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Physicochemical and Microbial Analysis of Distillery Effluents of Industrial Region of Ch. Sambhajinagar (Aurangabad), India

P. P. Pardeshi* and S. B. Mali

Department of Microbiology, Shramjivi Shikshan Prasarak Mandal's Adarsh Mahavidyalaya, Omerga Dist. Dharashiv, Maharashtra, India

**Corresponding author*

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ABSTRACT

The present study investigates the physicochemical and microbial characteristics of distillery effluents collected from the industrial region of Chhatrapati Sambhajinagar (formerly Aurangabad), Maharashtra, India. Ten effluent samples were analyzed to assess key environmental parameters, including pH, electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), nutrients (total phosphorus and total nitrogen), heavy metals (Cd, Cr, Ni, Pb, Zn, Fe), and total viable count (TVC). The results revealed that all measured parameters significantly exceeded the permissible limits set by the Central Pollution Control Board (CPCB), World Health Organization (WHO), and American Public Health Association (APHA), indicating high levels of organic and inorganic pollution. The effluents were acidic (pH ~5.0), dark in color, and rich in recalcitrant organics and heavy metals, with exceptionally high COD (up to 27,303 mg/L), BOD (14,984 mg/L), and microbial loads (up to 1.0×10^7 CFU/mL). The findings highlight the environmental threat posed by untreated or inadequately treated distillery wastewater in the region. This study underscores the urgent need for advanced effluent treatment strategies, particularly microbial bioremediation, to mitigate pollution and ensure environmental compliance for sustainable industrial practices.

Introduction

The distillery industry is a significant contributor to industrial pollution worldwide, particularly in developing countries like India, where rapid industrialization has led to increased environmental degradation. Distilleries produce large volumes of wastewater, known as distillery effluents, during the production of alcohol and related products. These effluents are characterized by high organic load, dark color, and the presence of toxic compounds such as heavy metals and phenolic substances (Mohana *et al.,* 2009). The untreated or inadequately treated discharge of these effluents into water bodies or onto land poses severe environmental and public health risks, making their management a critical concern. Aurangabad, a prominent industrial hub in Maharashtra, India, hosts several distilleries that contribute significantly to the region's economy. However, the environmental impact of these industries, particularly their effluent discharge, has raised concerns among environmentalists and policymakers. The effluents from distilleries are rich in organic matter, primarily in the form of sugars, proteins, and melanoidins, which are complex polymeric compounds formed during the Maillard reaction in the distillation process (Kumar and Chandra, 2006; Chawla, 2023). Melanoidins are particularly problematic due to their recalcitrant nature, making them resistant to conventional treatment methods.

The physicochemical properties of distillery effluents, such as high biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS), contribute to their polluting potential. High BOD and COD levels indicate the presence of organic pollutants that deplete dissolved oxygen in water bodies, leading to the death of aquatic life and disruption of ecosystems (Chowdhary *et al.,* 2018). Additionally, the dark color of the effluents reduces light penetration in water bodies, affecting photosynthesis and the survival of aquatic plants.

Heavy metals, such as lead (Pb), cadmium (Cd), and chromium (Cr), are often present in distillery effluents due to the use of metal-containing equipment and raw materials.

These metals are toxic, non-biodegradable, and tend to accumulate in the environment, posing long-term risks to human health and ecosystems (Singh *et al.,* 2020). For instance, lead exposure can cause neurological disorders, while cadmium is a known carcinogen. The presence of these metals in effluents necessitates stringent treatment measures to prevent their entry into the food chain.

Microbial contamination is another critical aspect of distillery effluents. The high organic content provides an ideal environment for the growth of pathogenic microorganisms, including bacteria, viruses, and fungi. Studies have reported the presence of coliforms, *Escherichia coli*, and *Salmonella spp.* in distillery effluents, indicating fecal contamination and the potential for waterborne diseases (Saha *et al.,* 2018). The discharge of such effluents into water bodies or their use for irrigation can lead to the spread of diseases such as cholera, typhoid, and gastroenteritis, particularly in communities lacking access to clean water and sanitation facilities.

In India, the Central Pollution Control Board (CPCB) has established standards for the discharge of industrial effluents to protect water resources and public health. However, compliance with these standards remains a challenge for many distilleries due to the high cost of advanced treatment technologies and inadequate enforcement of regulations (CPCB, 2019). As a result, untreated or partially treated effluents continue to be discharged into the environment, exacerbating pollution and health risks. The environmental impact of distillery effluents is particularly pronounced in regions like Aurangabad, where the concentration of distilleries is high, and the availability of freshwater resources is limited. The discharge of effluents into local water bodies, such as rivers and lakes, has led to the degradation of aquatic ecosystems and the contamination of groundwater, which is a primary source of drinking water for many communities (Patil *et al.,* 2021). Additionally, the use of untreated effluents for irrigation has resulted in soil degradation and the accumulation of toxic substances in crops, posing risks to food safety and human health.

Despite the growing awareness of the environmental and health impacts of distillery effluents, there is a lack of comprehensive studies focusing on the physicochemical and microbial characteristics of these effluents in the Aurangabad region. Most existing studies have focused on individual parameters or treatment methods, with limited attention to the combined effects of organic pollutants, heavy metals, and microbial contamination.

This study aims to fill this gap by providing a detailed analysis of the physicochemical and microbial properties of distillery effluents in Aurangabad, highlighting their environmental and health implications, and proposing sustainable management strategies.

The findings of this study are expected to contribute to the development of effective effluent treatment and management practices, ensuring compliance with regulatory standards and minimizing the environmental and health risks associated with distillery effluents. By addressing the challenges posed by distillery effluents, this study aims to promote sustainable industrial practices and protect the region's water resources and public health.

Materials and Methods

Study Area and Sample Collection

The study was conducted in the industrial region (Walunj, Shendra, Pandharpur and Chikhalthana) of Aurangabad, Maharashtra, India, which is home to several distilleries. A total of 10 effluent samples were collected from different discharge points of distilleries in the region. Sampling was carried out during the peak production season to ensure representative results.

Samples were collected in pre-cleaned, sterilized polyethylene bottles and transported to the laboratory under refrigerated conditions (4°C) to prevent any physicochemical or microbial changes.

Physicochemical Analysis

The collected samples were analyzed for the following physicochemical parameters using standard methods as prescribed by the American Public Health Association (APHA, 2017) and the Central Pollution Control Board (CPCB, 2019):

Color: The color of the effluent samples was measured using a spectrophotometer at a wavelength of 475 nm. The optical density (OD) was recorded, and the color intensity was expressed in Hazen units (HU).

Electrical Conductivity (EC): Electrical conductivity was measured using a digital conductivity meter. The results were expressed in microsiemens per centimeter (µS/cm).

pH: The pH of the samples was determined using a calibrated digital pH meter.

Dissolved Oxygen (DO): DO was measured using the Winkler's method. The results were expressed in milligrams per liter (mg/L).

Chemical Oxygen Demand (COD): COD was determined using the closed reflux titrimetric method. Potassium dichromate ($K_2Cr_2O_7$) was used as the oxidizing agent, and the results were expressed in mg/L.

Biological Oxygen Demand (BOD): BOD was measured using the 5-day BOD test at 20°C. The results were expressed in mg/L.

Total Phosphorus (TP): TP was analyzed using the ascorbic acid method after digesting the samples with potassium persulfate. The results were expressed in mg/L.

Total Nitrogen (TN): TN was determined using the Kjeldahl method, which involves digestion, distillation, and titration. The results were expressed in mg/L.

Total Solids (TS): TS were measured by evaporating a known volume of sample at 105°C and weighing the residue. The results were expressed in mg/L.

Total Dissolved Solids (TDS): TDS were measured by filtering the sample through a 0.45 µm membrane filter and evaporating the filtrate at 105°C. The residue was weighed, and the results were expressed in mg/L.

Total Suspended Solids (TSS): TSS were determined by filtering a known volume of sample through a pre-weighed glass fiber filter and drying the filter at 105°C. The increase in weight was recorded, and the results were expressed in mg/L.

Heavy Metal Analysis: Heavy metals, including cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn), and iron (Fe), were analyzed using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) and Atomic Absorption Spectroscopy (AAS). The samples were digested using a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) before analysis. The results were expressed in milligrams per liter (mg/L).

Microbial Analysis: Microbial analysis was conducted to determine the total viable count (TVC) and the presence of pathogenic microorganisms. The following steps were followed:

Total Viable Count (TVC): TVC was determined using the pour plate method. Serial dilutions of the samples were prepared, and 1 mL of each dilution was mixed with molten plate count agar. The plates were incubated at 37°C for 24–48 hours, and the colonies were counted. The results were expressed as colony-forming units per milliliter (CFU/mL).

Results and Discussion

The present study evaluates the physicochemical and microbial characteristics of distillery effluents from the industrial region of Aurangabad, Maharashtra. A total of

10 effluent samples were analyzed for parameters including color, pH, electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), total phosphorus (TP), total nitrogen (TN), total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), heavy metals, and microbial load.

Physicochemical Characteristics

The physicochemical and microbial analysis of distillery effluents collected from the Aurangabad industrial region reveals a significantly high level of pollution across all measured parameters, strongly suggesting the presence of untreated or inadequately treated wastewater. This data, obtained from ten representative samples, highlights the deteriorated quality of effluents, posing a serious threat to environmental and public health.

The color intensity**,** measured as optical density (OD) at 475 nm, ranged from 0.79 to 1.43 across the samples. Such high OD values are indicative of a dark brown coloration, commonly associated with the presence of recalcitrant organic compounds such as melanoidins, humic substances, and other polyphenolics, which are known to be poorly biodegradable.

This parameter alone suggests that the effluent is unsuitable for direct discharge into natural water bodies without proper treatment. Electrical conductivity (EC) values varied between 3,917 and 7,363 µS/cm, reflecting high concentrations of dissolved ionic species such as chlorides, sulfates, and nitrates.

The elevated EC values suggest significant salinity levels in the effluent, which can adversely affect soil structure and fertility when such effluents are discharged into agricultural fields or used for irrigation.

Moreover, pH values across the samples were acidic, ranging from 4.5 to 5.3. Acidic pH can cause leaching of heavy metals from the soil and is harmful to aquatic life and soil microbiota. According to CPCB and WHO standards, the acceptable pH range for discharge is 6.5 to 8.5, which none of the samples meet.

Dissolved Oxygen (DO) levels in the effluents were alarmingly low, from 0.13 to 1.33 mg/L. Such levels are inadequate to sustain aerobic aquatic life, as a minimum of 4–6 mg/L is required. The low DO values are a result of the high organic load in the effluent, as confirmed by the extremely high values of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). COD ranged from 22,030 to 33,952 mg/L, while BOD ranged from 12,049 to 18,657 mg/L.

These values far exceed the CPCB limits of 250 mg/L (COD) and 30 mg/L (BOD) for treated industrial wastewater. These high oxygen demand values indicate a substantial presence of biodegradable and non-biodegradable organic matter, which, if discharged untreated, will deplete oxygen levels in receiving water bodies, leading to hypoxic conditions and fish kills.

The Total Phosphorus (TP) levels, which varied from 40.7 to 57.8 mg/L, and Total Nitrogen (TN) levels, ranging from 70.0 to 89.3 mg/L, also exceed permissible limits. Excessive nutrients can lead to eutrophication of surface water bodies, causing algal blooms, aquatic weed growth, and subsequent reduction in water quality and biodiversity. Total Solids (TS) and Total Dissolved Solids (TDS) levels were exceptionally high, ranging from 74,315 to 94,463 mg/L and 60,614 to 76,676 mg/L respectively, while Total Suspended Solids (TSS) were recorded in the range of 3,517 to 13,256 mg/L. These values indicate a dense pollutant load, further confirmed by the turbidity and sludge formation potential of the effluent.

The heavy metal content in the effluents also exceeded acceptable safety limits as per WHO and APHA standards. Cadmium (Cd) levels reached up to 0.096 mg/L, Chromium (Cr) up to 0.483 mg/L, Nickel (Ni) up to 0.514 mg/L, and Lead (Pb) up to 0.393 mg/L. These values are several folds higher than permissible limits (e.g., Cd $\leq$ 0.003 mg/L, Pb $\leq$ 0.01 mg/L).

Long-term exposure to such metals is associated with severe health effects, including nephrotoxicity, carcinogenicity, and neurological disorders. Furthermore, Zinc (Zn) and Iron (Fe) levels were also elevated, with maximum values of 5.51 mg/L and 9.29 mg/L, respectively, which can lead to phytotoxicity and staining issues in potable water supplies.

The Total Viable Count (TVC) of microorganisms in the effluent was found to be extremely high, ranging from 1.0×10^6 to 1.0×10^7 CFU/mL. Such a high microbial load reflects the untreated nature of the effluent and poses a risk of pathogenic contamination if discharged into water bodies or reused without disinfection.

Table.1 Physicochemical and microbial parameters in the distillery effluents from the industrial region of Aurangabad.

S.No.	Color ((OD at 475 nm)	Colour Intensity	EC (ÂµS/cm)	pH	DO (mg/L)	COD (mg/L)	BOD (mg/L)	TP (mg/L)	TN (mg/L)	TS (mg/L)	TDS (mg/L)	TSS (mg/L)	Cd (mg/L)	Cr (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)	Fe (mg/L)	TVC (CFU/mL)
1	0.91	Light Yellow	5805	5	1.04	32083	13241	57.8	74.3	93778	76017	5418	0.087	0.332	0.271	0.087	0.67	6.28	1.0×10^6
2	0.8	Pale Yellow	7029	5.1	0.31	31923	16347	57.5	79	86034	62087	13206	0.046	0.483	0.13	0.051	2.91	5.69	2.5×10^6
3	1.42	Dark Brown	4609	4.7	0.59	22030	13813	49.3	89.3	93927	67661	13256	0.076	0.115	0.203	0.315	1	3.77	3.0×10^6
4	0.79	Pale Yellow	4079	5.3	1.33	22391	13351	42.7	83.1	83662	73604	8341	0.072	0.122	0.387	0.098	2.88	2.66	4.0×10^6
5	1.24	Brown	4208	5.2	0.51	33952	17442	54.7	73	84332	76676	6181	0.038	0.367	0.427	0.23	4.21	4.39	5.0×10^6
6	1.43	Dark Brown	3917	4.5	0.7	27777	13659	48.5	87.7	94463	63722	3517	0.052	0.165	0.295	0.266	2.52	4.64	6.0×10^6
7	1.14	Reddish Brown	5471	5.3	1.2	27089	18657	45.5	70.1	74315	75377	7599	0.042	0.419	0.305	0.393	1.26	1.88	7.0×10^6
8	1.23	Brown	5410	4.6	0.84	28171	15259	57.6	74.9	75370	62949	3965	0.096	0.32	0.514	0.217	5.3	9.29	8.0×10^6
9	0.82	Light Yellow	7363	4.6	0.13	23569	12049	51.3	70	81366	73516	12872	0.062	0.473	0.36	0.215	5.51	8.09	9.0×10^6
10	1.08	Yellowish Brown	5430	5.2	0.55	24047	16017	40.7	72.9	82615	60614	6047	0.02	0.412	0.5	0.145	4.46	2.75	1.0×10^7

Table.2 Heavy metals analysis of distillery effluents from the industrial region of Aurangabad

Metal	Range (mg/L)	Observation
Cd	0.02–0.096	Above WHO limit (0.003 mg/L), toxic even in low concentrations
Cr	0.115–0.483	May include carcinogenic Cr(VI), exceeds WHO/APHA limits
Ni	0.13–0.514	Known for toxicity, far above WHO limit (0.02 mg/L)
Pb	0.051–0.393	Exceeds safe limits (WHO/APHA 0.01 mg/L), neurotoxic
Zn	0.67–5.51	Some values exceed WHO limit (3 mg/L), phytotoxic at high doses
Fe	1.88–9.29	Exceeds WHO safe limit (0.3 mg/L), causes staining and taste issues

Table.3 Physicochemical and microbial parameters in the distillery effluents from the industrial region of Aurangabad, along with the permissible limits set by the Central Pollution Control Board (CPCB) standards

Parameter	Observed Value	Permissible Limit (CPCB Standards)	Permissible Limit (WHO Standards)	Permissible Limit (APHA Standards)
Color (OD at 475 nm)	1.09	0.1	Not specified	≤0.1
Electrical Conductivity (EC, µS/cm)	5332	2,100	400–1500	1500–2000
pH	5.0	6.5–8.5	6.5–8.5	6.0–9.0
Dissolved Oxygen (DO, mg/L)	0.72	4–6	≥5	≥5
Chemical Oxygen Demand (COD, mg/L)	27303	250	Not specified	≤250
Biological Oxygen Demand (BOD, mg/L)	14984	30	Not specified	≤30
Total Phosphorus (TP, mg/L)	50.6	5	0.1	≤1
Total Nitrogen (TN, mg/L)	77.4	100	10	≤10
Total Solids (TS, mg/L)	84986	2,100	500	≤500
Total Dissolved Solids (TDS, mg/L)	69222	2,100	500–1000	≤500
Total Suspended Solids (TSS, mg/L)	8040	100	5	≤5
Cadmium (Cd, mg/L)	0.059	0.01	0.003	≤0.01
Chromium (Cr, mg/L)	0.321	0.05	0.05	≤0.05
Nickel (Ni, mg/L)	0.339	0.1	0.02	≤0.02
Lead (Pb, mg/L)	0.202	0.1	0.01	≤0.01
Zinc (Zn, mg/L)	3.07	2.0	3.0	≤5.0
Iron (Fe, mg/L)	4.94	3.0	0.3	≤0.3
Total Viable Count (TVC, CFU/mL)	$2–5 \times 10^6$	Not specified	1×10^3	1×10^3

Table 3 presents a comparative analysis of observed values for key physicochemical and microbial parameters in distillery effluents from Aurangabad, benchmarked against the permissible limits prescribed by the Central Pollution Control Board (CPCB – India), the World Health Organization (WHO), and the American Public Health Association (APHA). The findings highlight significant environmental and public health concerns arising from untreated or partially treated effluents discharged from distilleries. The color of the effluent, represented as OD at 475 nm, was recorded at 1.09, which greatly exceeds the CPCB and APHA permissible limit of 0.1. The dark color signifies the presence of non-biodegradable compounds such as melanoidins formed during molasses fermentation. WHO does not specify a limit for color in effluent standards, but such a high value indicates strong visual pollution and potential ecological impact.

Electrical Conductivity (EC), which measures the concentration of dissolved salts and ions, was observed at 5332 µS/cm, far exceeding the CPCB limit of 2,100 µS/cm, WHO's limit of 400–1500 µS/cm, and APHA's range of 1500–2000 µS/cm. High EC reflects the presence of inorganic dissolved solids that can make water unsuitable for irrigation and damage soil quality. The pH of the effluent was 5.0, indicating acidic conditions. This is below the acceptable range for all three agencies (CPCB and WHO: 6.5–8.5, APHA: 6.0–9.0). Acidic effluents are corrosive and can adversely affect aquatic ecosystems and microbial diversity in soil and water bodies.

Dissolved Oxygen (DO) was found to be 0.72 mg/L, drastically lower than the required minimum of 4–6 mg/L by CPCB and ≥5 mg/L by both WHO and APHA. Such low DO levels signify severe oxygen depletion due to high organic pollution, which is detrimental to aquatic life.

The Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) values were reported at 27,303 mg/L and 14,984 mg/L, respectively. These values far exceed the permissible CPCB limits (COD ≤ 250 mg/L, BOD ≤ 30 mg/L) and APHA standards. WHO does not prescribe specific limits for COD and BOD, but such high levels indicate excessive organic and inorganic pollution, suggesting the effluent is heavily loaded with biodegradable and toxic materials.

The total Phosphorus (TP) was measured at 50.6 mg/L, surpassing all guideline values (CPCB: 5 mg/L, WHO: 0.1 mg/L, APHA: ≤1 mg/L). Elevated phosphorus levels can promote eutrophication in receiving waters, leading to algal blooms and oxygen depletion. Total Nitrogen (TN), observed at 77.4 mg/L, falls within CPCB limits (≤100 mg/L) but exceeds WHO and APHA limits (10 mg/L).

This can contribute to the formation of nitrites and nitrates, which are harmful to human health and aquatic ecosystems. The levels of Total Solids (TS), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) were alarmingly high: 84,986 mg/L, 69,222 mg/L, and 8,040 mg/L, respectively. These values exceed all standard limits (CPCB and WHO: ≤2100 mg/L for TDS, APHA: TS ≤ 500 mg/L, TSS ≤ 5 mg/L). High solid content leads to increased turbidity, sedimentation in water bodies, and potential clogging of irrigation channels

The present study revealed that the distillery effluents from Aurangabad exhibit severely degraded quality, with values exceeding permissible limits across nearly all parameters. The color (OD_{475} = 1.09) and EC (5332 µS/cm) indicate a high organic and ionic load, similar to findings by Wani *et al.,* (2023), who reported persistent melanoidin pigmentation and salinity in spent wash. The acidic pH (5.0) and low DO (0.72 mg/L) reflect poor biodegradability and oxygen-depleting potential, aligning with Kumar *et al.,* (2019) who observed similar trends in untreated effluents. Extremely high COD (27,303 mg/L) and BOD (14,984 mg/L) support reports by Satyawali and Balakrishnan (2008), highlighting the urgent need for tertiary treatment. Nutrient values (TP = 50.6 mg/L, TN = 77.4 mg/L) risk eutrophication, consistent with Pant and Adholeya (2007). Solids (TDS > 69,000 mg/L) further indicate turbidity and sedimentation issues. Heavy metals such as Pb, Cd, and Cr surpassed WHO/APHA limits, echoing Shinde *et al.,* (2020). TVC levels of 10^6 CFU/mL reflect a high microbial burden, as noted by Patel *et al.,* (2023). Overall, this study confirms earlier findings and emphasizes the need for integrated, site-specific effluent management strategies.

The findings confirm that distillery effluents from Aurangabad are highly polluted and pose serious environmental and health risks. Conventional treatment alone is insufficient; hence, there is an urgent need for microbial bioremediation strategies to degrade recalcitrant organics, reduce nutrient load, and detoxify heavy metals. Employing efficient microbial consortia offers a cost-effective, eco-friendly solution for sustainable wastewater management.

Author Contributions

P. P. Pardeshi: Investigation, formal analysis, writing—original draft. S. B. Mali: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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