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Comparative Study of Wastewater Generated from Mineral Water Factories, Arunachal Pradesh

Jumbom Ruti, Mudo Puming

***Abstract**: The increasing need for packaged drinking water has resulted in the growth of mineral water production units, particularly in developing areas such as Northeast India. But the environmental effects of wastewater released by such units are usually left behind. This study is a comparative analysis of wastewater produced by two well-known mineral water plants in the Nirjuli area of Papumpare District, Arunachal Pradesh, namely M/S Renu Beverage (the producer of Orchid Drop) and M/S Polo International (the manufacturer of Polo Mineral Water). The main aim was to analyse the physicochemical properties of the wastewater and check compliance with the allowable discharge standards set by the regulatory authorities. In order to obtain accurate and representative data, wastewater samples were taken at 10-minute intervals from the outlet of each factory. This process was done for five months, with a one-month gap between consecutive sampling runs to account for seasonal or operational changes. The parameters examined were major water quality parameters such as pH, temperature, turbidity, chloride, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen (DO). The parameters were analysed using standard APHA laboratory procedures. The findings reported that although majority of the physicochemical values stayed within proper limits of discharge, considerable discrepancies in BOD, TSS, and turbidity levels existed. Interestingly, wastewaters of the Polo unit showed high levels of BOD and turbidity as opposed to Orchid Drop, and that indicates variation in effluent treatment practices being applied. Differences depict the levels of operational proficiency as well as the wastewater handling protocols being implemented across different units. Aside from comparative evaluation, the research further investigated possibilities for reuse of treated wastewater for industrial and agricultural applications. From analysing monthly trends and scrutinizing changes in loads of pollutants, the research discerns opportunities to include treated wastewater within sustainable water management systems. This reuse may reduce freshwater usage to a very low level and assist in conserving water long-term in regions under water scarcity. This research offers vital information on a frequently neglected environmental concern in the bottled water sector. It stresses the significance of regulatory enforcement, regular monitoring, and enhanced treatment facilities in the provision of environmentally friendly operations. The research contributes to the larger discussion on wastewater management in industries and provides actionable directions towards pollution reduction and resource recovery through water reuse strategies.*

***Keywords**: Wastewater Analysis, Water Quality Parameters, Drinking Water Factories, Physicochemical Assessment, Sustainable Water Management, Wastewater Reuse.*

Abbreviations:
TDS: Total Dissolved Solids
TSS: Total Suspended Solids
BOD_5: Biochemical Oxygen Demand
DO: Dissolved Oxygen
RO: Reverse Osmosis
Cd: Conductivity
NTU: Nephelometric Turbidity Units
BIS: Bureau of Indian Standards
FSSAI: Food Safety and Standards Authority of India
$CaCO_3$: Calcium Carbonate
MBBR: Moving Bed Biofilm Reactor
UV: ultraviolet
COD: Chemical Oxygen Demand

I. INTRODUCTION

Water is one of the most critical resources on our planet, being an integral part of all living organisms known to mankind and a crucial element in the sustenance of human life. With water quality and availability issues increasing day by day, the demand for packaged drinking water has grown remarkably high in areas like Northeast India. This has resulted in very fast growth in mineral water production units, which, while producing, discharge enormous amounts of wastewater [1]. The current research carries out a comparative study of wastewater produced by two prominent bottled water plants in the Nirjuli region of Papumpare District, Arunachal Pradesh, namely M/S Renu Beverage (Orchid Drop) and M/S Polo International (Polo Mineral Water) [2].

The study mainly seeks to describe the physicochemical parameters of wastewater from both factories and establish their compliance with acceptable discharge standards established by regulatory bodies [3]. Wastewater samples were obtained every 10 minutes at the outlet of each factory over a period of five months. One month was allowed between consecutive sampling sessions to account for changes arising from operational and seasonal fluctuations [6].

APHA standard laboratory procedures were employed to analyze the samples for key

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water quality indicators like pH, temperature, turbidity, chloride, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen (DO) [6].

The findings indicated that while most of the parameters were found within acceptable limits, considerable deviations were noted for others. Specifically, Polo wastewater registered higher BOD and turbidity readings than Orchid Drop, which indicates inefficiencies in the treatment systems or variations in operational management [7].

The research also determines the viability of using treated wastewater for irrigation purposes and industry through reuse. With the analysis of monthly pollutant variations and patterns of loads, it suggests strategic possibilities for applying wastewater reuse within sustainable water resource management practices for conserving freshwater resources in areas of water scarcity [7].

Finally, the study contributes to the wider debate on regulation of industrial wastewater and underscores the need for strong monitoring systems, enhanced treatment technologies, and policy-based interventions in order to encourage environmental responsibility and sustainable use of resources in the packaged drinking water industry [8].

With increasing concerns over water scarcity and environmental pollution, it is critical to have effective monitoring and treatment processes for industrial wastewater. The results of this comparative study will help in better understanding the characteristics of wastewater in the packaged drinking water industry and provide suggestions for enhancing wastewater treatment and reuse. With the adoption of sustainable water management practices, the industry can reduce its ecological impact while maintaining compliance with environmental standards [8].

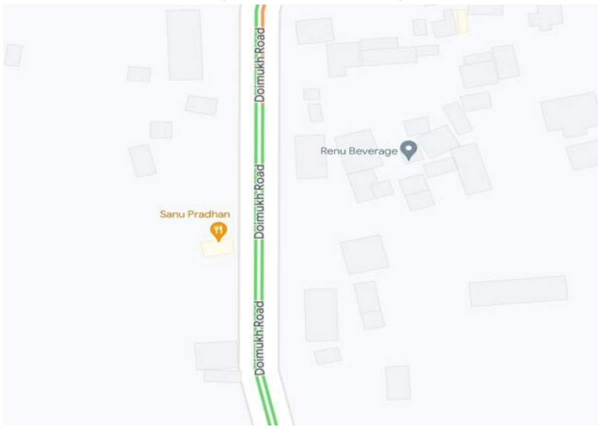
This research not only emphasizes the significance of wastewater evaluation in the bottled water industry but also indicates the necessity for responsible management of water resources for long-term environmental sustainability [8].

II. STUDY AREA

The selected study area includes two packaged drinking water manufacturing units—M/S Renu Beverage and M/S Polo International—situated in Nirjuli, Papumpare District, Arunachal Pradesh. Wastewater from these units was systematically collected and analyzed at the Environmental Laboratory of NERIST to evaluate its physicochemical characteristics and potential environmental implications.

A. Renu Beverage – Orchid Drop Mineral Water Factory

Renu Beverage manufactures Orchid Drop Mineral Water using the Reverse Osmosis (RO) method, a popular method of water treatment. RO applies a semi-permeable membrane to remove dissolved solids, microbial impurities, and other impurities under pressure. The process produces high-quality drinking water that is safe for use. RO-treated water is used widely in domestic, commercial, and industrial applications because of its efficiency and consistency [9].

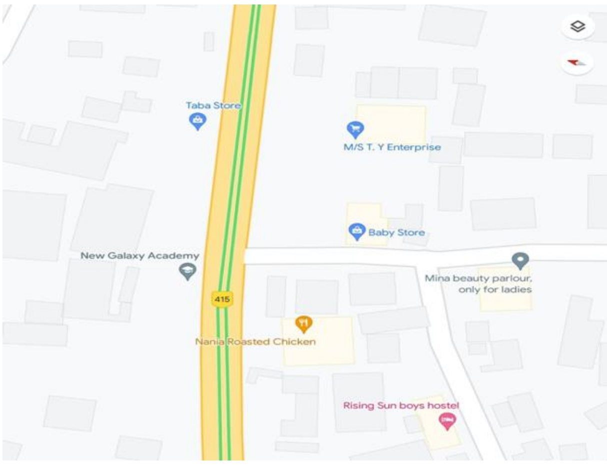


[Fig.1: Map View of Orchid Drop Factory (Renu Beverage), Nirjuli]

The wastewater generated from this facility contains concentrated contaminants removed during filtration, requiring assessment to determine its compliance with environmental discharge standards.

B. M/S Polo International – Polo Mineral Drinking Water Factory

M/S Polo International manufactures Polo Mineral Drinking Water and is engaged in the process of packaged drinking water plant systems development. The work of their business includes designing, assembling, and installing water treatment and bottling equipment. The plant uses a mixture of filters, high-pressure pumps, ultraviolet (UV) sanitizing, and automated bottling systems to maintain that its production guidelines comply with the quality standards defined by BIS and FSSAI regulations [10].



[Fig.2: Map View of Polo Mineral Water Factory (M/S T. Y Enterprise), Nirjuli]

Since the factory employs multiple water treatment processes, analyzing its wastewater discharge is essential to assess environmental impact and compliance with wastewater regulations. This study compares wastewater characteristics from both factories to evaluate water treatment efficiency and sustainability.

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III. WATER TREATMENT AND PACKAGING PROCESS

The water treatment and packaging of water and the management of wastewater discharge are important for the production of high-quality, safe drinking water and for the reduction of environmental footprint. Both M/S Renu Beverage and M/S Polo International adhere to a systematic method of water treatment and bottling that includes modern treatment methods and regulatory guidelines [11]. In this research, they are assessed with regard to their wastewater production, treatment effectiveness, and compliance with environmental regulations [12].

A. Water Treatment Process

The process of treatment includes various steps to get rid of the contaminants and check if the end product is compliant with BIS (Bureau of Indian Standards) and FSSAI (Food Safety and Standards Authority of India) regulations. The important steps are;

i. Chlorine/Hypochlorite Dosing System

Raw water is treated with sodium hypochlorite, which kills bacteria, viruses, and other microorganisms. This process also oxidizes iron and manganese, which prevents discoloration and bad taste. A diaphragm dosing pump provides controlled chemical addition to ensure water safety without overdosing [13].

ii. Raw Water Storage and Antiscalant Dosing

After disinfection, water is then held in a raw water storage tank prior to further processing. High mineral content in certain water sources will lead to scaling on RO membranes, lowering the efficiency of filtration. To prevent this, an antiscalant solution is introduced, creating a protective layer which prevents precipitation of hardness salts and improves the longevity of the RO membranes [14].

iii. Micron Filtration

Water is micron filtered prior to passing through the reverse osmosis (RO) system. This process entails cartridge filters with pore sizes between 20 microns and 1 micron, sequentially removing larger to smaller suspended particles, sediments, and contaminants [15]. The filters are replaced from time to time to ensure efficiency.

iv. Reverse Osmosis (RO) System

The RO process is the main purification process, in which water is pushed through a semi-permeable membrane under pressure. This eliminates dissolved solids, heavy metals, minerals, and microbial impurities, greatly enhancing water quality. The process efficiently lowers TDS (Total Dissolved Solids), providing clean and safe drinking water [16].

v. OZONE Treatment and Contact Tank

Prior to bottling, the treated water is ozone-treated, during which ozone gas (O_3) is introduced into the water for further disinfection. Ozone kills bacteria, viruses, and organic contaminants without leaving any harmful byproducts such as chlorine. The ozone contact tank provides enough mixing and contact time for efficient sterilization. This process also improves the taste and shelf life of the water [17].

B. Packaging Process

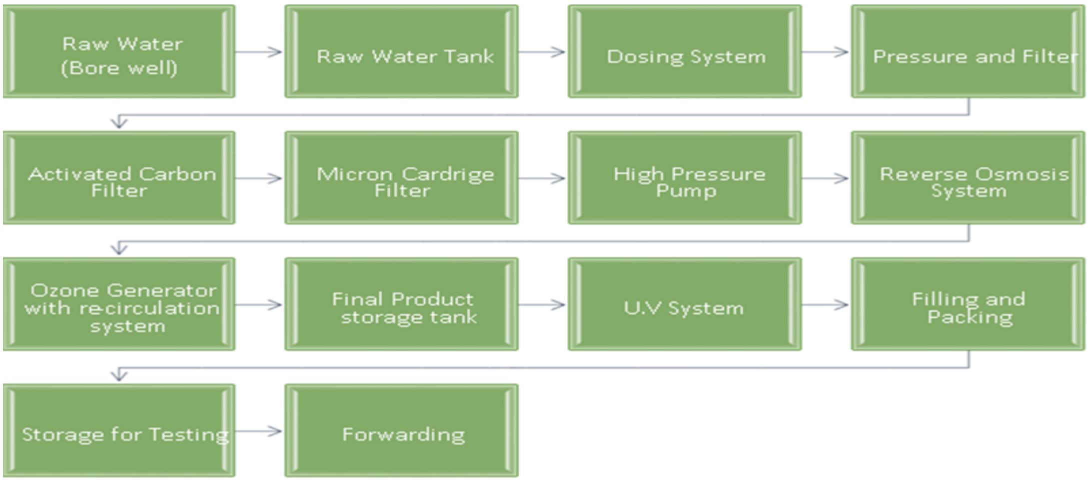
The packaging operation adheres to rigorous hygienic and quality control procedures to ensure product integrity and safety. The major steps are;

i. PET Bottle Manufacturing

Polyethylene Terephthalate (PET) bottles are manufactured on-site using stretch blow molding machines. This process ensures lightweight, durable, and food-grade bottles that meet industry standards [18]. The production capacity varies based on automation levels, with high-speed machines producing up to 3600 bottles per hour.

ii. Rinsing, Filling, and Capping

Bottles are automatically rinsed, filled, and capped using an integrated system to prevent contamination. The filling process is done using gravity or pressure-based fillers, ensuring precise volume control [19]. Caps are sealed tightly and stamped with manufacturing and expiry dates for traceability.



[Fig.3: A Typical Process Flowchart [11]]

iii. Labeling and Shrink Wrapping

Labels containing brand details, batch numbers, and regulatory information are applied to the bottles. Additionally, neck sleeves provide tamper-proof security. A shrink tunnel ensures that the labels and sleeves fit tightly to the bottle for a professional finish.

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iv. Final Packing and Distribution

Bottles are packed manually or through automatic packing machines into cartons for distribution. Fully automated packing machines enhance efficiency by integrating washing, filling, sealing, and labeling processes in a single unit.

C. Wastewater Monitoring and Management

The treatment and packaging processes generate wastewater containing residual chemicals, dissolved solids, and microbial contaminants. To prevent environmental pollution, wastewater quality is monitored using key parameters such as:

pH (acidity/alkalinity balance)
TSS (Total Suspended Solids)
TDS (Total Dissolved Solids)
DO (Dissolved Oxygen)
BOD (Biological Oxygen Demand

This study compares the wastewater discharge from Renu Beverage and Polo International, assessing their water treatment efficiency, regulatory compliance, and sustainability practices. The findings can help identify strategies to improve wastewater management and promote resource conservation in the bottled water industry [18].

Sl. No.	Parameters	Unit	Range	
			Permissible Limit	Maximum Limit
1	Odor	-	Agreeable	Agreeable
2	Temperature	°C	Agreeable	Agreeable
3	Taste	-	Agreeable	Agreeable
4	pH	-	6 to 9	No relaxation
5	TDS	ppm	500	2000
6	Conductivity (Cd)	mS	1	5
7	Turbidity	NTU	0	<5
8	Dissolved Oxygen (DO)	mg/l	2	8
9	Chloride	mg/l	250	1000
10	Alkalinity (as $CaCo_3$)	mg/l	100	600
11	Total suspended solids (TSS)	mg/l	30	1000
12	BOD_5	mg/l	20	30
13	Total Hardness	mg/l	0	250
14	Acidity (as $CaCo_3$)	mg/l	0	1000

[Fig.4: Standard wastewater specimen [Ministry of Environment, Forest and Climate Change (MoEFCC), 1986b, 2015, 2017b; National Green Tribunal order, 2019]

IV. WASTEWATER ANALYSIS AND MANAGEMENT IN MINERAL WATER FACTORIES

Mineral water factories typically discharge wastewater below permissible limits, but large volumes (6000-8000 L/day) can lead to the accumulation of chemicals, minerals, and contaminants, causing environmental concerns [19]. To assess variations in wastewater quality, three samples were collected from each factory at 10-minute intervals over two months (Dec 2022 – Jan 2023). However, M/S Polo International relocated near Don Bosco College, Jollang, and ceased operations, limiting further analysis. A five-month study (Dec 2022 – Apr 2023) continued at Renu Beverage, ensuring comprehensive parameter evaluation.

The study analyzed physical and chemical parameters based on BIS (Bureau of Indian Standards) guidelines and plotted monthly variations. The objective was to propose wastewater management solutions to optimize quality, quantity, and potential reuse, minimizing water loss and health hazards [19].

Key Water Quality Parameters Monitored:

- pH & Total Acidity
- Total Alkalinity & Chloride
- Dissolved Oxygen (DO)
- Biochemical Oxygen Demand (BOD)
- Total Hardness & Total Dissolved Solids (TDS)
- Total Suspended Solids (TSS) & Turbidity.
- Temperature & Specific Conductance.

V. AIMS AND OBJECTIVES

A. To determine the physical parameters according to the Standard Parameter such as pH, Temperature, turbidity, Total Dissolved Solids, Total Suspended Solids and Conductivity of Waste Water Discharge from Orchid Mineral Water Factory and Polo Mineral water Factory located in Nirjuli, Arunachal Pradesh.

B. To determine chemical parameters according to Standard Parameters such as Chloride, Dissolved Oxygen, Alkalinity, Acidity, Biochemical Oxygen demand and Total Hardness of Waste Water Discharge from Orchid Mineral Water Factory and Polo Mineral water Factory located in Nirjuli, Arunachal Pradesh.

C. To Propose a solution for the management of Waste Water generated in terms of Quality, Quantity, and Reuse of Waste Water Discharge.

VI. LITERATURE REVIEW

A. Weiner (2000) emphasized the importance of monitoring water quality through parameters like pH, turbidity, and TDS is essential in environmental resource management.

B. Subhadradevi G. et al. (2003) evaluated water quality in Velseo, Goa, identifying contamination risks by comparing physicochemical parameters against WHO standards.

C. Sonune A. et al. (2004) highlighted advanced wastewater treatment technologies, focusing on membrane filtration for water recycling. Membrane technology was noted for its efficiency, chemical-free operation, and lower energy consumption, making it a sustainable wastewater treatment solution.

D. Dietrich M. Andrea (2006) explored the sensory perception of drinking water, analyzing factors affecting taste and odor [5]. The study emphasized the importance of addressing aesthetic water quality issues and suggested future research directions for improving water treatment and consumer acceptance.

E. Krishnan Radha R. et al. (2007) evaluated drinking, borewell, and sewage water quality in Sivakasi,

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analyzing physicochemical and bacterial parameters. While chemical parameters were within limits, bacterial contamination exceeded WHO standards, indicating the need for boiling and sewage management.

F. **Tavor D. et al. (2007)** investigated geopolymer cement for immobilizing heavy metals in industrial wastewater, reducing pollutant leaching and allowing safe wastewater reuse. The study highlighted geopolymerization as a sustainable wastewater treatment method.
G. **Hussaina S. et al. (2010)** compared physicochemical properties of treated and untreated water in Ahmedpur, Latur. The results showed significant improvements post-treatment, reinforcing the effectiveness of water purification systems.
H. **Gaikwad R. W. et al. (2011)** analyzed groundwater quality in Lonar Lake, detecting high iron, chloride, fluoride, calcium, and magnesium levels. The study recommended treatment measures to ensure safe water consumption and protect groundwater from contamination.
I. **Gorde S. P. et al. (2013)** stressed the impact of industrialization and agriculture on water quality, emphasizing the need for regular monitoring of pH, turbidity, salinity, nitrates, phosphates, and macroinvertebrates to assess pollution sources and ecosystem health.

VII. METHODOLOGY

This section outlines the procedures, materials, and methods used to analyze water quality parameters from Orchid Drops and Polo Mineral Water Factory. It details the sampling process, instruments used, and data collection techniques for assessing the physicochemical properties of collected samples.

A. Experimental Procedure

The study employed various instruments and techniques to determine water quality parameters. The instruments used are listed below,

Table-I: Water Quality Parameters and Instruments Used

Sl. No	Water Quality Parameters	Name of the Instrument
1	Temperature	Celsius Thermometer / Multiparameter
2	Turbidity	Turbidity meter
3	Dissolved Oxygen	Multiparameter
4	pH	Multiparameter
5	Total Dissolved Solid	Multiparameter
6	Alkalinity	Titration Method
7	Specific Conductivity	Multiparameter
8	Chlorides	Titration Method
9	Total Hardness	Titration Method
10	Biological Oxygen Demand (BOD)	Multiparameter Standard Method (5-day BOD)
11	Total Suspended Solids	Gravimetric Method

B. Sampling

Water samples were collected from three different points at 10-minute, 20-minute, and 30-minute intervals from both Polo and Orchid Drop Mineral Water Factories for testing at NERIST Environmental Lab. Sampling was conducted from December 2022 to April 2023, with three readings recorded and averaged for accuracy.

- Samples from Orchid Drop were collected in ½-liter bottles and from Polo in 1-liter bottles.
- After January 2023, M/S Polo International ceased operations, making further sample collection from this factory impossible.
- From February to April 2023, only rejected water from Renu Beverage (Orchid Drop) was collected monthly for continued analysis.

[Fig.5: Water Samples from Orchid Water Factory]

[Fig.6: Water Samples from Polo Water Factory]

Study analyzed wastewater quality to assess environmental impact and ensure regulatory adherence.

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VIII. INSTRUMENT USED

Table-II: Instruments Used for Measuring Physico-Chemical Parameters

Instrument	Description	Parameters Measured	References
Multiparameter	An advanced analytical device capable of simultaneously measuring multiple electrochemical parameters such as pH, temperature, DO, turbidity, conductivity, salinity, resistivity, millivolts (mV), TDS, and barometric pressure.	pH, DO, TDS, Temperature, Cd	[1]
Turbidity Meter	Also known as a Nephelometer, it operates by emitting light and detecting the scattered light caused by suspended particles in the sample. The measurement units depend on light wavelength and detection angle, typically recorded in NTU or FNU.	Turbidity	[4]
Titration Setup	Laboratory titration apparatus including burette, pipette, and indicators like phenolphthalein and methyl orange, used for quantitative chemical analysis.	Alkalinity, Acidity, Chlorides, Hardness, Chlorides, Nitrates	[9]
Gravimetric Setup	Consists of filter paper, filtration unit, and a drying oven to measure the mass of suspended solids after filtration and drying.	Total Suspended Solids (TSS)	[10]
BOD Incubator / Setup	Standard BOD incubator or setup for 5-day biochemical oxygen demand test, involving airtight flasks and DO monitoring.	Biochemical Oxygen Demand (BOD_5)	[18]

IX. PHYSICO-CHEMICAL PARAMETERS

Physico-chemical parameters are used to evaluate water quality, composition, and suitability for different applications. These parameters help determine the potential environmental impact of wastewater discharge from mineral water factories. The study analyzed samples from Polo and Orchid Drop Mineral Water Factories to track variations over time and assess their compliance with regulatory standards [20].

A. Total Acidity

Acidity measures the presence of acid-forming substances in water, which can corrode pipes and affect water chemistry [20]. In this study, no acidity was detected in any wastewater samples from Polo and Orchid Drop factories

B. pH

pH is a measure of acidity or alkalinity, with a scale ranging from 0 to 14. A neutral pH is 7, the values below indicate acidity, and the values above indicate alkalinity.

Table-III: Average pH Value of Wastewater from both source

Months	Polo (Average Ph Value)	Orchid (Average Ph Value)
December	7.28	6.55
January	7.36	6.57
February	-	6.41
March	-	7.18
April	-	7.19

The pH of natural and processed water is influenced by dissolved minerals, gases, and other substances. Maintaining a balanced pH is essential for water treatment, industrial processes, and environmental sustainability [21].

C. Alkalinity

Alkalinity is water's ability to neutralize acids, preventing sudden pH fluctuations. It is essential for maintaining stable water chemistry and protecting aquatic life. It is measured in mg/L as $CaCO_3$ (calcium carbonate equivalent) [22].

Table-IV: Average Alkalinity Value of Wastewater from both Sources

Months	Polo (Average Alkalinity Value) mg/l	Orchid (Average Alkalinity Value) mg/l
December	508.00	453.33
January	509.33	483.33
February	-	451.33
March	-	502.00
April	-	508.67

D. Total Dissolved Solids (TDS)

TDS refers to the total concentration of dissolved inorganic and organic substances in water, measured in ppm (mg/L). It influences water purity, taste, and suitability for drinking and industrial use. High TDS levels can cause scaling in pipelines and affect the efficiency of filtration systems [23].

Table-V: Average TDS Value of Wastewater from both Sources

Months	Polo (Average TDS Value) ppm	Orchid (Average TDS Value) ppm
December	279.33	90.50
January	274.67	105.00
February	-	138.67
March	-	174.60
April	-	150.70

E. Total Suspended Solid (TSS)

TSS refers to solid particles in water that do not dissolve and can clog filtration systems, reduce light penetration, and carry pollutants. High TSS levels indicate increased contamination and potential sedimentation issues [24].

Table-VI: Average TSS Value of Wastewater from both Sources

Months	Polo (Average TSS Value) mg/l	Orchid (Average TSS Value) mg/l
December	250.44	181.11
January	235.56	206.67
February	-	186.67
March	-	225.37
April	-	214.94

F. Conductivity (Cd)

Conductivity (Cd) measure's ability of water to conduct an electric current, which depends on the presence of dissolved ions such as salts, acids, and bases. High conductivity values indicate a greater concentration of ions, which may affect water quality and industrial usage. It is expressed in milli Siemens per meter (mS/m) [25].

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Table-VII: Average Cd Value of Wastewater from both Sources

Months	Polo (Average Cd Value) mS	Orchid (Average Cd Value) mS
December	0.42	0.14
January	0.24	0.12
February	-	0.24
March	-	0.26
April	-	0.21

G. Biochemical Oxygen Demand (BOD_5)

BOD_5 measures the oxygen required by microorganisms to decompose organic matter in water over five days. High BOD levels indicate organic pollution, which can deplete oxygen levels in aquatic environments, leading to water quality degradation [26].

Table-VIII: Average BOD5 Value of Wastewater from both Sources

Months	Polo (Average BOD_5 Value) mg/l	Orchid (Average BOD_5 Value) mg/l
December	6.39	1.67
January	5.00	3.89
February	-	2.50
March	-	12.50
April	-	3.33

H. Turbidity

Turbidity represents the cloudiness or haziness of water due to suspended particles like sediments, organic matter, and microorganisms. High turbidity can reduce light penetration, affect aquatic life, and interfere with water treatment processes. It is measured in Nephelometric Turbidity Units (NTU) [27].

Table-IX: Average Turbidity Value of Wastewater from both Sources

Months	Polo (Average Turbidity Value) NTU	Orchid (Average Turbidity Value) NTU
December	3.81	0
January	3.59	0.03
February	-	0.04
March	-	0.22
April	-	0.20

I. Total Hardness

Hardness measures the concentration of calcium and magnesium ions in water [28]. Hard water can cause scaling in pipelines and appliances, affecting industrial and household water use [29]. It is expressed in mg/L as $CaCO_3$ [30].

Table-X: Average Total Hardness Value of Wastewater from both Sources

Months	Polo (Average Total Hardness Value) mg/l	Orchid (Average Total Hardness Value) mg/l
December	64.56	51.07
January	65.00	46.60
February	-	43.98
March	-	45.39
April	-	49.00

J. Dissolved Oxygen (DO)

Dissolved Oxygen (DO) refers to oxygen available in water for aquatic organisms. It is essential for sustaining aquatic life and biochemical reactions [28]. DO levels depend on factors like temperature, organic pollution, and water flow. Low DO levels indicate pollution and potential harm to ecosystems [31].

Table-XI: Average DO Value of Wastewater from both Sources

Months	Polo (Average DO Value) mg/l	Orchid (Average DO Value) mg/l
December	5.40	5.73
January	5.47	5.40
February	-	7.23
March	-	7.77
April	-	7.23

K. Temperature

Temperature influences water chemistry, biological activity, and oxygen solubility [28]. Warmer water holds less oxygen, which may affect aquatic life and water quality [32]. Sudden temperature changes can disrupt ecosystems and industrial processes [33].

Table-XII: Average Temperature Value of Wastewater from both Sources

Months	Polo (Average Temperature Value) ^oC	Orchid (Average Temperature Value) ^oC
December	21.13	20.20
January	21.10	21.93
February	-	22.80
March	-	22.90
April	-	28.10

L. Chloride

Chloride content in water comes from natural sources, industrial discharge, and road salts. High chloride levels can cause corrosion in pipelines, affects taste. The presence of excessive chloride indicates potential contamination [28].

Table-XIII: Average Chloride Value of Wastewater from both Sources

Months	Polo (Average Chloride Value) mg/l	Orchid (Average Chloride Value) mg/l
December	35.55	41.67
January	36.36	39.17
February	-	43.39
March	-	39.38
April	-	39.80

X. RESULTS

This section outlines the measured outcomes and observations from laboratory testing, results and analysis of wastewater samples collected from Polo Drinking Water Factory (Dec 2022 – Jan 2023) and Orchid Drop Factory (Dec 2022 – Apr 2023). Comparative analysis for December and January was done for both factories, while extended monitoring was conducted solely for Orchid Drop due to Polo factory's shutdown in early 2023. It includes all collected data, calculations, and averages derived from the experimental process. Results are presented in a structured format and form the basis for further interpretation and discussion in terms of water quality, environmental impact, and sustainable reuse possibilities.

The study focuses on evaluating key

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physico-chemical parameters, identifying deviations from BIS standards, and proposing measures for quality control, wastewater quantity management, and potential reuse.

The results include data on pH, TDS, DO, BOD, turbidity, temperature, hardness, alkalinity, chloride, and other important indicators of water quality. These are presented through tables and graphs for clarity and to highlight month-wise fluctuations and trends.

Table-XIV: Physico-Chemical Parameters of Waste Water Sample of Polo of the Month Dec. 2022 and Jan. 2023

Sl. No.	Parameters	Units	Months	
			December 2022	January 2023
1	pH	-	7.28	7.36
2	TDS	ppm	279.33	274.67
3	Cd	mS	0.42	0.24
4	Turbidity	NTU	3.81	3.59
5	DO	mg/l	5.40	5.47
6	Temperature	ºC	21.13	21.10
7	Chloride	mg/l	35.55	36.36
8	Alkalinity	mg/l	508.00	509.33
9	TSS	mg/l	250.44	235.56
10	BOD_5	mg/l	6.39	5.00
11	Hardness	mg/l	64.56	65
12	Acidity	mg/l	-	-

A. Polo Factory Water Analysis (Table 14)

- pH (7.28–7.36): Slightly alkaline but within acceptable range. No strong acidity or alkalinity detected.
- TDS (279–274 ppm): Relatively high for wastewater, indicating significant dissolved solids, possibly from mineral rejection in filtration units.
- Conductivity (0.42 to 0.24 mS): Mirrors the TDS trend; December showed higher ionic load.
- Turbidity (3.81–3.59 NTU): Indicates presence of suspended particles, likely fine sediments or treatment by-products.
- DO (5.40–5.47 mg/l): Moderate levels; suggests the wastewater isn't highly anaerobic or toxic but still needs aeration before reuse.
- BOD_5 (6.39 → 5.00 mg/l): Above typical discharge norms, pointing to a moderate organic load.
- TSS (250–235 mg/l): Fairly high, showing visible suspended waste particles.
- Alkalinity, Hardness, Chloride: All within typical range, suggesting chemical stability but the cumulative effect of discharge could alter receiving water bodies.
- Acidity: Not detected.

Polo's wastewater shows signs of moderate contamination especially in terms of BOD, TSS, and TDS. Regular discharge in this condition could harm natural water bodies if not properly treated.

Table-XV: Physico-Chemical Parameters of Waste Water Sample of Orchid from Dec. 2022 – April. 2023

Sl. No.	Parameters	Units	Months				
			Dec-22	Jan-23	Feb-23	Mar-23	Apr-23
1	pH	-	6.55	6.57	6.41	7.18	7.19
2	TDS	ppm	90.5	105	138.67	174.6	150.7
3	Cd	mS	0.14	0.12	0.24	0.26	0.21
4	Turbidity	NTU	0	0.03	0.04	0.22	0.2
5	DO	mg/l	5.73	5.4	7.23	7.77	7.23
6	Temperature	ºC	20.2	21.93	22.8	22.9	28.1
7	Chloride	mg/l	41.67	39.17	43.39	39.38	39.8
8	Alkalinity	mg/l	453.33	483.33	451.33	502	508.67
9	TSS	mg/l	181.11	206.67	186.67	225.37	214.94
10	BOD_5	mg/l	1.67	3.89	2.5	12.5	3.33
11	Hardness	mg/l	51.07	46.6	43.98	45.39	49
12	Acidity	mg/l	-	-	-	-	-

B. Orchid Drop Wastewater Analysis (Table 15)

- pH (6.41–7.19): Gradually stabilizes to near-neutral — initially slightly acidic, which could affect aquatic life if discharged untreated.
- TDS (90.5 → 174.6 ppm): Indicates increasing dissolved solids, possibly due to system inefficiencies or buildup over time.
- Conductivity (0.12 → 0.26 mS): Correlates with TDS rise needs control to prevent excessive salt accumulation in reuse settings like irrigation.
- Turbidity (0 → 0.22 NTU): Generally low, but rising trend may reflect ineffective filtration or sediment accumulation in discharge tanks.
- DO (5.4 → 7.77 mg/l): Improvement suggests good aeration and low immediate toxicity, which is favorable for reuse scenarios.
- BOD_5 (1.67 → 12.50 mg/l): Sharp spike in March, indicating increased organic pollutants — possibly due to system maintenance lapses or higher load.
- TSS (181 → 225 mg/l): Comparable to Polo's, but with a spike in March — must be filtered before any reuse.
- Alkalinity (453 → 508 mg/l): Consistently high — may buffer pH but indicates carbonate build-up.
- Temperature (20.2 → 28.1°C): Rises with ambient climate — influences microbial activity and BOD behavior.
- Hardness (43.9 → 51 mg/l): Moderate — could impact pipe scaling if reused in industrial cooling or cleaning processes.
- Acidity: Absent across all months.

Orchid Drop's wastewater is generally cleaner than Polo's, especially in early months, but shows rising trends in pollutants by March, particularly in BOD and TSS. These must be addressed for safe reuse or disposal.

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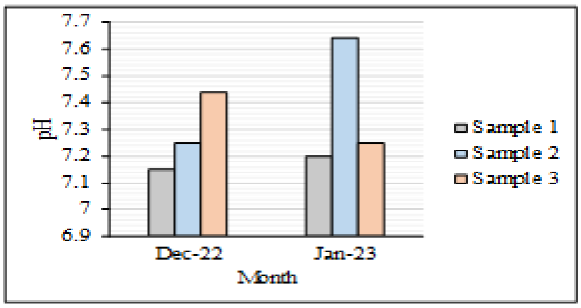
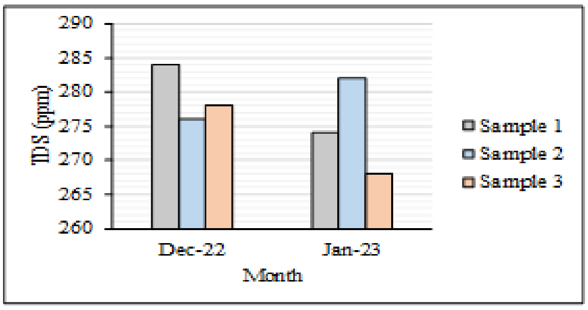
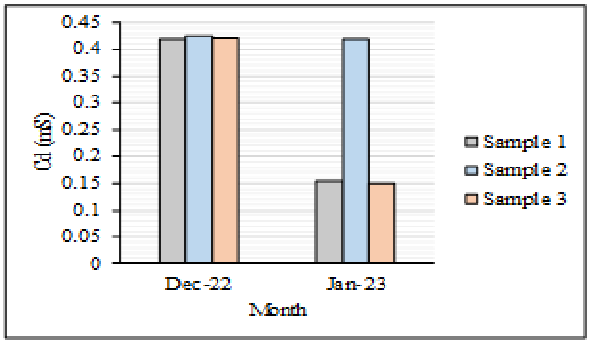
C. Followings are the Graphs for Variation of Values of Different Physico-Chemical Parameters for Polo Factory Wastewater Observed During December 2022 – January 2023 is Presented



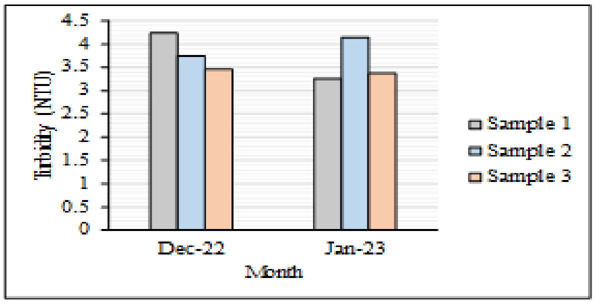
[Fig.7: Variation of pH in the Range of (7.15 – 7.64)]



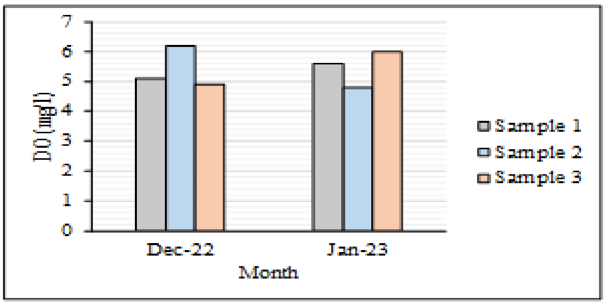
[Fig.8: Variation of TDS in the Range of (268 – 284) ppm]



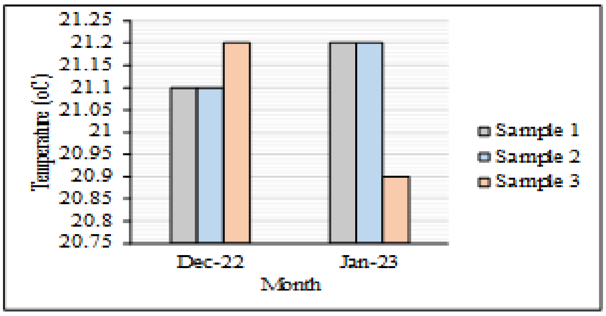
[Fig.9: Variation of Cd in the Range of (0.149 – 0.424) mS]



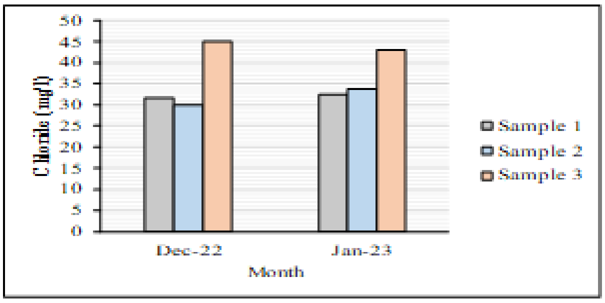
[Fig.10: Variation of Turbidity in the Range of (3.25 – 4.24) NTU]



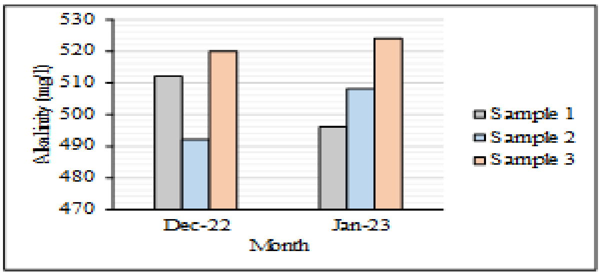
[Fig.11: Variation of DO in the Range of (4.8 – 6.2) mg/l]



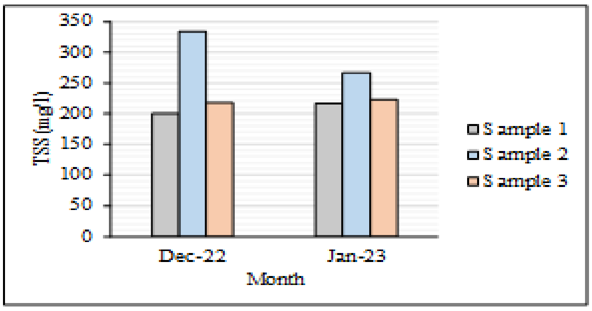
[Fig.12: Variation of Temperature in the range of (20.9 – 21.2) oC]



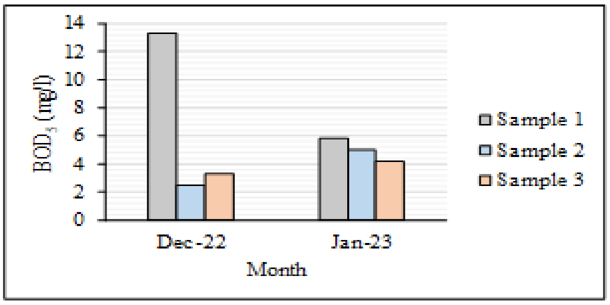
[Fig.13: Variation of Chloride in the Range of (30 - 45) mg/l]



[Fig.14: Variation of Alkalinity in the Range of (492 - 524) mg/l]



[Fig.15: Variation of TSS in the Range of (200 – 333.33) mg/l]



[Fig.16: Variation of BOD5 in the Range of (2.5 – 13.33) mg/l]

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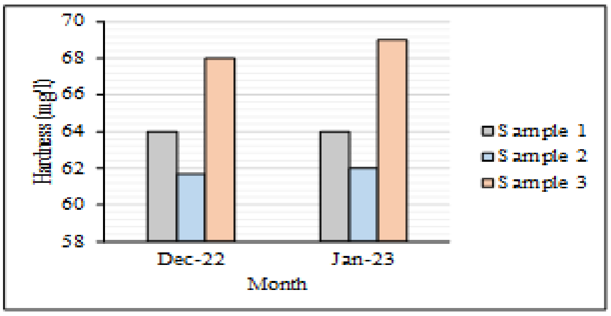
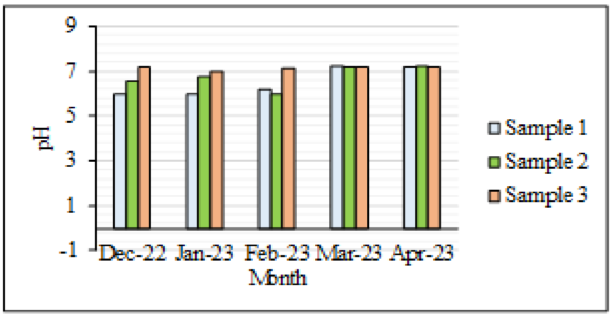
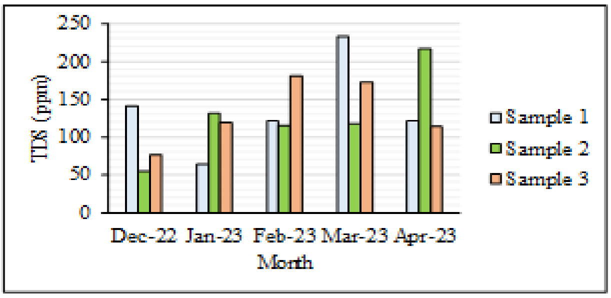


[Fig.17: Variation of Hardness in the Range of (61.67 - 69) mg/l]

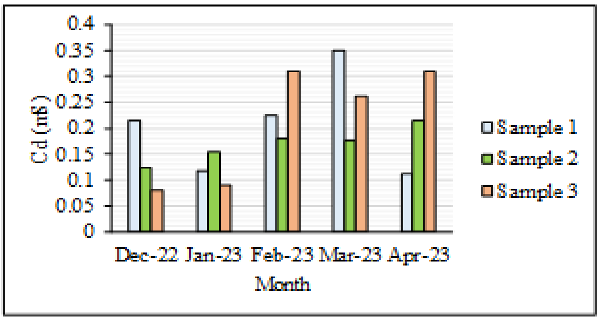
D. Followings are the graphs for variation of values of different physico-chemical parameters for Orchid Drinking Water factory wastewater observed during December 2022 – April 2023 is presented



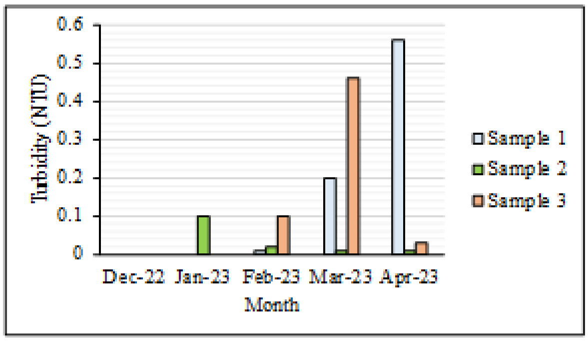
[Fig.18: Variation of pH in the Range of (5.95 – 7.21)]



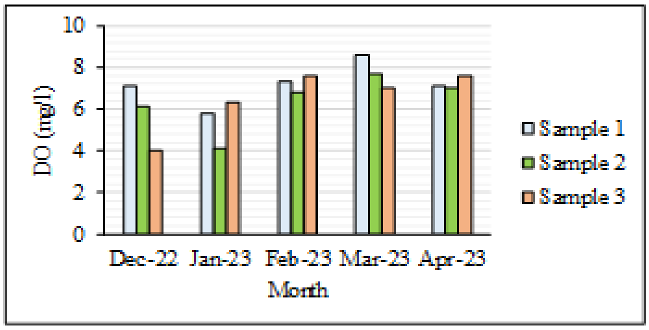
[Fig.19: Variation of TDS in the Range of (54.5 – 233) ppm]



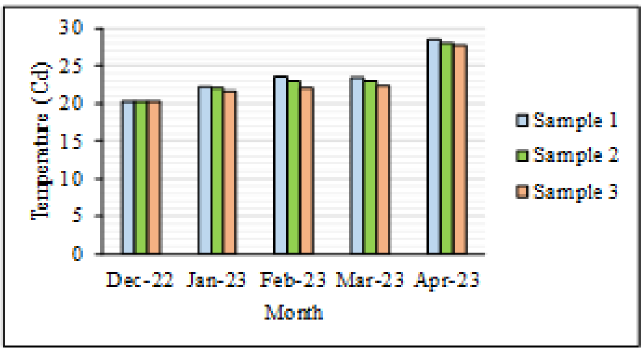
[Fig.20: Variation of Cd in the Range of (0.081 – 0.35) mS]



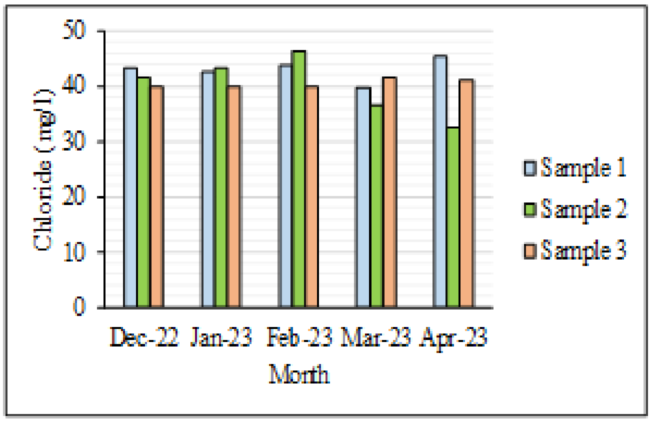
[Fig.21: Variation of Turbidity in the Range of (0 – 0.56) NTU]



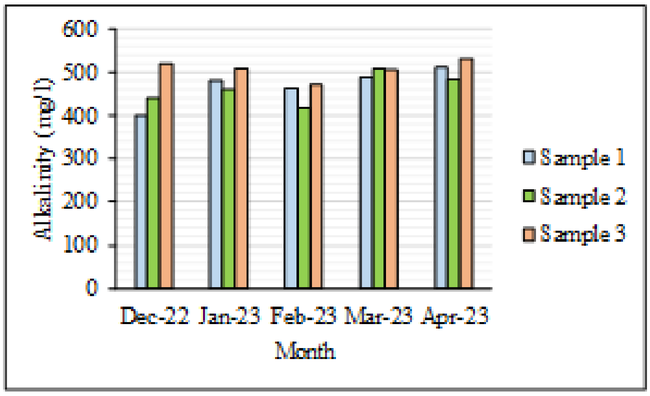
[Fig.22: Variation of DO in the Range of (4 - 8.6) mg/l]



[Fig.23: Variation of Temperature in the Range of (20.2 – 28.5) oC]



[Fig.24: Variation of Chloride in the Range of (32.65 – 46.5) mg/l]



[Fig.25: Variation of Alkalinity in the range of (400 – 530) mg/l]

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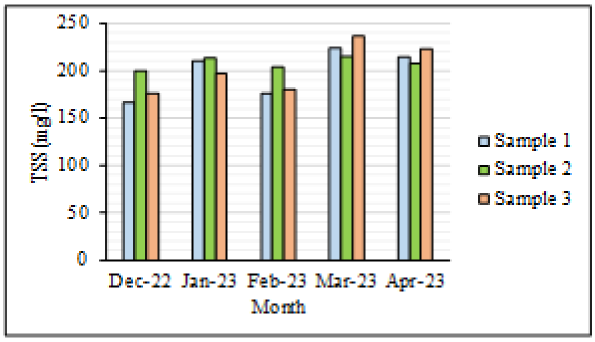
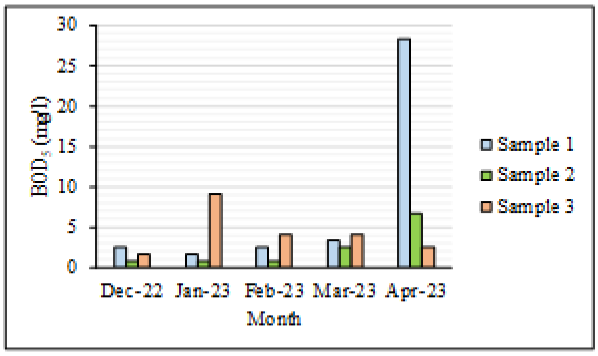
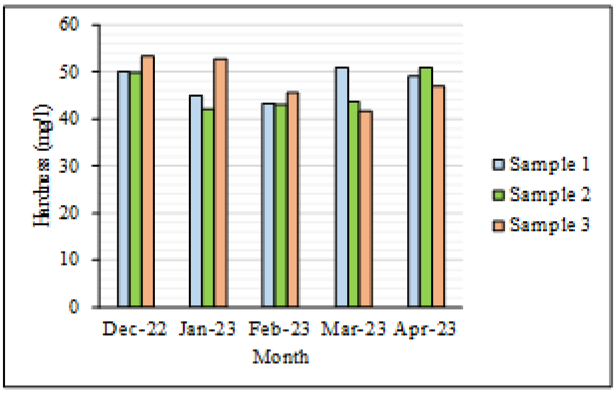


[Fig.26: Variation of TSS in the Range of (166.67 – 236.67) mg/l]



[Fig.27: Variation of BOD5 in the Range of (0.833 – 28.33) mg/l]



[Fig.28: Variation of Total Hardness in the Range of (41.67 – 53.4) mg/l]

E. Key Component Insights

Parameter	Polo Wastewater (2 Months)	Orchid Wastewater (5 Months)
TDS	Higher & consistent	Lower, but increasing
TSS	High	Moderate, rising in March
BOD5	Moderate to high	Low initially, spiked in March
DO	Moderate	Higher and better oxygenation
pH	Neutral	Slightly acidic to neutral
Turbidity	High	Low, but rising

XI. DISCUSSIONS

Based on the analysis of wastewater samples collected from Polo Mineral Water Factory (Dec 2022–Jan 2023) and Orchid Drop (Dec 2022–Apr 2023), most physico-chemical parameters were found to be within or below the permissible limits as per wastewater discharge standards.

A. Parameter-wise Summary

- pH values for both factories ranged between 6.0–7.5, which falls within the acceptable range of 6–9.
- Total Dissolved Solids (TDS) remained well below the permissible range of 500–2000 ppm, indicating low mineral saturation in the wastewater.
- Conductivity (Cd) readings were significantly below the limit (1–5 mS), suggesting minimal ionic contamination.
- Turbidity stayed below 5 NTU in both cases, with Orchid showing near-zero values—indicating clearer effluent.
- Dissolved Oxygen (DO) levels were healthy (5–8 mg/l), supporting aerobic conditions in the effluent.
- Chloride content (35–44 mg/l) was far below the concern threshold of 250 mg/l.
- Alkalinity values for both units (450–510 mg/l) stayed within the safe buffering range (100–600 mg/l).
- Total Suspended Solids (TSS) were moderate (180–250 mg/l), reflecting particulate content but still within the limit.
- Biochemical Oxygen Demand (BOD_5) was significantly low (Polo: ~5–6.5 mg/l, Orchid: 1–13 mg/l), far under the standard range of 20–30 mg/l.
- Total Hardness for both plants ranged between 40–70 mg/l, which is well below the 250 mg/l threshold.
- Acidity was not detected in any sample, suggesting stable pH buffering.

The wastewater from both factories does not indicate major pollution risks based on the analyzed parameters. However, Orchid's March BOD_5 spike (12.5 mg/l) and a gradual increase in TDS and turbidity call for regular monitoring to ensure consistent compliance. With an estimated daily discharge of 6,000–8,000 liters, the wastewater generated from Orchid Drop and Polo Mineral Water Factories presents a significant opportunity for reuse and sustainable management. Given that the wastewater falls within permissible limits for most key parameters, it can be safely repurposed for various non-potable applications, provided proper treatment is in place.

B. Potential Uses of Treated Wastewater

- Irrigation: Treated wastewater can be used for agricultural fields, landscaping, and urban green zones, reducing pressure on freshwater for irrigation.
- Industrial Use: Reuse in cooling towers, floor washing, or process water in nearby industries, especially where high-quality water isn't essential.
- Aquaculture (with caution): After comprehensive treatment, reuse in fish farming systems is possible. However, regular quality checks and compatibility assessments are crucial.
- Groundwater Recharge: Wastewater can be directed to recharge pits to improve aquifer levels, help combat land subsidence, and support long-term water security.
- Urban Utility (Non-potable): Ideal for toilet flushing, car washing, dust suppression, construction works, and street cleaning – saving large volumes of freshwater.

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- Environmental Flow Augmentation: Treated water may be safely released into natural water bodies like Dikrong River (Doimukh) to help maintain ecological balance.

XII. RECOMMENDATIONS

To ensure efficient and responsible handling of wastewater from packaged drinking water factories, several key measures can be adopted,

A. Water Efficiency Improvements

Improving water efficiency is the first and most cost-effective step. This can be achieved by conducting regular water audits to identify and fix leakages throughout the system. The use of low-flow fixtures and the integration of closed-loop rinse systems can significantly reduce water consumption during production. Also, lightly contaminated water such as rinse water from bottles or machinery, can be reused internally for non-critical operations like floor washing or cleaning, thereby conserving freshwater.

B. Modular Treatment Systems

The installation of compact, decentralized treatment systems is essential for small to medium-scale operations. Technologies such as Moving Bed Biofilm Reactors (MBBRs), biofilters, or sand/charcoal filters provide low-cost and low-maintenance alternatives for on-site treatment. These modular systems can be designed to suit limited space and fluctuating flow rates. In addition to this, simple settling tanks with efficient sludge management systems should be adopted to treat solid waste generated during the process.

C. Structured Reuse Plans

An explicit reuse plan is critical to achieve optimum recovery of resources. Factories must develop a comprehensive reuse plan that considers seasonal variations in effluent amount and quality. Pilot schemes can be initiated to pilot-test wastewater reuse for applications such as landscape irrigation, vehicle washing, or toilet flushing within the factory. Further, collaboration with local farms or small industries can also allow the external utilization of treated wastewater, generating a win-win environmental as well as economic advantage.

D. Monitoring, Testing and Automation

Accurate data is essential for effective wastewater management. There should be a monthly monitoring system to monitor major water quality parameters like TDS, BOD_5, TSS, pH, and DO. For real-time visibility and responsiveness, factories can implement IoT-based water quality sensors and monitoring dashboards. Regular recording of equipment maintenance, chemical consumption, and sludge handling operations should also be kept to provide transparency and compliance with regulations.

E. Future-Proofing the System

In the future, it is necessary to extend the scope of testing to encompass microbiological parameters such as E. coli and total coliforms, particularly if the wastewater is to be used for irrigation or reuse close to human populations. Feasibility studies need to be undertaken to assess the scalability of existing reuse operations. In addition, government agency, NGO, or university collaboration can facilitate the creation of circular water management models specific to the packaged drinking water sector—providing both environmental and long-term operating resilience.

XIII. CONCLUSION

The examination of the wastewater of Renu Beverage (Orchid Drop) and M/S Polo International has rendered valuable information concerning the quality and nature of the effluent produced by packaged drinking water plants. Even though discharges ranging between 6,000–8,000 liters per day occurred, most the major parameters including pH, TDS, DO, BOD_5, and TSS, were at acceptable limits reflecting minimal environmental burdens. Nonetheless, the regular monitoring and enhanced management are necessary to avoid long-term risk of pollution. The research reaffirms sustainable wastewater management, which entails onsite treatment, reuse, and recycling, to minimize wastage of water and stress to the environment.

Through taking up efficient treatment systems, recycling treated water for non-potable uses, and imposing routine testing, these plants can convert wastewater into a useful commodity, favoring water conservation, protection of the ecosystem, and business sustainability.

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DECLARATION STATEMENT

I, Jumbom Ruti, hereby declare that the manuscript titled "**Comparative Study of Wastewater Generated from Mineral Water Factory, Arunachal Pradesh**" is my original work and has not been published previously, nor is it under consideration for publication elsewhere. All sources used and contributions from others have been properly acknowledged and cited in accordance with academic and publishing standards.

This work was carried out under the guidance of Dr. Mudo Puming, Associate Professor, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, Arunachal Pradesh..

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** Yes, I received financial support during my M.Tech program in the form of a monthly scholarship through the GATE qualification, funded by the Ministry of Education, Government of India. This

scholarship supported my academic research and contributed to the successful execution of this study. https://www.education.gov.in/ministry-education

- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** Each author has individually contributed to the article.
  - Jumbom Ruti (Main Author): Conducted the research, collected and analyzed the data, and prepared the manuscript.
  - Dr. Mudo Puming (Co-author): Provided supervision, academic guidance, and critically reviewed the final manuscript.

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AUTHOR'S PROFILE

Jumbom Ruti is a PhD Research Scholar in Civil Engineering at NERIST, specializing in the field of solid waste management. His current research focuses on Anaerobic Digestion using Moss, Algae, and Biochar, particularly for rural areas in Arunachal Pradesh. This work aims to develop sustainable and efficient methods for managing solid waste through biological processes, with a focus on enhancing biogas production and improving process stability. Previously, He completed his M.Tech in Environmental Engineering, specializing in Wastewater Management. His M.Tech thesis focused on the wastewater generated from the Polo and Orchid Drop Mineral Water factories, contributing to sustainable water treatment solutions in the Nirjuli region of Arunachal Pradesh. He is passionate about finding innovative solutions for the sustainable management of waste and wastewater in rural and industrial settings.

Dr. Mudo Puming is an Associate Professor in the Department of Civil Engineering at NERIST, Arunachal Pradesh. With a strong academic and research background in Environmental Engineering Dr. Puming has made notable contributions to the fields of solid waste management, eco-friendly waste processing, waste water treatment, water quality monitoring and sustainable environmental technologies. She has guided multiple postgraduate and doctoral research scholars and continues to be a pivotal figure in advancing practical and research-driven solutions for the region's environmental challenges. Dr. Puming has co-authored and reviewed several research papers in reputed journals and her mentorship has helped shape the academic trajectory of scholars working on cutting-edge environmental topics. As a faculty member committed to academic excellence and applied research Dr. Puming remains actively engaged in capacity building, student mentorship and research projects aimed at promoting environmental sustainability in northeast India.

APPENDIX

Appendix A: Sampling Information

Factory Name	Location	Sample Interval
Renu Beverage (Orchid Drop)	Nirjuli, Arunachal Pradesh	10 min, 20 min, 30 min
M/S Polo International	Nirjuli, Arunachal Pradesh (till Jan 2023)	10 min, 20 min, 30 min

Appendix B: Instrument Used for Analysis

Sl. No	Parameter	Instrument/Method Used
1	pH	Multiparameter Meter
2	Turbidity	Turbidity Meter (NTU)
3	Dissolved Oxygen (DO)	Multiparameter Meter
4	Temperature	Multiparameter Meter
5	Total Dissolved Solids (TDS)	Multiparameter Meter
6	Conductivity (Cd)	Multiparameter Meter
7	Alkalinity	Titration Method (Phenolphthalein + M.O.)
8	Chloride	Titration Method
9	Total Hardness	EDTA Titration Method
10	BOD_5	5-Day Standard Method
11	Total Suspended Solids (TSS)	Gravimetric Method
12	Acidity	Titration Method

Appendix C: Regulatory Limits for Reference (Based on BIS and MoEFCC Guidelines)

Sl. No.	Parameter	Unit	Permissible Range
1	pH	-	6.0 – 9.0
2	TDS	mg/L	500 – 2000
3	Conductivity (Cd)	mS	1 – 5
4	Turbidity	NTU	<5
5	DO	mg/L	2 – 8
6	Chloride	mg/L	250 – 1000
7	Alkalinity	mg/L	100 – 600
8	TSS	mg/L	30 – 1000
9	BOD_5	mg/L	20 – 30
10	Total Hardness	mg/L	<250
11	Acidity	mg/L	Not Applicable