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# Seasonal Variations in the Microbial and Physico-Chemical Properties of Soil in Tiruppathur District, Tamil Nadu, India

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**This study investigates seasonal variations in the microbial and physico-chemical properties of soil in the Ambur, Vaniyambadi, and Pernambut taluks, regions in Tiruppathur District, India impacted by tannery effluents. Soil samples, collected during both the wet and dry seasons of 2021, were analysed for microbial contamination and key physico-chemical factors. The microbial analysis detected Escherichia coli, Staphylococcus spp., Klebsiella pneumoniae, Bacillus cereus, and Pseudomonas aeruginosa, with higher microbial counts observed in the wet season, likely due to runoff from tannery waste. Physico-chemical analysis showed slightly alkaline soil (pH 6.81 to 8.91), with more pronounced alkalinity in the dry season. Electrical conductivity (EC) ranged from 2297.3 μS/cm to 4300 μS/cm, peaking in the dry season due to the concentration of salts from evaporation. Elevated levels of phosphorus, calcium carbonate, and heavy metals such as chromium, lead, zinc, and nickel were detected, particularly in the dry season. These findings indicate significant soil contamination from tannery effluents, leading to soil degradation and posing potential risks to both the environment and public health. The study highlights the urgent need for effective waste management and treatment to mitigate the adverse effects of tannery effluents on soil and surrounding ecosystems. Seasonal variations further emphasize the importance of targeted measures to reduce contamination, especially during the dry season. Future research should focus on sustainable waste disposal solutions and evaluate the long-term ecological impacts of tannery-related pollution.**

**Keywords:** Heavy metals; Physico-chemical analysis; Tannery effluent; Soil contamination.

Soil contamination, particularly by industrial effluence, is a significant environmental challenge that adversely affects the soil quality, agricultural productivity and human health. One of the primary sources of soil pollution is the leather industry, which generated large quantity of wastes in the form of tannery effluents. These effluents, often rich in heavy metals, salts and other toxic heavy metals, can drastically alter the physical and chemical properties of the soil, leading to long term degradation of the environment. In regions with a high concentration of turning units such as Ambur, Vaniyambadi and Peranambut taluks in Tiruppathur District, Tamil Nadu. The surrounding soils are particularly vulnerable to contaminations, leading to elevated levels of hazardous substance that threaten local ecosystems and communities. Despite regulations, effluent treatment in Tiruppathur is inadequate, with many tanneries not complying with norms. Efforts to

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improve wastewater treatment technologies are slow, emphasizing the need for technological solutions and stricter enforcement of environmental regulations to address the impact of tannery effluents on the region. Tamilnadu Pollution Control Board reports over 20 million liters of untreated effluents are released daily, causing widespread water pollution and ecosystem degradation.[1-4]

The leather industry, particularly the tanneries in Tiruppathur District, Tamil Nadu, plays a crucial part in the local economy. However, it faces environmental concerns due to the release of waste. The effluents produced by tanneries contain hazardous elements like chromium, organic compounds, and various chemicals, posing a risk of contaminating soil and groundwater[5,6] Evaluating soil contamination caused by tannery waste relies significantly on the physicochemical characteristics of the soil. Key parameters for this assessment encompass pH levels, electrical conductivity, the presence of organic materials, and levels of contaminants like chromium, frequently employed in the leather tanning industry. [7,8] In polluted environments, such as those affected by industrial activities like tannery operations, physicochemical parameters serve as indicators of contamination levels and potential ecological impacts. These parameters include pH, electrical conductivity, organic matter content, and concentrations of pollutants like heavy metals and organic compounds. For instance, in soils contaminated by tannery effluents, high levels of heavy metals such as chromium can alter soil pH and microbial activity, thereby influencing nutrient cycling and plant growth[9].

Microbiological parameters, on the other hand, focus on microbial communities in the environment. Microorganisms play crucial roles in biogeochemical cycles, soil fertility, and the degradation of organic pollutants. In polluted soils, microbial diversity, biomass, and enzymatic activities can be significantly affected by the existence of contaminants, leading to shifts in community structure and function.[9] The presence of tannery effluent contamination can influence various microbiological aspects like microbial diversity, biomass, and enzymatic activities. Research indicates changes in both the composition and functions of microbial communities in tainted soils, potentially influencing soil quality and the cycling of nutrients.[10] Various accurate scientific methodologies are at our disposal to reduce or eliminate substances in the soil that might exceed acceptable levels. Bioremediation, an environmentally friendly approach, relies on natural processes to decrease pollutant levels by either eliminating or transforming pollutants into a harmless state [11]. Comprehending these factors is crucial for successful environmental control and clean-up plans in regions impacted by tanneries, such as Tiruppathur District. This research seeks to offer a thorough examination of the physical, chemical, and biological aspects of soil contaminated by tannery waste near Tiruppathur District.

The findings of this study will not only contribute to a better understanding of the local pollution dynamics but also offer insights into potential sustainable solutions that could be implemented in other tannery hubs across India. The aim of the paper is to investigate seasonal variations in soil physico-chemical properties and contamination by tannery effluents in Ambur, Vaniyambadi, and Pernambut taluks in Tiruppathur District, India.

## MATERIAL AND METHODS

### Study area

Tiruppathur District, Ambur (20 samples), Vaniyambadi (20 samples) and Pernambut (10 samples) are leather industries in southern India. Tiruppathur is connected with major cities in the states of Tamil Nadu and Andhra Pradesh, two Revenue Divisions, four Taluks, and fifteen Revenue Firkas (latitude: 12.4950° N, 78.5678° E). The soil samples near the tannery were collected from Marapattu, Vadacheri, Kachirapet, Alankuppam, Chinnavarigam, Somalapuram, Solur, Thuttipattu, Devalapuram, and Samanthikuppum in Tiruppatur district. These sites were selected due to their closeness to tannery waste-water discharge locations, water bodies, and farmland, facilitating an evaluation of the spatial spread of contaminants from tannery discharges.

### Collection of Soil samples

Soil samples (50 samples/500 g) for this study were collected from several sites near tannery areas in Ambur taluk (2020), Vaniyambadi taluk

(2021), and Pernambut taluk (2022), during both the wet and dry seasons. The sampling locations were selected based on their proximity to tannery effluents, ensuring a thorough assessment of the contamination across different sites in these regions. Soil samples were taken at a depth of 5 to 10 cm and placed into sterile, labelled Polythene bags, to prevent contamination and to preserve soil properties. The samples were then brought to the laboratory in coolers filled with ice to undergo microbiological and physicochemical analyses. Soil samples were allowed to air dry before being sieved through a 20 mm sieve for chemical analysis as per the standard procedure of the American Public Health Association.[12]

**Physico- Chemical characterization of tannery effluent**

The effluent's physico-chemical characteristics, such as pH, electrical conductivity (EC), phosphorous, nitrate, sulfates, and chlorides, were determined as per the standards prescribed by the Bureau of Indian Standards (BIS). The pH and conductivity levels were assessed at 25°C by utilizing a pH and conductivity meter following the standard procedures outlined in APHA.[13] Phosphorous levels were assessed utilizing the molybdo-vanado phosphoric acid technique as outlined in ASTM D 515, employing a UV-visible spectrophotometer to measure absorbance at 400 nm relative to a blank solution. Chromium ($Cr^{3+}$) was quantified following the ASTM D1687 protocol. Nitrite ($NO_2$) and nitrate ($NO_3$) were quantified using a colorimetric technique with a UV-visible spectrophotometer in an acidic pH range of 2.0 –2.5, with absorbance readings taken at 543 nm for $NO_2$ and 220 nm for $NO_3$. Chloride (Cl) content was determined through a silver nitrate titration method utilizing potassium chromate as an indicator as per APHA-AWWA-WPCF (1989) guidelines. Sulfate ($SO_4^{2-}$) levels were determined by assessing the absorbance at 420 nm using a UV-visible spectrophotometer post-formation of a $BaSO_4$ precipitate in a medium of $CH_3COOH$ with $BaCl_2$.

**Soil sample digestion**

The soil samples containing Cr, Pb, Cd, and Zn were quantitatively analysed by following the ISO 11466 thermal heating methods. Initially, 5 g of crushed soil samples were weighed and placed in clean 100-ml glass beakers. Subsequently, the samples were moistened with 2 ml of deionized water. The addition of 24 ml of HCl and 8 ml of $HNO_3$ followed, along with 18 ml of diluted $HNO_3$ (0.5 M) to each beaker. The beakers were then left at room temperature (27–300 °C). Later, each mixture was refluxed on a heating plate for 2 hours, cooled, filtered through Whitman No. 42 filter paper, and stored at room temperature for later analysis.

**Heavy Metals**

Following the digestion of soil samples, the metals chromium (Cr), lead (Pb), cadmium (Cd), and zinc (Zn) were examined using a flame atomic absorption spectrometer (FAAS, Model Varian Spectra A240) at the Technology Business Incubator Lab, Department of Science and Technology, VIT University in Vellore, Tamil Nadu. A specific hollow cathode lamp for each metal was utilized: Cd (Wavelength 228.8 nm), Cr (Wavelength 357.9 nm), Pb (Wavelength 283.3 nm), and Zn (Wavelength 213.9 nm). The instrument has a minimal detection limit of 0.01 mg/L for Cd, 0.10 mg/L for Cr, 0.20 mg/L for Pb, and 0.01 mg/L for Zn in the flame method. Samples were nebulized, and their absorbance was measured against a blank solution (deionized water). Standard samples with varying concentrations were used to generate a calibration curve for each metal.

**Microbiological Analysis of the Soil Sample**

The samples underwent soil microbiological testing following the procedures outlined by Rabah and Oyeleke.[14,15] To identify and characterize the bacterial isolates, standard Biochemical tests were employed, as detailed by Cheesebrough, (2006).[16] These tests involved gram staining, motility assessment, catalase and oxidase tests, as well as examinations for methyl red nitrate, Voges-Proskaeur indole production, urease activity, and citrate utilization.

**Statistical Analysis**

The statistical analysis involved measuring the mean and standard deviation for all the data.

## RESULTS AND DISCUSSION

**Physico-Chemical Properties of Soil Samples**

The physico-chemical properties of soil samples collected from tannery areas in Ambur taluk during the wet and dry seasons of 2020

**Table 1.** Seasonal variation of the Physico–chemical analysis of soil samples collected near tanneries in Ambur taluk tanneries during wet season in the year 2020

| No. | Parameters | Soil samples collected sites near tannery areas in Ambur Taluk | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 |
| 1 | pH at 25° C | 8.13±0.03 | 7.65±0.13 | 8.60±0.05 | 7.54±0.05 | 8.21±0.07 | 7.75±0.17 | 8.09±0.08 | 8.34±0.04 | 7.90±0.02 | 7.55±0.05 |
| 2 | Conductivity | 1301.03±1.89 | 1750.75±0.96 | 2300±0.58 | 2400.75±0.6 | 1950±0.96 | 1600.75±0.0 | 1851.50±0.9 | 2400.25±0.5 | 2201±1.89 | 1800±0.50 |
| 3 | Organic P | 17.47±0.35 | 12.33±0.31 | 18.43±0.42 | 16.33±0.51 | 13.50±0.40 | 15.47±0.51 | 12.57±0.32 | 13.53±0.21 | 17.40±0.26 | 16.50±0.35 |
| 4 | Inorganic P | 17.47±0.35 | 12.33±1.50 | 28,25±0.50 | 23±0.82 | 28,25±0.96 | 24±0.82 | 26±0.82 | 25±0.82 | 25.75±1.50 | 23.25±0.96 |
| 5 | Chloride | 1931±0.82 | 2345.25±0.96 | 2270.75+0.96 | 1214.25±0.96 | 1874.75±29 | 1690.7±0.95 | 2461±1,15 | 2121±1.4 | 1924.25±0.95 | 1893.5±1.2 |
| 6 | Nitrate | 312.25±00.96 | 302.25±0.50 | 290.25±0.50 | 221±0.82 | 317.25±0.50 | 295.75±0.96 | 310±0.82 | 343.5±1,91 | 256±1.41 | 287.25±1.26 |
| 7 | Sulphate | 325.75±0.96 | 390±0.82 | 428.25±0.96 | 442.25±0.96 | 537±0.82 | 320.75±0.96 | 298.25±0.50 | 395±0.98 | 433.25±0.96 | 456.75±0.95 |
| 8 | Ca | 561.3±1,15 | 485.7±0.57 | 472.7±0.58 | 390±0.71 | 485±0.58 | 470±1.00 | 564.7±0.58 | 583.5±0.71 | 648.5±0.71 | 466±1.00 |
| 9 | Mg | 167.5±0.70 | 202.9±0.90 | 196.33±0.57 | 140±0.00 | 213.33±0.57 | 230.83±0.28 | 297±1.00 | 360±0.00 | 294.5±0.70 | 324±0.28 |
| 10 | F | 295±0.70 | 233.4±0.5 | 337.43±0.53 | 214.0.00 | 304.33±0.56 | 277.16±1.60 | 345.33±0.58 | 397.53±0.50 | 321.53±0.28 | 310.16±0.28 |
| 11 | Cr | 152.90±0.17 | 126.77±0.40 | 127±0.00 | 125.77±0.40 | 132.3+0.5 | 143.33±0.33 | 158.77±0.40 | 145±0.00 | 138.16±0.28 | 141.16±0.28 |
| 12 | Pb | 29.25±0.50 | 29.5±1.2 | 29.15±0.70 | 45.25±0.96 | 22±0.00 | 30.63±0.40 | 35.25±0.96 | 24.15±0.70 | 43.14±0.33 | 47.19±0.01 |
| 13 | Cd | 1.84±0.02 | 1.85±0.00 | 1.84±0.02 | 1.67±0.03 | 1.95±0.01 | 1.85±0.00 | 1.72±0.02 | 1.97±0.05 | 1.72±0.01 | 1.63±0.57 |
| 14 | Fe | 46.47±0.45 | 46.50±0.25 | 46.5±0.25 | 55.2±0.97 | 67.1±0.75 | 48.3±0.70 | 53.9±0.01 | 56.6±0.45 | 44.5±0.25 | 67.9±0.01 |
| 15 | Co | 3.64±0.01 | 3.65±0.00 | 3.65±0.05 | 2.18±0.02 | 3.27±0.03 | 2.83±0.04 | 3.16±0.04 | 3.37±0.05 | 2.15±0.70 | 3.72±0.02 |
| 16 | Mn | 5.12±0.70 | 5.12±0.00 | 5.12±0.60 | 3.85±0.00 | 4.69±0.01 | 4.32±0.08 | 5.32±0.06 | 4.52±0.07 | 5.37±0.03 | 3.49±0.00 |
| 17 | Ni | 9.85±0.01 | 9.85±0.01 | 9.85±0.01 | 17.77±0.40 | 8.95±0.01 | 19.25±0.50 | 15.25±0.50 | 19.47±0.45 | 10.18±0.02 | 9.05±0.01 |
| 18 | Cu | 23.10±0.01 | 23.10±0.01 | 23.10±0.01 | 27.65±0.05 | 24.80±0.02 | 30.11±0.08 | 29.30±0.06 | 19.23±0.01 | 29.76±0.03 | 30.24±0.01 |
| 19 | Zn | 79.50±0.01 | 79.50±0.01 | 79.50±0.01 | 81.56±0.04 | 73.21±0.03 | 79.77±0.40 | 65.50±0.35 | 73.90±0.01 | 62.76±0.03 | 80.22±0.01 |
| 20 | Al | 18.7±0.01 | 18.7±0.01 | 18.7±0.01 | 26.8±0.02 | 29.3±0.01 | 20.1±0.04 | 17.3±0.01 | 16.18±0.02 | 25.68±0.01 | 18.20±0.02 |

A1 - Solur, A2 - Thuttipet, A3 - Kommerswaram, A4 - Chinnvarikam, A5 - Periavarikam, A6 - Santorkuppam, A7, A8 - Alankuppam, A9, A10 - Devalapuram
All the value are presented Mean ±SD.

**Table 2.** Seasonal variation of the Physico-chemical analysis of soil samples collected near tanneries in Ambur taluk tanneries during dry season in the year 2020

| S.No | Parameters | Soil samples collected sites near tannery areas in Ambur Taluk | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A11 | A12 | A13 | A14 | A15 | A16 | A17 | A18 | A19 | A20 |
| 1 | pH at 25° C | 8.90±0.03 | 8.65±0.13 | 7.60±0.05 | 6.45±0.06 | 7.90±0.01 | 7.80±0.0 | 8.10±0.01 | 7.75±0.02 | 7.50±0.02 | 7.10±0.01 |
| 2 | Conductivity | 2450.03±0.90 | 1950.75±0.96 | 2700±0.58 | 3250.50±0.02 | 2950±0.96 | 5600.75±0.0 | 3551.50±0.8 | 4800.25±0.5 | 3450±0.02 | 5250±0.02 |
| 3 | Organic P | 10.17±0.35 | 11.36±0.32 | 13.43±0.42 | 19.33±0.51 | 15.50±0.01 | 12.47±0.51 | 15.91±0.02 | 21.35±0.25 | 18.72±0.02 | 17.50±0.35 |
| 4 | Inorganic P | 20.55±0.35 | 33.33±0.50 | 28,25±0.50 | 26±0.01 | 30.95±0.01 | 34±0.82 | 25.96±0.22 | 25.85±0.57 | 32.16±0.03 | 27.49±0.01 |
| 5 | Chloride | 1295±0.82 | 1345.25±0.96 | 2296.55+0.96 | 2075.25±0.96 | 1490.75±29 | 1927.7±0.59 | 1235±1,15 | 1837±0.04 | 2178±0.02 | 2881.5±0.01 |
| 6 | Nitrate | 185.25±00.96 | 208.25±0.50 | 195.25±0.50 | 297±0.82 | 313.25±0.50 | 215.75±0.96 | 224±0.82 | 159±1,0.02 | 195±0.01 | 236±0.26 |
| 7 | Sulphate | 445.75±0.96 | 314±0.82 | 427.25±0.96 | 325.25±0.96 | 459±0.82 | 283.75±0.96 | 237.25±0.50 | 322±0.97 | 246.25±0.96 | 351.75±0.95 |
| 8 | Ca | 865.3±1,15 | 726.7±0.57 | 634.7±0.58 | 791±0.71 | 684±0.58 | 972±0.01 | 621.7±0.58 | 765±0.01 | 592±0.71 | 845±1.00 |
| 9 | Mg | 165.5±0.02 | 202.9±0.90 | 196.33±0.57 | 140±0.00 | 213.33±0.57 | 230.83±0.28 | 297±1.00 | 360±0.00 | 295.5±0.01 | 327.01±0.02 |
| 10 | F | 385±0.70 | 437.4±0.5 | 238.43±0.53 | 447.0±.0.01 | 315.33±0.50 | 285±0.02 | 436.35±0.02 | 376.25±0.50 | 415.53±0.28 | 349.06±0.01 |
| 11 | Cr | 146.3±0.01 | 151.8±0.20 | 134±0.00 | 161.45±0.02 | 139.3±0.05 | 136.33±0.33 | 141.5±0.02 | 154.7±0.00 | 145.3±0.20 | 168.16±0.28 |
| 12 | Pb | 29.25±0.50 | 41.5±0.03 | 37.9±0.01 | 52.1±0.20 | 48.2±0.01 | 25.9±0.02 | 32.25±0.96 | 41.15±0.70 | 25.14±0.33 | 32.19±0.01 |
| 13 | Cd | 1.65±0.02 | 2.85±0.00 | 3.18±0.02 | 3.14±0.02 | 1.16±0.06 | 2.53±0.01 | 1.27±0.02 | 3.72±0.02 | 2.31±0.02 | 2.63±0.57 |
| 14 | Fe | 45.53±0.45 | 62.50±0.25 | 57.5±0.25 | 39.64±0.02 | 42.1±0.75 | 51.3±0.70 | 46.9±0.01 | 33.25±0.50 | 42.18±0.20 | 37.9±0.01 |
| 15 | Co | 1.64±0.01 | 2.85±0.00 | 3.19±0.05 | 1.18±0.02 | 2.57±0.03 | 1.28±0.04 | 3.76±0.02 | 2.37±0.05 | 2.35±0.70 | 2.72±0.02 |
| 16 | Mn | 8.77±0.58 | 6.52±0.00 | 7.92±0.60 | 5.25±0.01 | 8.35±0.02 | 10.32±0.08 | 11.82±0.03 | 9.11±0.07 | 9.56±0.01 | 10.17±0.01 |
| 17 | Ni | 12.45±0.02 | 18.85±0.01 | 19.85±0.01 | 12.77±0.40 | 8.35±0.02 | 9.56±0.96 | 9.25±0.50 | 11.47±0.45 | 12.27±0.01 | 13.45±0.02 |
| 18 | Cu | 32.93±0.01 | 27.10±0.01 | 43.09±0.02 | 38.25±0.50 | 46.30±0.02 | 43.15±0.02 | 30.48±0.04 | 45.83±0.03 | 43.85±0.01 | 31.42±0.02 |
| 19 | Zn | 59.75±0.96 | 44.85±0.02 | 35.97±0.0 | 52.52±0.50 | 48.30±0.02 | 45.17±0.01 | 23.56±0.02 | 32.83±0.03 | 21.67±0.04 | 37.60±0.04 |
| 20 | Al | 17.78±0.01 | 28.7±0.01 | 19.3±0.01 | 25.91±0.02 | 16.84±0.01 | 10.15±0.04 | 22.17±0.01 | 18.92±0.01 | 23.58±0.02 | 13.64±0.01 |

A11 - Solur, A12 - Thuttipet, A13 - Kommerswaram, A14 - Chinnvarikam, A15 - Periavarikam, A16 - Santorkuppam, A17, A18 - Alankuppam, A19, A20 - Devalapuram
All the value are presented Mean ±SD.

**Table 3.** Seasonal variation of the Physico - chemical analysis of Soil samples collected sites near tanneries in Vaniyambadi taluk during wet season in the year 2021
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| S.No | Parameters | Soil samples collected sites near tannery areas in Vaniyambadi Taluk | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 |
| 1 | pH at 25° C | 8.14±0.04 | 7.63±0.15 | 8.73±0.20 | 7.41±0.08 | 8.26±0.25 | 7.46±0.3 | 7.9±0.1 | 7.81±0.01 | 8.25±0.21 | 8.23±0.3 |
| 2 | Conductivity | 3442.6±1.2 | 3820±0.04 | 2968±0.5 | 2798.3±0.6 | 3752.6±0.4 | 2297.3±6.4 | 2750±6.4 | 3165±108 | 3454.3±9.2 | 3885.6±26.5 |
| 3 | Organic P | 17.45±0.5 | 19.28±0.9 | 14.1±0.18 | 16.23±0.3 | 20.19±0.28 | 16.2±0.4 | 15.03±0.47 | 16.07±1.8 | 17.3±0.4 | 18.07±0.20 |
| 4 | Inorganic P | 38.33±0.37 | 20.48±0.37 | 38.1±0.33 | 27.3±0.54 | 34.86±0.79 | 16.36±0.41 | 14.04±0.2 | 13.36±0.44 | 17.09±0.16 | 15.29±0.31 |
| 5 | Chloride | 1832.3±2.5 | 1364.6±4.5 | 1551.3±1.5 | 1722.6±2.5 | 1854±4.5 | 1930±2 | 2354.3±8.1 | 2268.6±3.2 | 1212±2.6 | 1874.6±4.1 |
| 6 | Nitrate | 293.6±4.1 | 188±2.6 | 279.3±4.04 | 282.6± | 196.6±1.5 | 232±2.6 | 300.3±1.5 | 299±1 | 322.6±3.05 | 315.6±1.5 |
| 7 | Sulphate | 453.3±3.05 | 520.6±6.02 | 432.66±6.8 | 532.6±2.5 | 381.6±2.08 | 247.3±0.5 | 232.3±2.5 | 324.6±4.5 | 242.6±2.5 | 436±5.5 |
| 8 | Ca | 776.6±10 | 730.33±4.5 | 678.33±7.6 | 594±3.6 | 654.33±4.04 | 764.33±4.04 | 860±0.01 | 734.33±4.04 | 931±1 | 833.66±3.2 |
| 9 | Mg | 135.33±2.5 | 226.33±1.5 | 144.33±4.4 | 277±3.6 | 263.3±3.2 | 191±2.6 | 188.6±1.5 | 193.3±5.5 | 538.6±4.1 | 307.6±6.8 |
| 10 | F | 267.6±2.5 | 484.6±5.8 | 277.3±9.2 | 339±4.3 | 346±4.5 | 374.6±13.05 | 326.6±9.07 | 234±4.5 | 140.3±1.5 | 116.3±2.5 |
| 11 | Cr | 184.4±0.4 | 164.7±1.3 | 157.5±.3 | 143.4±3 | 138.8±0.7 | 35.32±0.5 | 44.09±0.2 | 41.37±0.4 | 32.25±0.3 | 37.05±0.5 |
| 12 | Pb | 38.06±0.19 | 45.26±0.3 | 36.31±0.4 | 28.06±0.1 | 42.17±0.2 | 59.61±0.15 | 52.80.43± | 48.64±0.38 | 52.04±0.09 | 45.08±0.25 |
| 13 | Cd | 0.856±0.85 | 1.12±1.07 | 0.79±0.7 | 1.08±1.07 | 0.869±0.8 | 1.29±1.3 | 1.8±1.8 | 1.22±1.2 | 1.78±1.39 | 1.24±1.24 |
| 14 | Fe | 45.59±0.39 | 56.11±0.13 | 48.2±0.29 | 40.5±0.45 | 54.3±0.38 | 83.4±0.46 | 76.09±0.11 | 65.36±0.36 | 83.36±0.48 | 94.00± 0.20 |
| 0.15 | Co | 1.82±0.03 | 1.21±0.05 | 2.58±0.42 | 2.54±0.34 | 1.23±0.07 | 1.48±0.22 | 1.79±0.08 | 2.12±0.10 | 3.04±0.08 | 3.45±0.20 |
| 16 | Mn | 6.41±0.06 | 7.52±0.03 | 8.59±0.05 | 6.66±0.07 | 5.62±0.19 | 9.56±0.31 | 10.23±0.12 | 9.05±0.09 | 10.15±0.15 | 9.18±0.19 |
| 17 | Ni | 12.11±0.20 | 18.5±0.3 | 13.3±0.4 | 14.36±0.29 | 17.23±0.26 | 3.11±0.08 | 3.01±0.10 | 2.55±0.34 | 1.4±0.21 | 1.23±0.23 |
| 18 | Cu | 37.5±0.06 | 35.3±0.4 | 43.4±0.41 | 29.9±0.28 | 39.24±0.30 | 43.46±0.46 | 47.46±0.41 | 43.2±0.51 | 40.09±0.10 | 39.1±0.22 |
| 19 | Zn | 56.3±0.29 | 45.21±0.34 | 37.19±0.09 | 50.3±0.23 | 40.28±0.14 | 29.61±0.5 | 34.36±0.39 | 39.47±0.44 | 64.63±0.5 | 58.23±0.1 |
| 20 | Al | 20.39±.04 | 25.48±0.3 | 18.87±0.17 | 22.82±0.05 | 23.7±.14 | 23.3±.35 | 21.5±0.48 | 19.27±0.24 | 15.23±0.24 | 13.27±0.20 |

Samples (V1, V2, V3 ) = Kachiarpet, Samples (V4,V5,V6) = Valayampattu, Samples, (V7,V8) = Samanthikuppam, Samples (V9, V10) = Marapattu . All the value are presented Mean ±SD.

**Table 4.** Seasonal variation of the Physico - chemical analysis of Soil samples collected sites near tanneries in Vaniyambadi taluk during dry season in the year 2021

| S.No | Parameters | Soil samples collected sites near tannery areas in Vaniyambadi Taluk | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | V11 | V12 | V13 | V14 | V15 | V16 | V17 | V18 | V19 | V0 |
| 1 | pH at 25° C | 8.70±0.02 | 7.53±0.15 | 7.61±0.01 | 7.95±0.02 | 8.91±0.22 | 7.46±0.3 | 6.81±0.1 | 7.80±0.01 | 8.15±0.21 | 6.90±0.02 |
| 2 | Conductivity | 4300±0.50 | 2900.33±0.58 | 3799.83±0.76 | 4200±0.00 | 3899,67±0.76 | 2400.50±0.50 | 3250.50±50 | 4350±0.76 | 3400.33±0.58 | 4250.30±0.44 |
| 3 | Organic P | 12.80±0.56 | 14.28±0.9 | 20.1±0.19 | 18.23±0.3 | 16.9±0.30 | 13.5±0.5 | 15.9±0.41 | 21.01±0.08 | 19.3±0.4 | 17.04±0.20 |
| 4 | Inorganic P | 35.33±0.37 | 30.48±0.37 | 42.1±0.33 | 48.3±0.50 | 36.86±0.79 | 30.36±0.41 | 29.8±0.2 | 41.36±0.44 | 39.2±0.16 | 27.5±0.25 |
| 5 | Chloride | 1690.3±2.5 | 1412±0.02 | 1591.2±0.56 | 1776±0.01 | 1913±0.96 | 1732±0.22 | 1340.3±0.01 | 1970±0.56 | 2717±0.38 | 1898.6±0.89 |
| 6 | Nitrate | 211.6±0.41 | 126±0.26 | 139.3±0.04 | 191.6±0.01 | 217.6±1.5 | 312±0.26 | 280.3±0.15 | 251.09±0.01 | 189±0.00 | 375.6±0.15 |
| 7 | Sulphate | 237±.35 | 132.6±0.62 | 329.66±0.68 | 335.6±2.5 | 289.6±0.08 | 237.3±0.5 | 320.3±0.25 | 324.6±4.5 | 246±0.25 | 351±0.55 |
| 8 | Ca | 285.6±0.01 | 326.50±0.25 | 137.33±0.67 | 485±0.04 | 449.1±0.04 | 492±0.01 | 535±0.04 | 535±0.04 | 277.34±0.96 | 357±0.02 |
| 9 | Mg | 364.97±0.06 | 386.97±0.06 | 296.17±0.29 | 340.50±0.87 | 213.57±0.51 | 235,90±0.17 | 312,23±1.08 | 239.57±0.51 | 245.50±0.71 | 320.50±0.71 |
| 10 | F | 384.97±0.06 | 436.97±0.06 | 237.75±0.35 | 440.50±0.87 | 313.90±0.17 | 238,35±0.49 | 452,90±0.85 | 375.33±0.58 | 415.00±0.00 | 340.00±0.00 |
| 11 | Cr | 140.80±0.20 | 151.23±0.49 | 134.70±0.36 | 187,10±0.26 | 160.93±0.25 | 167.60±0.17 | 171.30±0.40 | 184,57±0.51 | 156.13±0.61 | 189.03±0.15 |
| 12 | Pb | 29.06±0.19 | 35.26±0.3 | 37.31±0.40 | 42.2±0.10 | 48.17±0.2 | 31.91±0.15 | 39.80±0.40 | 41.64±0.38 | 25.04±0.09 | 30.8±0.96 |
| 13 | Cd | 0.29±0.85 | 0.21±1.05 | 0.35±0.50 | 0.39±.07 | 0.18±0.20 | 1.78±0.02 | 1.56±0.24 | 1.45±1.2 | 1.37±0.39 | 1.68±0.24 |
| 14 | Fe | 46.57±0.17 | 62.10±0.13 | 57±0.00 | 42.5±0.45 | 34.5±0.40 | 34.4±0.64 | 46.09±0.11 | 33.36±0.26 | 58.5±0.38 | 52.00± 0.01 |
| 0.15 | Co | 2.62±0.06 | 2.81±0.07 | 3.19±0.42 | 3.14±0.02 | 1.15±0.25 | 2.48±0.22 | 1.29±0.09 | 3.72±0.10 | 2.31±0.01 | 2.66±0.02 |
| 16 | Mn | 20.71±0.54 | 13.52±0.03 | 16.9±0.02 | 12.50±0.25 | 19.62±0.19 | 12.17±0.38 | 12.63±0.14 | 13.33±0.09 | 11.44±0.25 | 18.9±0.19 |
| 17 | Ni | 13,19±0.01 | 12.20±0.05 | 8.16±0.03 | 7.63±0.04 | 12.14±0.04 | 12.35±0.05 | 14,31±0.34 | 10.87±0.04 | 13.26±0.05 | 9.46±0.04 |
| 18 | Cu | 31.95±0.03 | 48,76±0.05 | 43,35±0.39 | 28.25±0.05 | 36.36±0.06 | 13.17±0.04 | 30.47±0.04 | 15,81±0.01 | 23,85±0.03 | 31,65±0.03 |
| 19 | Zn | 39.94±0.04 | 54.86±0.04 | 25.92±0.03 | 52.91±0.01 | 48.3±0.05 | 55.2±0.03 | 63.57±0.03 | 32.33±029 | 21.7±0.04 | 46.55±0.06 |
| 20 | Al | 27.95±0.05 | 20.53±0.04 | 19.35±0.05 | 25.93±0.03 | 16.44±0.35 | 10.16±0.02 | 22.17±0.03 | 18.91±0.03 | 23.58±0.04 | 13.67±0.03 |

Samples (V11, V12, V13 ) = Kachiarpet, Samples (V14,V15,1V6) = Valayampattu, Samples, (V17,V18) = Samanthikuppam, Samples (V19, V20) = Marapattu . All the value are presented Mean ±SD.

**Table 5.** Seasonal variation Physico - chemical analysis of soil samples collected sites near tanneries in Pernambut taluk during wet season in the year 2022

| S.No | Parameters | Soil samples collected sites near tanneries in Pernambut taluk | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
| 1 | pH at 25° C | 8.04±0.01 | 8.18±0.07 | 7.56±.18 | 7.94±.05 | 7.80±.08 | 7.52±.14 | 7.37±.02 | 7.68±.10 | 7.78±.10 | 7.74±.09 |
| 2 | Conductivity | 0.25±0.01 | 0.40±0.02 | 0.48±0.02 | 0.94±0.01 | 0.56±0.03 | 0.32±0.03 | 0.35±0.03 | 0.26±.02 | 0.59±.01 | 0.36±.04 |
| 3 | PO4 | 0.84±0.05 | 0.93±0.04 | 0.90±0.06 | 0.93±0.02 | 0.79±0.03 | 0.65±0.02 | 0.68±0.01 | 0.94±0.03 | 0.59±0.01 | 0.77±0.03 |
| 4 | Caco3 | 406.25±1.50 | 502.75±2.06 | 454.25±4.92 | 424±4.55 | 376.75±1.26 | 508.5±0.58 | 495.75±0.9 | 343.75±2.0 | 494.75±0.96 | 460.5±1 |
| 5 | N | 145.63±0.30 | 105.6±0.17 | 96.56±0.25 | 88.7±0.26 | 113.66±0.32 | 124.7±0.1 | 81.33±0.15 | 71.66±0.32 | 103.53±0.40 | 114.56±0.35 |
| 6 | P | 10.46±0.15 | 9.6±0.10 | 5.6±0.44 | 5.5±0.14 | 15.76±0.15 | 3.733±0.21 | 9.53±0.15 | 8.26±0.12 | 5.53±0.31 | 5.76±0.23 |
| 7 | Na | 69.5±0.20 | 70.566±0.21 | 71.5±0.26 | 68.66±0.21 | 70.33±0.23 | 71.63±0.21 | 72.98±0.07 | 70.46±0.50 | 73.5±0.58 | 73.43±0.31 |
| 8 | K | 138.7±0.577 | 112.7±2.081 | 183.7±0.57 | 211.0±1 | 157.7±0.57 | 136.3±0.57 | 215.3±0.57 | 150.7±0.57 | 210.7±0.57 | 123.7±1.15 |
| 9 | Cr | 91.567±0.20 | 103.63±0.15 | 134±1 | 148.23±0.25 | 60.6±0.14 | 124.63±0.30 | 118.2±0.60 | 108.67±0.5 | 95.8±0.1 | 51.53±0.15 |
| 10 | Pb | 23.6±0.1 | 29.5±0.1 | 30.77±0.153 | 2.77±0.152 | 30.6±0.264 | 27.67±0.321 | 30.43±0.23 | 31.67±0.20 | 23.7±0.2 | 20.53±0.258 |
| 11 | Zn | 78.22±0.14 | 66.95±0.26 | 48.39±0.54 | 67.56±0.28 | 91.16±0.63 | 89.43±0.22 | 87.65±0.26 | 90.33±0.23 | 65.90±0.86 | 85.04±0.59 |
| 12 | Cu | 21.80±0.10 | 20.73±0.12 | 19.77±0.06 | 18.73±0.15 | 20.63±0.14 | 23.67±0.13 | 19.67±0.32 | 20.70±0.17 | 20.67±0.25 | 21.75±0.12 |
| 13 | Ni | 17.80±0.10 | 23.57±4.97 | 27.19±0.06 | 20.83±0.06 | 16.54±0.12 | 12.80±0.03 | 15.68±0.09 | 17.81±0.18 | 16.35±0.05 | 15.24±0.05 |
| 14 | Cd | 0.193±0.01 | 0.216±0.01 | 0.363±0.02 | 0.16±0.01 | 0.143±0.01 | 0.217±0.01 | 0.303±0.01 | 0.175±0.01 | 0.235±0.01 | 0.12±0.01 |
| 15 | Fe | 1.883±0.026 | 2.066±0.012 | 2.403±0.015 | 2.266±0.061 | 1.793±.057 | 2.19±0.01 | 2.173±0.01 | 0.94±0.01 | 0.956±0.005 | 1.173±0.030 |
| 16 | Mn | 0.74±0.02 | 0.806±0.02 | 0.46±0.01 | 0.533±0.05 | 0.566±0.03 | 0.673±0.01 | 0.473±0.02 | 0.493±0.01 | 0.873±0.04 | 0.836±0.02 |

Samples (P1,P2,P3,P4,P5) = Bakkallapalli, Samples (P6,P7,P8,P9, P10) = V.Kota road,Pernambut . All the value are presented Mean ±SD.

exhibited significant seasonal variations (Table 1 & 2).

Soil pH ranged from 7.54 to 8.60 in the wet season and 6.45 to 8.90 in the dry season. Most sites exhibited slightly alkaline conditions, typical of areas impacted by tannery effluents[17] . The higher pH values in the dry season can be attributed to reduce water content, leading to the accumulation of alkaline substances, such as sodium hydroxide, used in the tanning process. Alkaline pH levels can influence nutrient availability and microbial activity in soils. [18,19] Electrical conductivity (EC) values ranged from 1301.03 µS/cm (A1) to 2400.75 µS/cm (A4) in the wet season, and from 1950.75 µS/cm (A12) to 5600.75 µS/cm (A16) in the dry season. The increase in EC, especially during the dry season, indicates higher salinity, likely due to the leaching of salts from tannery wastewater[20-22]. The elevated EC in the dry season is also attributed to evaporation, which concentrates dissolved salts in the soil. Chloride levels were high, ranging from 1214.25 mg/kg (A4) to 2461 mg/kg (A7) in the wet season, and from 1235 mg/kg (A16) to 2881.5 mg/kg (A20) in the dry season. The higher chloride concentrations in the dry season suggest the persistence of pollutants from tannery effluents, which contain chlorine-based chemicals used in leather processing.[23] Nitrate concentrations ranged from 221 mg/kg (A4) to 343.5 mg/kg (A8) in the wet season, and from 159 mg/kg (A18) to 313.25 mg/kg (A15) in the dry season. Higher nitrate levels in the dry season, especially at sites A15 and A13, may be linked to agricultural activities, where nitrogen fertilizers are commonly applied. Sulphate concentrations ranged from 320.75 mg/kg (A6) to 537 mg/kg (A5) in the wet season, and from 237.25 mg/kg (A16) to 459 mg/kg (A5) in the dry season. Increased sulphate levels in both seasons suggest contamination from tannery chemicals, as sulphates are used in leather processing.[24]

**Table 6.** The frequency of occurrence of microorganisms isolated

| Bacterial Isolates | Frequency occurrence |
|---|---|
| *Escherichia coli* | 32 |
| *Bacillus cereus* | 11 |
| *Pseudomononas aeruginosa* | 10 |
| *Staphylococcus* | 27 |
| *Klebsiella pneumonia* | 14 |

**Heavy Metal contamination**

The study found elevated concentrations of heavy metals, particularly chromium (Cr), lead (Pb), and copper (Cu), which pose significant environmental and health risks. Chromium levels ranged from 125.77 mg/kg (A4) to 158.77 mg/kg (A7) in the wet season, and from 134 mg/kg (A13) to 168.16 mg/kg (A20) in the dry season. Chromium, especially hexavalent chromium, is a toxic by-product of tanning activities and poses severe risks to the environment and human health.[25-27] Lead concentrations ranged from 22 mg/kg (A5) to 47.19 mg/kg (A10) in the wet season, and from 25.9 mg/kg (A16) to 52.1 mg/kg (A14) in the dry season. Although not as high as chromium, lead contamination is concerning due to its toxicity and persistence in the soil. Copper levels ranged from 19.23 mg/kg (A8) to 30.24 mg/kg (A10) in the wet season, and from 27.10 mg/kg (A12) to 46.30 mg/kg (A15) in the dry season. Elevated copper levels are indicative of contamination from tannery effluents, as copper is used in the leather industry.[28,29] These metals exceed permissible limits for agricultural land, posing risks to soil health, crop production, and human well-being.

There were significant seasonal differences in the concentration of most parameters. In the dry season, the concentration of salts, metals, and other pollutants increased due to reduced water availability and higher evaporation rates. In contrast, the wet season, with increased rainfall, likely caused some leaching of pollutants, though high concentrations of salts and heavy metals remained in the soil.[17] These seasonal variations highlight the need for effective management of tannery effluents to mitigate their environmental impact.

**Soil Analysis from Vaniyambadi taluk (2021)**

The seasonal variations in soil properties near tanneries in Vaniyambadi taluk were also investigated in 2021 (Table 3 and 4).

Soil pH ranged from 6.81 to 8.91, with the highest pH recorded at site V15 (8.91) during the dry season, and the lowest at site V16 (6.81) in the dry season. The slightly alkaline pH across all sites is typical of areas impacted by tannery effluents.[30] The pH was slightly lower during the wet season, likely due to reduced chemical exposure.[31] EC ranged from 2297.3 µS/cm to 4300 µS/cm, with the highest values observed during the dry season at sites V11 and V15 (4300 µS/cm and 4200 µS/cm, respectively). These elevated EC values indicate higher soil salinity, a consequence of tannery effluent contamination, with evaporation in the dry season concentrating salts in the soil.[32,33] Organic phosphorus ranged from 12.8 to 21.01 µg/g, and inorganic phosphorus from 13.36 to 48.3 µg/g, with higher concentrations observed in the dry season. Elevated phosphorus levels reflect leaching from tannery effluents, which are rich in phosphorus compounds.[34, 35] Excessive phosphorus can lead to soil nutrient imbalances and eutrophication of surrounding water bodies.[36]

**Heavy Metal Concentrations in Vaniyambadi taluk**

Heavy metals including chromium (Cr), lead (Pb), cadmium (Cd), and iron (Fe) exhibited considerable variation across sites. Chromium (Cr) ranged from 32.25 to 189.03 µg/g, with the highest levels at site V20 (189.03 µg/g) during the dry season. Lead (Pb) ranged from 25.04 to 59.61 µg/g, with the highest concentration at site V6 (59.61 µg/g). Iron (Fe) showed consistently high levels, peaking at site V6 during the dry season (83.4 µg/g). These metals are common contaminants in tannery effluents, indicating pollution from local tanning activities.[37, 38]

Trace elements like zinc (Zn), copper (Cu), manganese (Mn), and nickel (Ni) also varied between seasons. Manganese (Mn) ranged from 5.62 to 20.71 µg/g, with the highest concentration at site V11 (20.71 µg/g) in the dry season. Zinc (Zn) ranged from 21.7 to 64.63 µg/g, and copper (Cu) ranged from 13.17 to 47.46 µg/g. Nickel (Ni) concentrations were higher in the dry season (1.23 to 18.5 µg/g). These metals are associated with tannery effluents, which contain metal salts used in leather processing.[39,40]

**Soil Analysis from Pernambut taluk (2022)**

Similar trends were observed in Pernambut taluk during the wet season of 2022 (Table 5). Soil pH ranged from 7.37 (P7) to 8.18 (P2), reflecting slightly alkaline conditions typical of tannery-impacted areas. EC ranged from 0.25 mS/cm (P1) to 0.94 mS/cm (P4), with higher values indicating increased salinity due to tannery effluent contamination.[32,41] Phosphate concentrations ranged from 0.59 mg/kg (P9) to 0.94 mg/kg (P8), further indicating nutrient pollution from tannery waste.[35,42] Calcium carbonate levels ranged from

343.75 mg/kg (P8) to 508.5 mg/kg (P6), which likely reflects the presence of lime in tannery effluents. Nitrogen concentrations ranged from 71.66 mg/kg (P8) to 145.63 mg/kg (P1), indicating contamination from organic waste and effluents rich in nitrogen.[43]

Heavy metal concentrations in Pernambut taluk also showed elevated levels of chromium (Cr) ranging from 51.53 mg/kg (P10) to 148.23 mg/kg (P3), lead (Pb) from 2.77 mg/kg (P4) to 31.67 mg/kg (P8), and zinc (Zn) from 48.39 mg/kg (P3) to 91.16 mg/kg (P5). High levels of these metals can be toxic to plants and soil organisms.[44,45]

The findings from Pernambut taluk (Table 3, 4 and Table 5) align with the Vaniyambadi taluk study, indicating significant contamination due to tannery effluents, with elevated levels of pH, electrical conductivity, and heavy metals. These contaminants pose long-term risks to soil health, fertility, and local ecosystems, importance the urgent need for effective waste management strategies to mitigate the impact of tannery effluents on soil and water quality.

**Microbial Contamination**

Microbial contamination analysis showed that Escherichia coli had the highest frequency of occurrence (32%), followed by *Staphylococcus aureus* (27%) and *Pseudomonas species* (10%) (Table 6). These microorganisms highlight the potential health risks associated with tannery effluent contamination, particularly regarding waterborne diseases and soil contamination.[46]

## CONCLUSION

The study on seasonal variations in the microbial and physico-chemical properties of soil in Ambur, Vaniyambadi, and Pernambut taluks underscores the significant impact of tannery effluents on soil quality. The results indicate increased microbial contamination, with higher frequencies of *Escherichia coli*, *Staphylococcus spp.*, *Klebsiella pneumoniae*, *Bacillus cereus*, and *Pseudomonas aeruginosa*, especially during the wet season, likely due to runoff. The physico-chemical analysis revealed that the soil was slightly alkaline, with pH values ranging from 6.81 to 8.91, and was particularly higher during the dry season. Electrical conductivity, a measure of soil salinity, was also elevated in the dry season due to increased evaporation. Additionally, the study found higher concentrations of phosphorus, calcium carbonate, and heavy metals such as chromium, lead, zinc, and nickel, with particularly elevated levels during the dry season. Overall, the study confirms that tannery effluents contribute significantly to soil contamination, particularly with heavy metals and nutrients, which negatively affect soil health and the environment. The seasonal variations, with elevated concentrations of pollutants during the dry season, emphasize the need for effective effluent management and waste treatment to mitigate their impact on soil and surrounding ecosystems

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**Data Availability Statement**

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**Ethics Statement**

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

**Informed Consent Statement**

This study did not involve human participants, and therefore, informed consent was not required.

**Clinical Trial Registration**

This research does not involve any clinical trials.

**Author contributions**

Moorthy Senthilkumar: completed the research work plan and Manuscript writing and supervision; Abubacker Thaminum Ansari :handled the editing and completed the review of the literature collection; Every author has reviewed and approved the published version of the manuscript.

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