPs) struggle to meet these requirements due to high organic load, salinity, and toxic metal contamination [9], [10].

Physicochemical characterization of effluents provides critical insights into pollution load and treatment efficiency. Parameters such as pH, conductivity, BOD, COD, TSS, TDS, and heavy metal concentrations are essential indicators of effluent quality [11]– [14]. Elevated levels of cadmium, chromium, and lead are particularly concerning due to their toxicity, persistence, and bioaccumulation potential [15], [16].

In parallel, microbial bioremediation has emerged as a promising eco-friendly alternative. Metallotolerant bacteria capable of surviving in heavy metal-rich environments exhibit unique morphological and physiological adaptations, including pigmentation changes, colony morphology variations, and Gram-type diversity [17]– [20]. These microorganisms can reduce, adsorb, or transform toxic metals, thereby mitigating environmental risks [21], [22]. Minimum Inhibitory Concentration (MIC) assays further reveal the tolerance levels of such strains, with cadmium-resistant isolates often showing higher resilience compared to chromium- and lead-resistant strains [23], [24].

This study integrates physicochemical analysis of textile effluents with microbial characterization of metallotolerant strains isolated from Amravati, Maharashtra. The findings highlight effluent non-compliance with CPCB standards and demonstrate the potential of cadmium-resistant bacteria for bioremediation applications. Such insights are crucial for developing sustainable treatment technologies that combine engineering approaches with biological solutions to address the growing challenge of textile wastewater management [25]– [30].

2. MATERIALS AND METHODS

Study Area and Sample Collection: The investigation was carried out in the one of the ETP of Amravati region of Maharashtra

Collection of samples: Untreated effluents were collected from textile industrial ETP in Amravati region (Maharashtra). And stored in polyethylene sterile bottle keep at 4 ^{0}C for more studies. Sample was collected during different times of the day to account for

differences in effluent discharge.

Collection site: ETP Raymonds Cotton Luxury, Amravati Location: Lat:21. 029371.Long:77.852061

Physico-Chemical Analysis of Effluents: Physicochemical analysis of textile effluents of the various parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), TSS, DO using the method of BIS and heavy metals (Pb, Cr, Cd & Zn) were analyzed by Atomic absorption spectroscopy.

Isolation of Bacteria from Effluents: Effluents sample grown in a Luria berani broth incorporated with 100ppm heavy metal overnight, use 1ml serial dilution method ranging from 10^{-1} to 10^{-6},100µlof sample to every dilution test tube was aseptically transfer with the help of micropipette to each of Heavy metal incorporated Luria bertani Agar Plate, plate was Incubated at 24 hrs duration at 37^{o}C. After Incubation Plates were seen bacterial colonies formorphology and Cultural characteristics. The purified isolates were preserved on Luria bertani agar slopes at 4°C for another use for further examination.

Morphology and cultural characteristics: All the selected isolated colonies carefully examined for colony morphology like shape margin, surface, elevation, size, colour and opacity. Then microscopic examination Gram's staining was performed. Screening of Resistant bacterial isolates for Heavy Metal: The bacterial isolates were examined for tolerance to heavy metals (Pb, Cd, and Cr) the resistance was assessed by

developing the bacterial isolates on Luria bertani broth with different concentrations of these compounds subsequently. The Minimum Inhibitory Concentration (MIC) was also acquired for all bacterial isolate on every of the sample media in which it was determined at which

bacterial concentration there was no turbidity.

3. RESULT AND DISCUSSION

Table 1: Physiochemical parameters of effluents of textile ETP

Parameters	Result
Color	Brown
PH	6.9
Conductivity(µS/cm)	4490
Oil & Grease(mg/lit)	72.8
Hardness(mg/lit)	480
Alkalinity(mg/lit)	924
Chloride(mg/lit)	749.76
Sulphate(mg/lit)	276.94
TSS (mg/lit)	400
TDS (mg/lit)	2280
DO (mg/lit)	3.1
BOD (mg/lit)	420
COD (mg/lit)	1920
Cadmium (Cd) (ppm)	0.06
Chromium (Cr)(ppm)	BDL*
Lead (Pb) (ppm)	BDL*
Zinc (Zn) (ppm)	0.072

The textile effluent exhibited brown coloration with near-neutral pH (6.9). However, several parameters exceeded CPCB permissible limits. Oil & grease (72.8 mg/L), TSS (400 mg/L), TDS (2280 mg/L), BOD (420 mg/L), and COD (1920 mg/L) were significantly higher than the prescribed standards (10, 100, 2100, 30, and 250 mg/L respectively). DO (3.1 mg/L) was below the desirable level (≥4–5 mg/L), indicating oxygen depletion. Heavy metals such as Cadmium (0.06 ppm) also exceeded the limit (0.01 ppm), while Chromium and Lead were below detectable limits and Zinc (0.072 ppm) remained within permissible range.

Overall, the effluent quality demonstrates non-compliance with CPCB standards, reflecting high organic load, salinity, and toxic metal contamination. This highlights the inefficiency of the current ETP and the urgent need for advanced treatment measures to mitigate environmental risks.

Table 2: Morphological Characteristics of bacterial strain

Strain name	Pigment	Shape	surface	margin	Opacity
Cr-resistance	White	Small Circular	Smooth	entire, Convex	Opaque
Cd-resistance	Creamy	Small,Large Circular	Smooth, Rough	entire, Convex	Opaque
Pb-resistance	Brown	Small Circular	Smooth	entire, Convex	Opaque

The morphological analysis of metallotolerant bacterial isolates revealed distinct pigmentation and colony features associated with heavy metal resistance. The Cr-resistant strain produced white, small circular colonies with smooth surface, entire margin, convex elevation, and opaque appearance. The Cd-resistant strain exhibited creamy colonies, varying from small to large circular forms, with both smooth and rough surfaces, entire margin, convex elevation, and opaque texture, suggesting morphological diversity under cadmium stress. The Pb-resistant strain formed brown, small circular colonies with smooth surface, entire margin, convex elevation, and opaque nature.

Overall, the isolates demonstrated stable colony morphology with characteristic pigmentation linked to specific metal resistance, indicating their adaptability and potential role in bioremediation of textile effluents

Table 3: Grams staining of Heavy metals resistance strains

Heavy metals resistant strains	Gram positive strains	Gram negative strains
Chromium resistant strain (4)	++	++
Cadmium Resistant strain (08)	+++	+++++
Lead resistant strains (4)	++	++

+ Denoted as Present

Gram staining of heavy metal resistant isolates revealed the presence of both Gram-positive and Gram-negative strains across all tested metals. Chromium- and lead-resistant strains showed balanced distribution, with equal representation of Gram-positive and Gram-negative bacteria. In contrast, cadmium-resistant strains exhibited greater diversity, with a higher proportion of Gram-negative isolates compared to Gram-positive. This suggests that Gram-negative bacteria may possess enhanced tolerance mechanisms against cadmium stress, while resistance to chromium and lead appears more evenly distributed between Gram types.

Table 4: Minimum Inhibitory Concentration of Heavy metals Resistance Bacterial Culture from various Concentrations

Heavy metals	Strains	100ppm	300ppm	500ppm	600ppm	700ppm
Chromium	03	MG	SG	-	-	-
Cadmium	03	VG	DG	MG	SG	
lead	03	MG	SG	-	-	-

SG-Slight growth, MG-Moderate growth, DG- Dense growth, VG- Vigorous growth The Minimum Inhibitory Concentration (MIC) assay revealed differential tolerance of bacterial isolates to heavy metals. Chromium- and lead-resistant strains showed growth only up to 300 ppm (moderate to slight growth), with complete inhibition beyond 500 ppm, indicating limited tolerance. In contrast, cadmium-resistant strains exhibited higher resilience, sustaining vigorous to dense growth up to 300 ppm, and moderate to slight growth even at 500–600 ppm, before inhibition at 700 ppm. Overall, the results suggest that cadmium-resistant bacteria possess stronger adaptive mechanisms compared to chromium- and lead-resistant strains, highlighting their potential role in bioremediation of cadmium-contaminated effluents.

4.CONCLUSION

The study highlights the poor quality of textile effluent from Amravati, with several physicochemical parameters (oil & grease, TSS, TDS, BOD, COD, and cadmium) exceeding CPCB permissible limits, thereby confirming non-compliance and significant environmental risk. The low DO further indicate oxygen depletion, making the effluent unsuitable for aquatic ecosystems.

Isolation and characterization of metallotolerant bacterial strains revealed distinct morphological traits and pigmentation linked to specific heavy metal resistance. Gram staining confirmed the presence of both Gram-positive and Gram-negative bacteria, with cadmium-resistant strains showing greater diversity and dominance of Gram-negative forms. MIC assays demonstrated that cadmium-resistant isolates possess higher tolerance levels

compared to chromium- and lead-resistant strains, sustaining growth even at elevated concentrations.
Overall, the findings suggest that while the textile effluent poses serious ecological threats, the metallotolerant bacterial isolates particularly cadmium-resistant strains exhibit promising potential for bioremediation. Harnessing these microbial capabilities could provide an effective, eco-friendly approach to mitigate heavy metal contamination and improve effluent treatment efficiency in textile industries.

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