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Comprehensive Characterization of Textile Effluents from Tiruppur: A Strategic Outlook of Environmental Burden and Scope for Sustainable Management

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ABSTRACT

Tirupur, one of India's most prominent textile manufacturing hubs, has gained global recognition for its knitwear production. However, the region's rapid industrialization has led to severe environmental challenges, particularly concerning the generation and discharge of untreated textile effluents. These effluents, laden with a mixture of organic, inorganic, and synthetic chemical compounds, have emerged as significant pollutants affecting local water bodies and ecosystems. This study presents a detailed characterization of the textile effluents such as physical, chemical, and biological parameters of the wastewater generated from the various processing units in Tirupur and explores the environmental and health risks posed by these discharges. Using an atomic adsorption spectrophotometer (AAS), analyses showed high levels of turbidity (NTU), specific conductivity, potential hydrogen (pH), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total dissolved solids (TDS), and toxic heavy metals such as lead (Pb), nickel (Ni), chromium (Cr), and zinc (Zn). The current treatment approaches, mainly comprising conventional methods such as sedimentation and biological oxidation, are often ineffective due to the complex nature of the effluent. The findings emphasize the urgent necessity for sustainable wastewater management systems and effective policy enforcement to mitigate the ecological degradation in and around Tirupur.

Keywords: Atomic adsorption Spectrophotometer (AAS), Heavy metals, chemical oxygen demand (COD), and biochemical oxygen demand (BOD), Textile effluents, Zero liquid discharge (ZLD).

1. INTRODUCTION

Industrial wastewater has been a problem for thousands of years, starting with ancient industries like textiles and mining. As industries grew, so did the amount of wastewater, which was often released into waterways without treatment. Textile manufacturing is a cornerstone of industrial growth, but it significantly contributes to environmental degradation through the release of untreated or inadequately treated effluents. These effluents, rich in dyes, salts, heavy metals, and organic load, pose severe ecological and health risks. The global textile industry, known for its economic impact and employment generation, has also been identified as a major polluter of freshwater resources. It uses a great deal of chemicals and water, especially during dyeing and finishing (Kant, 2012). The effluents generated are not only visually polluting due to intense coloration but are also chemically complex, containing surfactants, dyes, salts, and toxic metals (Yaseen & Scholz, 2019). In developing countries, where environmental regulations are weakly enforced, untreated textile wastewater is often discharged into natural water bodies, threatening aquatic ecosystems and human health (Verma and others, 2012). Therefore, building effective treatment systems and reducing environmental concerns require a detailed understanding of the effluent properties.

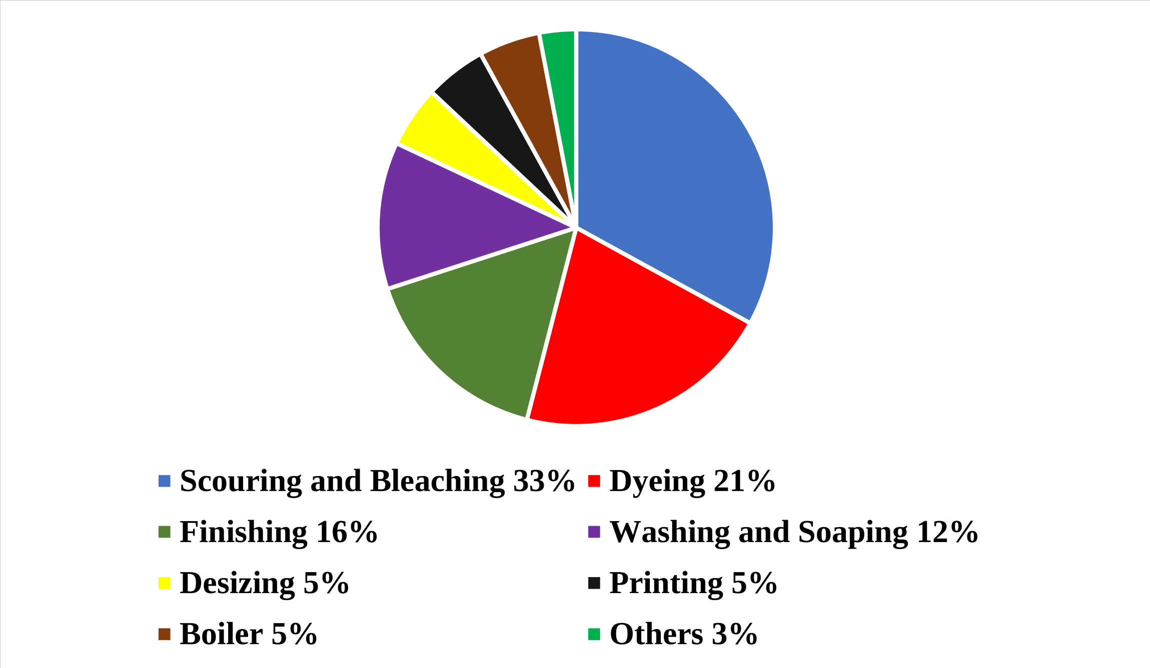

Fig. 1. Pie Chart of various sectors responsible for the discharge of textile effluent

2. SUPPLIES AND TECHNIQUES

2.1 Gathering of Samples

Erode, Namakkal and Tirupur are the textile cities for the small-, and large-scale industries in Tamil Nadu, India. Generally, the lower socio-economic industry depends on ground water for their production. These industries are completely responsible for rivers and groundwater pollution.

Effluent samples were collected from three selected dyeing and processing units with significant dyeing operations in Tirupur such as Common textile Effluent treatment plant, Polyester spinning mills and Fabric Dye printing mills. Composite samples were taken during active operational hours to reflect the typical characteristics of the effluents being discharged. To maintain sample integrity, samples were gathered in sterile, one-liter polyethylene bottles and kept at 4°C until analysis.

2.2 Study Area

For the study of this effective biosorption on textile effluent, different samples from different places were collected from Kasipalayam (11.1155ºN, 77.3850º E), V. Kallipalayam (11.068347ºN, 77.312785ºE) and, Iduvampalayam (11.0819ºN, 77.3238ºE) at Tirupur City, (11.108500°N 77.341100°E) which is bordered by the districts of Coimbatore, Erode, Karur, and Dindugul. Also, the treated dye effluents produced from the Kasipalayam are directly released into the river Noyyal.

Textile effluents from Tirupur are typically discharged after various stages of chemical processing, often without sufficient treatment. These effluents are complex in nature and contain dyes, surfactants, salts, heavy metals, and organic matter. Their uncontrolled release into water bodies like the Noyyal River has had far-reaching consequences for water quality, agriculture, and public health.

2.3 Analytical Techniques

The following parameters were analysed using standard procedures as outlined by IS 10500.

Physical Parameters: Colour, Turbidity and Temperature, Measurements of total suspended solids (TSS) were made.

Chemical Parameters: Potential hydrogen (pH), Specific conductivity was measured using a digital pH meter. Chemical oxygen demand (COD) and Biochemical oxygen d demand (BOD) were determined via dichromate oxidation and 2hrs reflux time for COD, 5-day incubation methods for BOD respectively. A digital TDS meter and a specific conductivity meter were used to test total dissolved solids (TDS) and particular conductivity. Using an atomic adsorption spectrophotometer (AAS), the presence of heavy metals (Pb, Ni, Cr, and Zn) will also be analyzed.

Biological Parameters: The Most Probable Number (MPN) method was employed to quantify coliform bacteria. Dissolved oxygen (DO) levels and microbial activity were assessed to evaluate biological impact.

Atomic Absorption Spectrophotometer

To identify an extensive number of metals, atomic absorption spectroscopy (AAS) is a widely utilized procedure. The most well-known application of AAS involves aspirating a fluid specimen containing the metals to be analyzed into an air-acetylene fire, which causes the solvent to evaporate and the free metal particles to vaporize. We call this process atomization. In the analyses, to decide a particular metal in a textile industrial effluent, AAS along with use of fire atomization will be utilized. Measurement of variable metals in the sample can be easily carried out using a spectrometer equipped with a lamp turret.

Standard parameters of wavelength for toxic metals

Metals	Wavelength of Adsorption (nm)	Ideal Bandpass for Spectra (nm)	Stoichiometry of Flames	Current of the Lamp (Ma)	Ideal operating range (ppm)	The requisite stock solution
Pb	283.3	1.0	Fuel-rich, Stoichiometric,	10-12	0.5-2.0	50ml of 100ppm

			and lean flames			
Ni	232.0	0.5	Fuel-rich	4-10	1-10	50ml of 100ppm
Cr	582	0.1	Fuel-rich	10-15	0.1-10	100ml of 100ppm
Zn	213.9	0.5	Fuel-rich, Stoichiometric, and lean flames	4-10	0.1-2.0	100ml of 100ppm

Characteristics of Textile Wastewater

Sl no	Specifications	Concentrations			Desirable Limits of IS 10500
		Specimen 1	Specimen 2	Specimen 3	
1.	pH	10.53	8.81	9.08	6.5-8.5
2.	Specific Conductivity (milli/mho)	495	576	975	Not Applicable
3.	Turbidity (NTU)	64.6	9	0	1
4.	Colour	Beige	Green	Dark Blue	Not Applicable
5.	Total Solids (mg/l)	2600	9400	2000	500
6.	Total Suspended Solids (mg/l)	6300	6500	2400	500
7.	Total Dissolved Solids (mg/l)	490	940	810	100
8.	BOD (mg/l)	1950	650	870	30
9.	COD (mg/l)	1088	5480	4680	250
10.	Lead	2.4	3.8	4.5	0.01
11.	Nickel	1.55	1.42	2.36	0.02
12.	Chromium	0.18	0.51	0.22	0.05
13.	Zinc	6.23	7.36	8.59	5

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics

Colour: Effluents were typically Beige, Green and Dark Blue in colour, with huge ranging from dark colours depending on the type of dyes used. This indicates the presence of insoluble particles and dyes (Forgacs et al., 2004).

Turbidity (NTU): High turbidity (NTU) levels were observed, as 64.6, 9 and 0, indicating a significant presence of undissolved solids.

Temperature: The Temperature levels were consistently above ambient levels, sometimes reaching 40–45°C due to steam-based operations.

Total Suspended Solids (TSS): On the other hand, the TSS (mg/l) values were 6300, 6500, and 2400, respectively.

3.2 Chemical Characteristics

The chemical analysis revealed the following:

Potential Hydrogen (pH): The pH values ranged between 10.53, 8.81 and, 9.08, highlighting the presence of alkaline discharges from various stages such as desizing and dyeing.

Total Dissolved Solids (TDS) and Specific Conductivity: TDS (mg/l) levels exceeded 490, 940, 810 mg/L from the collected samples, largely due to sodium chloride and sodium sulphate used in dye baths. TDS values reached up more than its limits shows a significant load of dissolved inorganic salts (Khandegar & Saroha, 2013).

Electrical conductivity: The Specific Electric Conductivity was found to be over 495, 576 and 975 in most cases, indicating a high ionic load.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD): Both biodegradable and non-biodegradable organic matter were indicated by the ranges of the chemical oxygen demand (COD) and biochemical oxygen demand (BOD) measurements, which were between 1088, 5480, and 4680 mg/L and 1950, 650, and 870 mg/L, respectively. The high COD/BOD ratio implies a predominance of synthetic and complex compounds in the wastewater.

Heavy Metals: Significant concentrations of lead (Pb), nickel (Ni), chromium (Cr), and zinc (Zn) were found in some samples. These were ascribed to dye-fixing agents and catalysts used in printing processes. The concentrations of lead (Pb) were 2.4, 3.8, and 4.5; those of nickel (Ni) were 1.55, 1.42, and 2.36; those of chromium (Cr) were 0.18, 0.51, and 0.22; and those of zinc (Zn) were 6.23, 7.36, and 8.59. These were exceeded its limits, surpassing the recommended discharge limits.

3.3 Biological Characteristics

Low dissolved oxygen levels were consistently recorded, sometimes dropping below 1 mg/L. Such low DO levels can severely affect aquatic ecosystems. Microbial analysis indicated the presence of pathogenic bacteria, especially in effluents that were mixed with domestic sewage, posing serious public health risks. Low DO levels (1.2–2.5 mg/L) and high BOD/COD ratios indicated a substantial presence of biodegradable organic matter. MPN tests confirmed faecal coliform contamination, likely from cross-contamination in mixed industrial zones (Khatiwada et al., 2015).

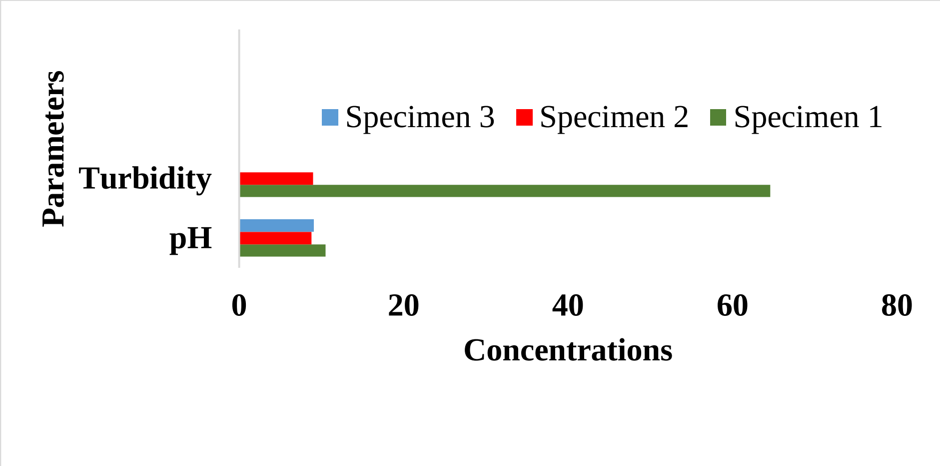

Fig. 2. Visual Display of Parameters Against Turbidity and pH Concentrations

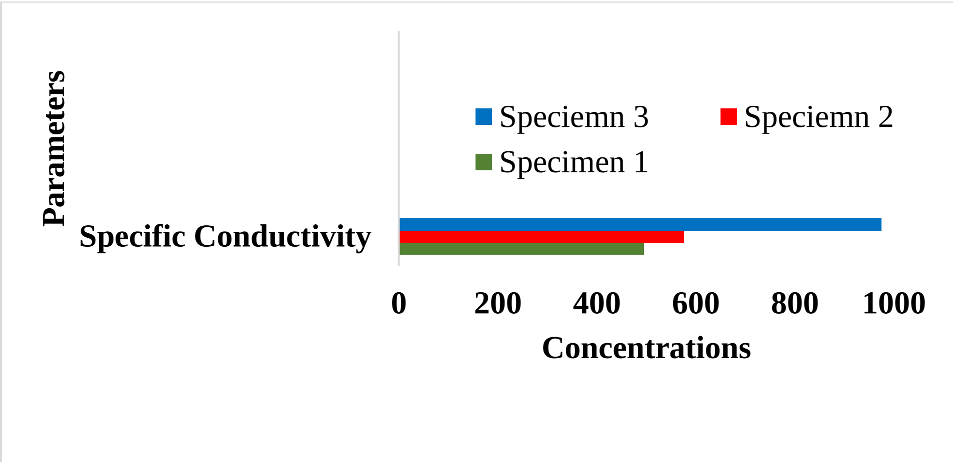

Fig. 3. Visual Display of Parameters Against Specific Conductivity Concentrations

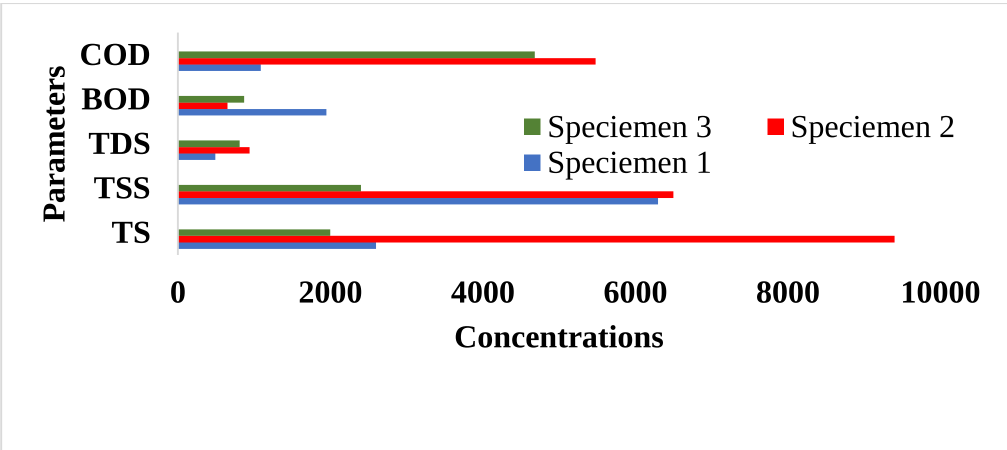

Fig. 4. Visual Display of Parameters Against Concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Solids (TS), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS)

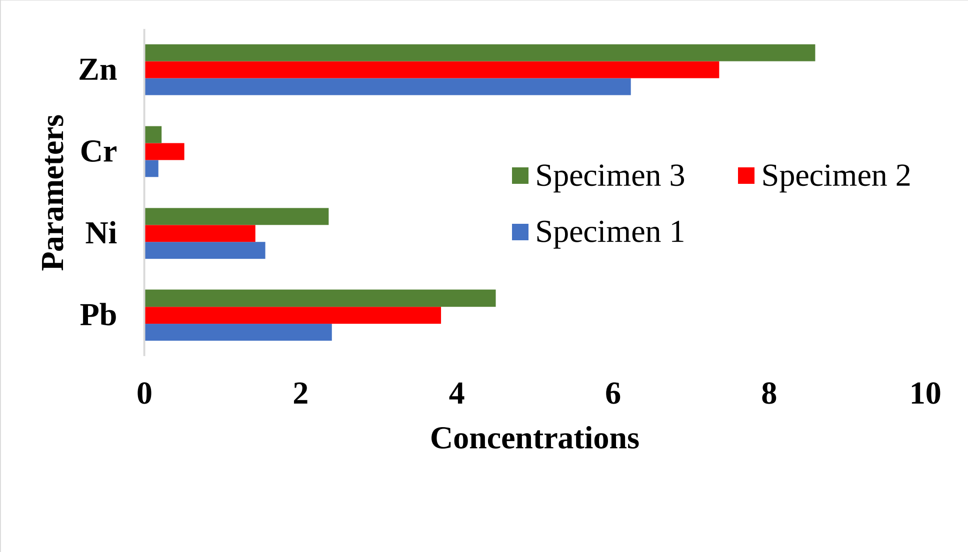

Fig.5. Visual Display of Parameters Against Concentrations of Metal elements- Lead (Pb), Nickel (Ni), Chromium (Cr), and Zinc (Zn)

3.4 Environmental and Health Implications

Numerous environmental problems have resulted from the release of untreated textile effluents into the Noyyal River and the nearby land areas:

Water Pollution: Salts, dyes, and metals have contaminated surface and groundwater supplies, making them unsuitable for irrigation and drinking.

Soil Degradation: Prolonged exposure to effluent-contaminated water has led to increased soil salinity, reduced fertility, and decreased agricultural productivity.

Biodiversity Loss: Aquatic life in the Noyyal River has been severely affected due to oxygen depletion and toxicity caused by heavy metals and synthetic dyes.

Human Health Risks: Communities using contaminated water have reported skin diseases, gastrointestinal infections, and respiratory ailments.

3.5 Current Treatment Practices and Limitations

Tirupur was among the first industrial clusters in India to implement Zero Liquid Discharge (ZLD) systems. While several units have installed Common Effluent Treatment Plants (CETPs), there are still challenges related to high operational costs, inconsistent performance, and non-compliance by smaller units. Many units bypass ZLD protocols to reduce operational costs, leading to continued pollution. Current Treatment Practices and Limitations

Primary and secondary treatment techniques include sedimentation, neutralization, and activated sludge procedures are primarily used in the textile industry. While these systems are cost-effective, they are insufficient for removing non-biodegradable dyes, surfactants, and heavy metals (Holkar et al., 2016).

Key limitations include:

- ❖ Inefficiency against recalcitrant compounds
- ❖ Generation of secondary sludge
- ❖ Operational and maintenance challenges
- ❖ Inadequate removal of colour and toxicity
- ❖ These issues underline the need for more robust, adaptable, and integrated treatment systems.

3.6 Recommendations and Future Scope

- ❖ **Technological Upgradation:** Utilizing specific microbial consortia to adopt cutting-edge treatment technologies such membrane filtration, electrochemical oxidation, and biodegradation.
- ❖ **Policy Enforcement:** Strengthening monitoring mechanisms and imposing stricter penalties for non-compliance.
- ❖ **Capacity Building:** Supplying small and medium-sized businesses (SMEs) with financial assistance and training to help them implement sustainable practices.
- ❖ **Public Awareness:** Educating stakeholders in the sector and nearby communities about the dangers untreated effluents have to human health and the environment.
- ❖ **Advanced Treatment Technologies:** High removal efficiency for dissolved pollutants are provided by membrane filtration systems, like as reverse osmosis and nanofiltration, which are examples of advanced treatment. Advanced Oxidation Processes (AOPs) using ozone, UV/H_2O_2, or Fenton's reagent can effectively degrade persistent organic compounds (Mahmoodi et al., 2006). Constructed wetlands and phytoremediation offer eco-friendly, sustainable alternatives for long-term management (Ali et al., 2013).
- ❖ **Policy and Monitoring Enhancements:** Stricter enforcement of effluent discharge standards, Real-time monitoring systems for effluent quality, Incentives for industries to adopt zero-liquid-discharge (ZLD) systems

Future Scope for Research Needs

- ❖ Development of low-cost biosorbents and catalysts
- ❖ Pilot-scale testing of hybrid systems
- ❖ Studies on the fate of micropollutants and antibiotic residues in effluents

4. CONCLUSION

The environment and public health are seriously threatened by the complex mixture of physical, chemical, and biological pollutants found in Tirupur's textile effluents. Even with the implementation of ZLD technologies and regulatory frameworks, the region still faces difficulties managing its wastewater. A coordinated approach involving technological innovation, regulatory enforcement, and community engagement is essential to achieve sustainable textile production and environmental conservation in Tirupur.

The characterization of textile effluent reveals a complex mixture of physical, chemical, and biological pollutants. Elevated pH, Turbidity, TS, TDS, TSS, COD, BOD, and toxic metal concentrations indicate a high pollution load, while conventional treatment systems fall short in handling these challenges. To reduce the risks to the environment and public health posed by textile wastewater, advanced treatment techniques must be combined with sustainable practices and robust regulatory frameworks. This study emphasizes how crucial novel treatment technology and effluent monitoring are to attaining sustainable industrial development.

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