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Physico Chemical Analysis of Wastewater in Perspective of Sustainable Development for an Urban Agglomeration in India and Nigeria

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ABSTRACT

Urban wastewater in Kota, Rajasthan, primarily arises from power plants and manufacturing industries, posing significant challenges due to industrial discharge and rapid urbanization. In contrast, Bauchi Metropolis in northeastern Nigeria is a rapidly growing city with diverse agricultural, commercial, and small-scale industrial activities but struggles with inadequate wastewater infrastructure for collection and treatment. Sustainable development, which seeks to balance environmental, economic, and social goals, requires collaboration among government, businesses, and individuals to foster long-term changes. Both cities must adopt localized and scalable wastewater treatment solutions, enhance infrastructure, and ensure regulatory compliance. Collaborating with international organizations and embracing innovative solutions will be essential for improving water quality and ensuring sustainable urban growth. This study analyzed water samples from both cities during winter and summer seasons, focusing on water quality parameters. The results revealed significant seasonal variations: in India, domestic wastewater pH dropped from 5.22 in winter to 2.22 in summer, while BOD in Nigeria increased from 8.04 mg/L to 8.45 mg/L. DO show a slight increase in India, reaching 8.0 mg/L for industrial wastewater in summer. Turbidity in Nigeria's domestic wastewater decreased from 357.4 NTU to 180.3 NTU in summer. Hardness was higher in winter, particularly in India's industrial wastewater at 105 mg/L, while no significant seasonal differences were observed in density. Higher values for electrical conductivity, chloride ion concentration, and calcium hardness were noted in winter. Correlation analysis identified relationships among the analyzed parameters, guiding the selection of appropriate wastewater treatment methods for implementation in treatment plants.

Introduction

Wastewater is the main source of micro and macro industries. It is originating from domestic, industrial, and agricultural activities, poses a significant environmental challenge due to the presence of pollutants, including organic matter, heavy metals, and chemicals. Wastewater treatment is a crucial aspect of environmental protection and sustainable development. A variety of studies have focused on improving treatment techniques to ensure the conservation

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of water resources while reducing pollution. Biological, chemical, and physical methods that are increasingly being combined for optimal wastewater treatment. Anaerobic digestion, membrane bioreactors, and constructed wetlands technologies are identified as key to advancing sustainable practices. Al-Gheethi et al., 2023, discussed various integrated sustainable wastewater treatment technologies, emphasizing the importance of reducing environmental footprints and improving efficiency. Physico-chemical treatment methods, such as coagulation, flocculation, and chemical oxidation, remain vital for the removal of suspended solids and organic contaminants in wastewater (Kumar et al., 2023). Reverse osmosis, ultrafiltration, and advanced oxidation processes are the advanced treatment technologies for wastewater reuse and reuse of treated water in agriculture, industry, and even potable water applications (meng et al., 2023). The applications of bioremediation techniques using microbial consortia in treating wastewater. Various microbes are capable of degrading pollutants like oils, heavy metals, and organic compounds in wastewater (Singh and Gupta, 2023). Eco-friendly development is a broad and integrative concept focused on addressing current needs while safeguarding the ability of future generations to fulfill theirs without limitation. Managing water resources, particularly through wastewater treatment and recycling, is a critical component of sustainable development. Wastewater management directly aligns with several of the United Nations' Sustainable Development Goals (SDGs), especially Goal 6, prioritize ensuring access to clean water and sanitation for everyone. Wastewater management is essential for maintaining the quality of aquatic supply, which are progressively strained due to population growth, industrialization, and urbanization. Poorly treated or untreated wastewater leads to water pollution, affecting both human health and ecosystems. More than 80% of wastewater globally is released into the environment without sufficient treatment, leading to the degradation of aquatic ecosystems and diminishing the availability of clean water (WHO, 2024) (https://www.unwater.org/publications/sdg-6-progress-reports).

By improving wastewater treatment, sustainable development can ensure that water resources are protected, ecosystems remain functional, and communities have access to clean and safe water. Proper wastewater management also supports other areas of sustainability, such as climate change mitigation, poverty reduction, and improved public health (United Nations, 2018). Modern wastewater treatment processes are evolving from simply treating waste to transforming wastewater into a resource. This concept, known as resource recovery, is key to sustainable wastewater management. It includes recovering energy, nutrients (such as phosphorus and nitrogen), and water itself for reuse in agricultural irrigation, industrial processes, and even drinking water in some regions (Larsen et al., 2016). Technologies like anaerobic digestion can generate biogas from organic waste in wastewater, while advanced filtration and treatment systems allow the recycling of water, reducing the demand for freshwater.

Despite its importance, sustainable wastewater management faces numerous challenges. The high cost of advanced treatment technologies, particularly in developing countries, limits widespread implementation. Moreover, energy-intensive processes, such as reverse osmosis and advanced oxidation, can conflict with goals for energy efficiency and carbon reduction (Rao et al., 2022). The improper management of sewage and industrial wastewater in many regions also results in environmental contamination, particularly in low-income areas. Therefore, developing affordable, low-energy, and efficient treatment technologies is a priority for achieving sustainable development in the wastewater sector (Akhter et al., 2021). In pursuit of sustainability, innovative approaches such as decentralized wastewater treatment systems, the use of nature-based solutions, and the integration of renewable energy sources are gaining attention. Decentralized systems allow for smaller-scale, local treatment solutions that can be more cost-effective for rural or developing areas, where central treatment facilities may not be viable (Ghosh et al., 2021).

Nature-based solutions, such as constructed wetlands, mimic natural processes to purify wastewater, offering an eco-friendly alternative that requires less energy and maintenance. These systems can also provide additional ecosystem services, such as biodiversity support and carbon sequestration (Morrison et al., 2022). The United Nations Sustainable Development Goal (SDG) 6 aims to ensure universal access to water and sanitation and promote their sustainable management. Target 6.3 focuses on improving wastewater management, seeking to reduce the global percentage of untreated wastewater by half by 2030. It emphasizes improving water quality by reducing pollution and increasing the recycling and safe reuse of water worldwide. This target supports the broader objectives of minimizing environmental degradation, enhancing public health, and ensuring sustainable water management to meet the growing global demand for clean water and sanitation (United Nations, 2021). Achieving this target is essential for sustainable water management, particularly in water-stressed regions. Improving public health and well-being can be achieved by minimizing waterborne diseases through enhanced sanitation and access to clean water. Additionally, fostering sustainable consumption and production practices is essential, as it encourages the recycling and repurposing of resources. Furthermore, implementing sustainable climate practices plays a crucial role in reducing methane emissions from untreated wastewater and promoting the recovery of renewable energy. The management of wastewater is integral to sustainable development, providing environmental, economic, and social benefits. By advancing wastewater treatment technologies, promoting resource recovery, and addressing the challenges of cost and energy efficiency, societies can contribute to achieving global sustainability goals. Innovative solutions and policies that prioritize efficient wastewater management will be essential for ensuring the long-term sustainability of our water resources.

Wastewater, generated from domestic, industrial, and agricultural activities, is a significant environmental concern due to its potential to pollute water bodies if untreated. The composition of wastewater varies significantly based on its source, containing organic and inorganic pollutants, nutrients, heavy metals, and pathogens (Ghosh *et al.,* 2021). Understanding the physico-chemical characteristics of wastewater is crucial for evaluating its quality and determining appropriate treatment strategies (Akhter *et al.,* 2021). Physico-chemical characters are Ph, Turbidity, COD, BOD, TDS and Heavy metals. The pH level of wastewater affects its treatability and impacts the efficiency of biological treatment processes. Turbidity, an indicator of suspended solids, reflects the clarity of water and is essential for assessing treatment efficiency. COD and BOD are key measures of organic pollution. Elevated levels of COD and BOD indicate significant amounts of biodegradable organic material, which can deplete oxygen in water bodies and adversely affect aquatic life (Singh *et al.,* 2022). TDS levels indicate soluble substance concentration in wastewater. Elevated TDS can affect the physical and chemical properties of water, influencing treatment processes and end-use applications (Rao *et al.,* 2022). Heavy metal contamination in wastewater poses severe health risks and environmental challenges. Studies have shown that untreated wastewater can leach heavy metals, leading to soil and water contamination, which poses risks to human health and ecosystems (Zhao *et al.,* 2020). Biological, physical, chemical and innovative technology are the current treatment technology. Biological treatment is utilizing microorganisms to degrade organic pollutants. Aerobic and anaerobic processes are commonly employed to reduce BOD and COD levels effectively. However, the efficiency of biological treatment is changed by components such as temperature, pH, and the existence of toxic substances (Mohan et al., 2021). Physical methods (e.g., sedimentation, filtration) and chemical methods (e.g., coagulation, flocculation) are commonly employed to eliminate suspended solids and impurities. Chemicals treatment can also involve advanced oxidation processes, which are effective in degrading persistent organic pollutants (Khan *et al.,* 2021). Emerging technologies, such as membrane bioreactors and constructed wetlands, are gaining attention for their effectiveness in treating wastewater while promoting resource recovery (Raja *et al.,* 2022). These technologies not only treat wastewater but also facilitate reutilized of essential assets. Recent advancements emphasize the importance of wastewater resource retrieval as part of sustainable development. Technologies enabling nutrient recovery (e.g., P and N) from wastewater can contribute to sustainable agricultural practices (Tandukar *et al.,* 2021). Biogas production through anaerobic digestion of organic waste is another promising approach that provides renewable energy while reducing greenhouse gas emissions (Lee *et al.,* 2022). Disposal of unpurified effluent has far-reaching consequences on aquatic ecosystems and human health. Eutrophication, a result of nutrient loading, leads to algal blooms that deplete oxygen levels in water bodies, adversely affecting fish and other aquatic life (Schindler *et al.,* 2021). Additionally, exposure to pathogens and toxic substances in wastewater poses serious health risks to communities relying on contaminated water sources (WHO, 2021).

In developing countries like India and Nigeria, inadequate wastewater treatment infrastructure exacerbates this issue, leading to the contamination of freshwater sources, public health risks, and ecosystem degradation. Understanding the physicochemical properties of wastewater is critical for developing sustainable management practices that promoting sustainable water management, reducing pollution, and enabling the recycling of valuable nutrients and energy. This supports SDGs related to clean water, sanitation, climate action, and sustainable consumption. This paper analysis of wastewater in perspective of sustainable development for an urban agglomeration in India and Nigeria and study the pH, BOD, DO, COD, turbidity, and hardness in winter and summer season.

Material and Methods

Survey Site and Sample Collection

This research was conducted in India and Nigeria to analyze the physico-chemical properties of water from different sources. Samples were collected from seven different locations across the two countries, with three distinct types of water sampled from each country. The samples collected included tap water (TW), domestic wastewater (DWW), and industrial wastewater (IWW) from various locations, along with a standard bottled water sample for comparison.

Sampling Locations:

India:

- Sample 1 (TW): Tap water from Career Point University Campus, Kota.
- Sample 2 (DWW): Domestic wastewater from the kitchen hostel mess at Career Point University Campus, Kota.
- Sample 3 (IWW): Industrial wastewater from Shree

Shyam Rice Industries, Kota.

- Sample 4: Standard bisleri bottled water for comparison.

Nigeria:

- Sample 5 (TW): Tap water from a residential area at Federal Low-Cost, Bauchi.
- Sample 6 (DWW): Domestic wastewater from a residential area at Federal Low-Cost, Bauchi.
- Sample 7 (IWW): Industrial wastewater from Tirwun Rice Mill Industry, Bauchi.

Each sample was collected in 5-liter containers that were thoroughly cleaned and rinsed with the respective water sample before final collection to avoid contamination. The samples were stored in clean, sealed containers and transported to the laboratory for further analysis.

Physico-Chemical Parameters Analyzed

Various physico-chemical parameters were assessed to evaluate the water purity of the samples, providing insights into their purity and identifying potential contaminants. pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Turbidity, Electrical Conductivity (EC), Chloride Ion Concentration and Total Hardness

Seasons of Sampling

The water samples were collected and analyzed during two different seasons to examine the effect of seasonal variations on water quality:

- Winter: (December and January)
- Summer: (May and June)

By conducting analysis during these periods, differences due to temperature fluctuations were observed, enabling a comparative assessment of water quality between winter and summer.

Methods of Analysis

The following instruments and methods were used to evaluate the physico-chemical parameters of the water samples: pH was measured with a pH meter, indicating the acidity or alkalinity of the water. Dissolved oxygen (DO) was measured by the Winkler method, helping to assess aquatic ecosystem health. Biochemical oxygen demand (BOD) was determined using the 5-day test, measuring the oxygen consumption over five days. Chemical oxygen demand (COD) was measured by the open reflux method, quantifying oxygen required to oxidize organic matter. Electrical conductivity (EC) was measured with an EC meter, indicating the presence of dissolved ions and water's ability to conduct electricity. Turbidity was assessed using a turbidity meter, reflecting the concentration of suspended particles. Chloride ion concentration was determined by argentometric titration, indicating salinity and pollution levels. Total hardness was measured by the EDTA titration method, reflecting calcium and magnesium concentrations that influence water hardness.

Table-1: Physico-chemical parameters and intruments

Parameter	Instrument/Method
pH	pH meter
Turbidity	Turbidity meter
Electrical Conductivity (EC)	Electrical conductivity meter
Dissolved Oxygen (DO)	Winkler method
Biochemical Oxygen Demand (BOD)	5-day BOD test
Chemical Oxygen Demand (COD)	Open reflux method
Chloride Ion Concentration	Argentometric titration
Total Hardness	EDTA titration method

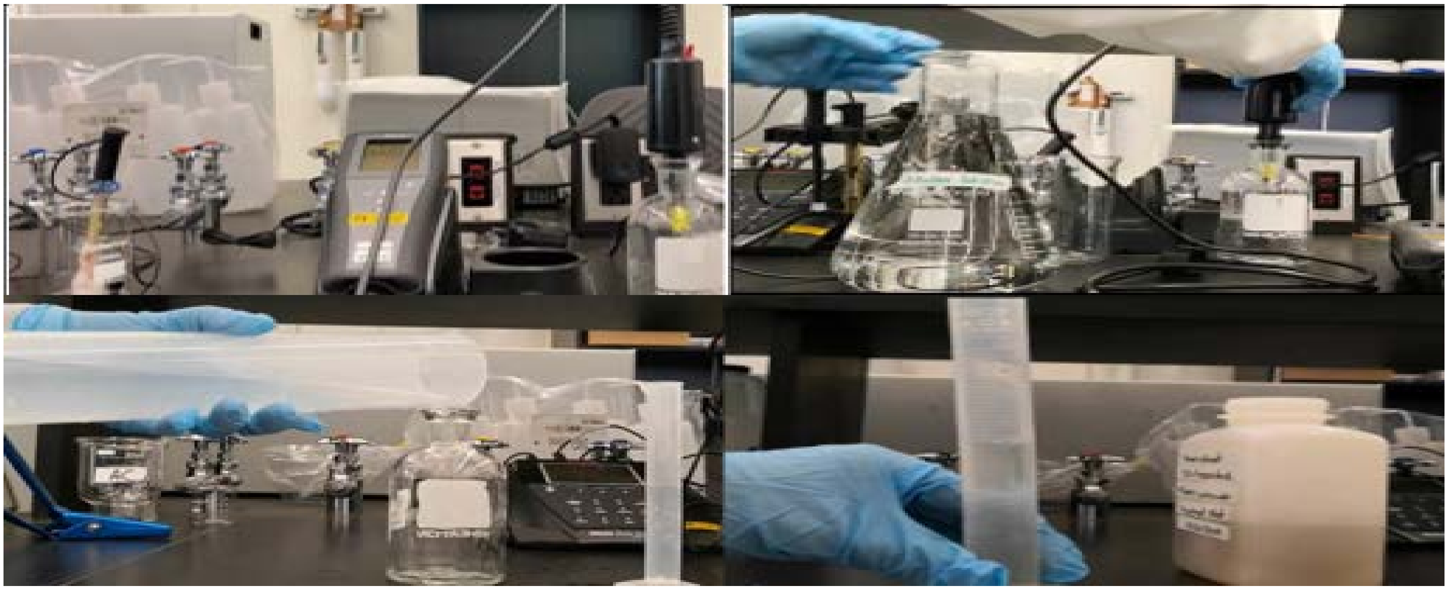

Figure-1: BOD and DO analysis

Biochemical oxygen demand is used to measure the strength of organic matter in waste water. For this study take

- 300 ml air tight seal test bottles
- Incubator for 20˚c
- Prepare 500 ml Dilution solution KH_2PO_4, K_2HPO_4, NH_4, Cl, $MgSO_4$, $CaCl_2$, $FeCl_3$
- DO meter
- Pipettes and graduated cylinders
- Take initial concentration of Dissolve oxygen
    - DO Concentration: 9.40 mg/L
    - DO Saturation: 103.6%
    - Temperature: 20.4˚c

Take 5% dilution solution and mix with waste water shake well and keep for 5 days at 20˚C. After 5 days measure the DO concentration of bottle.

Final concentration of Dissolve oxygen

- DO Concentration: 8.87 mg/L
- DO Saturation: 98.3%
- Temperature: 19.7˚c

BOD

D_1= Initial DO

D_2=Final DO

Vww= Volume of waste water (mL)

V_{DW}=Volume of dilution water (mL)

Vww+V_{DW}=300 Ml

5% Dilution

For 5% dilution

Initial DO:9.40 mg/L

Final DO: 8.87 mg/L

P:0.05

Comparative Analysis

Each parameter was analyzed during both winter and summer seasons to determine any significant variations that might arise due to temperature changes. A comparative analysis was conducted between the two countries (India and Nigeria) to assess the differences in water quality influenced by local anthropogenic activities.

Statistical Analysis

Data collected for the various parameters across the seven samples and two seasons were statistically analyzed to determine significant trends and correlations. Descriptive statistics were used to compare the mean values of physico-chemical parameters, and graphical representations were employed for clearer visualization of the seasonal and spatial variations. This comprehensive methodology ensures a detailed and systematic analysis of the physico-chemical characteristics of water in the selected urban areas in India and Nigeria. The study allows for better understanding of the impacts of anthropogenic activities on water quality, providing valuable insights for sustainable water management practices in urban environments.

Results and Discussion

The water quality analysis was conducted on various water samples collected from India and Nigeria across two different seasons (winter and summer). The physicochemical parameters including pH, biochemical oxygen demand (BOD), dissolved oxygen (DO), chemical oxygen demand (COD), density, turbidity, electrical conductivity, chloride ion concentration, and total hardness were measured. A detailed comparison of the results for each parameter in both seasons was performed to observe any variations and seasonal effects (Table-1).

Table-2 pH of the seven different sample in winter and summer season in India and Nigeria

S. No.	Sample	pH (Winter)	pH (Summer)
1	Sample 1 (Tap Water, India)	6.85	6.56
2	Sample 2 (Domestic Wastewater, India)	5.22	2.22
3	Sample 3 (Industrial Wastewater, India)	3.76	4.7
4	Sample 4 (Standard Water)	6.5	6.5
5	Sample 5 (Tap Water, Nigeria)	6.51	6.51
6	Sample 6 (Domestic Wastewater, Nigeria)	5.92	4.82
7	Sample 7 (Industrial Wastewater, Nigeria)	4.22	2.55

In winter Season the pH values across the samples ranged from 3.69 to 6.85. Samples 3 and 7 (industrial wastewater) showed the most acidic nature, while the rest of the samples were within acceptable ranges. In summer Season, the pH dropped significantly for most samples, especially sample 2 (domestic wastewater), which exhibited a highly acidic pH of 2.22. Sample 7 (industrial wastewater) also remained acidic with a pH of 2.55. The pH values in the summer season were generally lower than in the winter season, reflecting the impact of higher temperatures on water acidity. Samples with industrial waste were consistently more acidic. Seasonal changes significantly affect the pH of water bodies due to variations in temperature, biological activity, and chemical processes. Higher temperatures in summer often lead to increased metabolic rates in aquatic organisms, which can enhance organic matter decomposition and result in lower pH levels (Mason, 2002). This seasonal fluctuation underscores the importance of monitoring pH throughout the year to assess water quality and its ecological implications. Industrial wastewater is a major contributor to water pollution, frequently characterized by low pH values. Industries such as mining, pharmaceuticals, and food processing release acidic effluents that can drastically lower the pH of receiving waters (Kumar & Singh, 2015).

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand for winter season ranges from 1.04 to 8.04(mg/l). According to world health organization (WHO) BOD is < 5.0 mg/L. All the samples are within the acceptable range. Except sample (2) Domestic wastewater and sample (6) Domestic wastewater which are slightly above the normal range. The biochemical oxygen demand (BOD) in summer season. Basically, there is an increase in almost all the samples been analyzed for BOD in the summer season compared to one in winter. Except in standard sample which is 5.92mg/L(Table-2).

Table: - 3 BOD of the seven different sample in winter and summer season in India and Nigeria

S.No.	Sample	BOD (Winter)	BOD (Summer)
1	Sample 1 (Tap Water, India)	1.04	1.56
2	Sample 2 (Domestic Wastewater, India)	6.87	7.92
3	Sample 3 (Industrial Wastewater, India)	5.04	6.73
4	Sample 4 (Standard Water)	2.44	5.92
5	Sample 5 (Tap Water, Nigeria)	1.09	1.52
6	Sample 6 (Domestic Wastewater, Nigeria)	8.04	8.45
7	Sample 7 (Industrial Wastewater, Nigeria)	6.32	7.63

In winter season, the BOD values ranged from 1.04 to 8.04 mg/L. Samples 2 and 6 (domestic wastewater) exceeded the acceptable limit of 5.0 mg/L as per WHO standards. In summer season, BOD values generally increased in the summer, indicating higher oxygen demand for biological decomposition due to elevated temperatures. However, the standard water sample showed a BOD of 5.92 mg/L, just within the permissible limit. The increase in BOD values during the summer season suggests more organic matter was decomposing due to higher temperatures. High BOD values indicate a greater amount of biodegradable organic material, which can lead to oxygen depletion in aquatic ecosystems, adversely affecting aquatic life (APHA, 2017). Seasonal changes significantly influence BOD levels in wastewater. Studies show that BOD often increases during warmer months due to higher microbial activity and decomposition rates (Chand et al., 2019).

Dissolved Oxygen (DO)

Dissolved oxygen (DO) refers to the oxygen available in water, sourced from the atmosphere and aquatic vegetation. In all the samples analyzed, DO levels fall within the standard range of 6.5 to 8 mg/L.In a summer season, there is no doubt the difference is clearly shown for the two seasons; winter and summer. The dissolved oxygen is higher in summer season when compared to winter season. There is increase in value for all the samples analyzed samples in summer. But all the values measured are within the normal range (Tsble-3).

Table-4 DO of the seven different sample in winter and summer season in India and Nigeria

S.No.	Sample	DO (Winter)	DO (Summer)
1	Sample 1 (Tap Water, India)	8.87	7.1
2	Sample 2 (Domestic Wastewater, India)	6.5	7.2
3	Sample 3 (Industrial Wastewater, India)	7.8	8.0
4	Sample 4 (Standard Water)	7.0	7.1
5	Sample 5 (Tap Water, Nigeria)	6.7	7.0
6	Sample 6 (Domestic Wastewater, Nigeria)	7.4	7.9
7	Sample 7 (Industrial Wastewater, Nigeria)	6.9	7.5

In winter season, the dissolved oxygen levels were all within the normal range of 6.5 to 9 mg/L, indicating sufficient oxygen supply for aquatic life. In summer season, the dissolved oxygen levels were slightly higher in the summer, likely due to increased atmospheric interaction and photosynthetic activity. DO values remained within acceptable limits, showing no oxygen depletion in any sample. DO levels are influenced by multiple factors, including atmospheric diffusion, photosynthesis by aquatic plants, and temperature (Chapman, 2017). Temperature is a crucial factor affecting DO saturation in water bodies. According to studies, higher temperatures in summer can increase the metabolic rates of aquatic plants, leading to higher oxygen production through photosynthesis (García *et al.*, 2020).

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) indicates the amount of oxygen needed to chemically oxidize organic and inorganic substances in water. While the COD levels of most samples were within the WHO's permissible range, sample 2 (domestic wastewater) exhibited values lower than the acceptable limit. The chemical oxygen demand (COD) for the summer samples are here by stated with little difference in two (2) samples; which are sample (1) Tab water which is higher in values as compared with that of winter season as 6.63m/L and 5.5mg/L respectively. And also, that of sample (7) Industrial wastewater in summer season is higher than that of winter season which are 6.73mg/L and 4.2mg/L respectively. Then, the remaining samples were all shown no significance difference in both the winter and the summer seasons. So, the standard sample shows almost the same value in both the winter and summer season as 3.46mg/L in winter season and 3.74mg/L in summer season respectively (Table-4).

Table-5 COD of the seven different sample in winter and summer season in India and Nigeria

S.No.	Sample	COD (Winter)	COD (Summer)
1	Sample 1 (Tap Water, India)	5.50	6.63
2	Sample 2 (Domestic Wastewater, India)	4.93	4.70
3	Sample 3 (Industrial Wastewater, India)	6.20	6.73
4	Sample 4 (Standard Water)	3.46	3.74
5	Sample 5 (Tap Water, Nigeria)	5.14	5.88
6	Sample 6 (Domestic Wastewater, Nigeria)	4.52	4.60
7	Sample 7 (Industrial Wastewater, Nigeria)	4.20	6.73

In winter season, most of the samples had COD values within the permissible range, except for Sample 2 (domestic wastewater) which had a lower-than-normal value. In summer season, the COD values increased for most samples, indicating higher chemical oxygen demand during the summer season. This could be due to increased decomposition of organic and inorganic materials. High COD levels indicate a greater concentration of organic pollutants, which can lead to oxygen depletion in receiving waters, adversely affecting aquatic life (Hwang et al., 2017). Higher temperatures in summer often enhance the rate of chemical reactions and decomposition processes, potentially leading to increased COD levels (Pérez *et al.,* 2020).

Turbidity

In summer, sample 1 (tap water) showed increased turbidity (133.8 NTU) compared to winter (118.1 NTU). Domestic wastewater also exhibited a slight increase from winter (706.1 NTU) to summer (713.9 NTU). Conversely, industrial wastewater turbidity decreased from winter (310.6 NTU) to summer (238.0 NTU). Tap water turbidity decreased in summer (130.9 NTU) compared to winter (148.2 NTU). Similarly, domestic wastewater showed a significant drop from winter (357.4 NTU) to summer (180.3 NTU). Overall, turbidity levels exceeded the World Health Organization's recommended maximum of 50 NTU for drinking water, indicating poor clarity in most samples, except for the standard samples, which remained below this threshold (Table-5).

Table-6 Turbidity of the seven different sample in winter and summer season in India and Nigeria

S.No.	Sample	Turbidity (Winter)	Turbidity (Summer)
1	Sample 1 (Tap Water, India)	118.1	133.8
2	Sample 2 (Domestic Wastewater, India)	706.1	713.9
3	Sample 3 (Industrial Wastewater, India)	310.6	238.0
4	Sample 4 (Standard Water)	40.5	40.8
5	Sample 5 (Tap Water, Nigeria)	148.2	130.9
6	Sample 6 (Domestic Wastewater, Nigeria)	357.4	180.3
7	Sample 7 (Industrial Wastewater, Nigeria)	421.0	165.5

In winter season the turbidity levels were quite high, especially for domestic and industrial wastewater. High turbidity levels can indicate pollution and can have detrimental effects on aquatic ecosystems by reducing light penetration and impairing photosynthesis (Wetzel, 2001). In summer season the turbidity slightly increased in most cases, with some industrial wastewater samples showing a reduction, possibly due to sedimentation. High turbidity levels, especially in domestic and industrial wastewater, indicate significant particulate pollution. These results provide a comprehensive view of water quality, showing seasonal variations in key physicochemical parameters. Seasonal changes can significantly influence turbidity levels in water bodies. Your findings suggest that winter turbidity levels were high, particularly in domestic and industrial wastewater, while summer showed slight increases or reductions. Higher rainfall and runoff during certain seasons can lead to increased sediment and nutrient loading, raising turbidity levels (Baker et al., 2020). The differences observed highlight the impact of temperature and seasonal changes on water quality.

Density: -

The results of the density in all the sample. Specifically, there is no significance differences in all the given samples in both the two seasons: winter season and summer season. Even the standard sample has shown same result with zero point zero one difference (0.01) in both the two seasons (Fig-1).

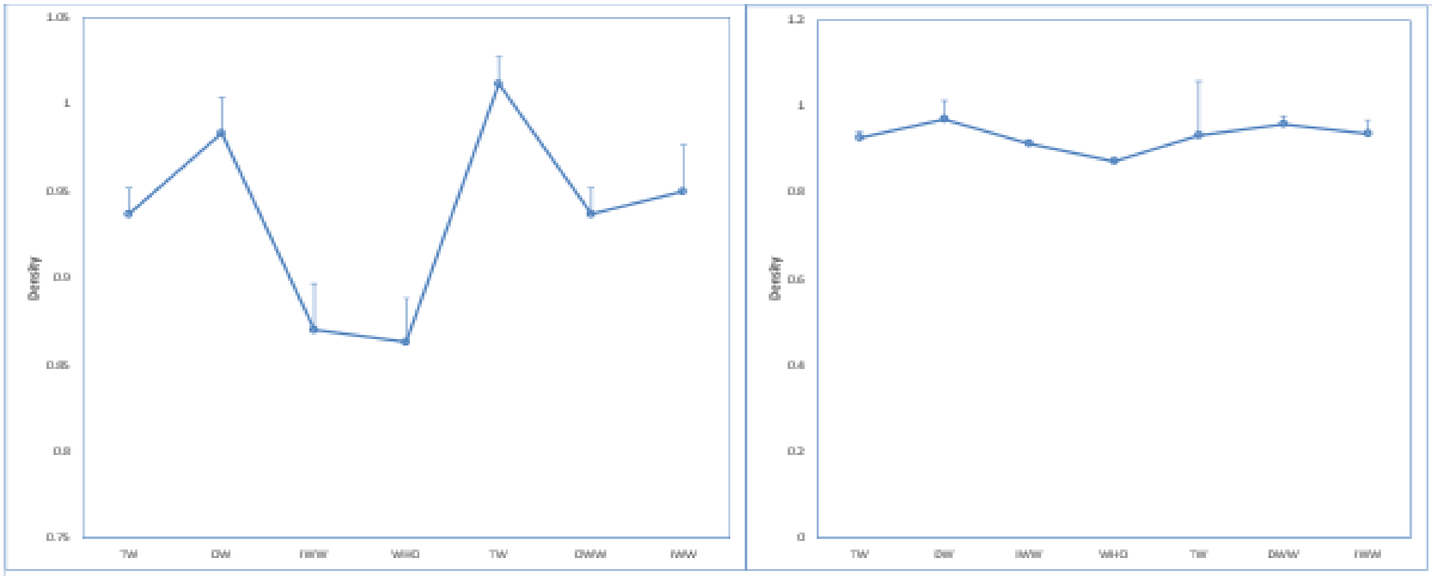

Fig-1: - The density of a liquid equals to the mass of the liquid divided by its volume; D=M/V. The density of the samples was all within the normal range of 0.89 to 1g/cm.

Water density is defined as the mass of water per unit volume, typically expressed in grams per cubic centimeter (g/cm³). It is a critical physical property of water that influences buoyancy, stratification, and circulation in aquatic systems (Woods, 2013). The density of water changes with temperature, typically decreasing as temperatures rise, which can affect aquatic organisms and nutrient dynamics. In colder conditions, water becomes denser, and this is crucial for the stratification of lakes and rivers during winter (Sharma *et al.*, 2016).

Electrical conductivity: -

The results of electrical conductivity for the two seasons were nearly similar across all samples. However, there were slight variations in industrial wastewater samples. Specifically, sample 3 (industrial wastewater) showed a slight decrease in conductivity from winter (1.61 mg/L) to summer (1.36 mg/L). Similarly, sample 7 (industrial wastewater) exhibited a higher conductivity in winter (1.86 mg/L) compared to summer (1.41 mg/L). These findings indicate a relatively stable electrical conductivity across the seasons, with minor fluctuations observed in the industrial wastewater samples (Fig-2).

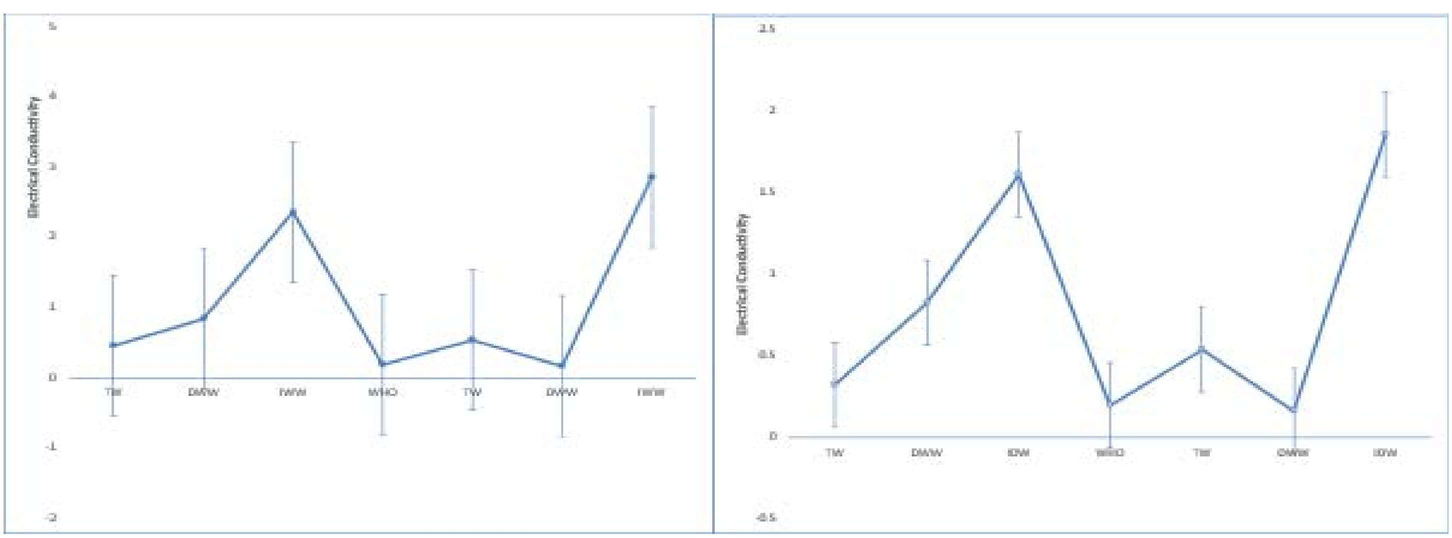

Fig-2:- Comparison of the results of Electrical conductivity for the two seasons winter and summer.

Electrical conductivity (EC) reflects water's capacity to conduct electricity, directly influenced by the concentration of dissolved ions such as inorganic salts, minerals, and metals. It serves as a crucial water quality parameter, offering information on salinity and total ion content (APHA, 2017). EC is widely used to assess the health of aquatic systems. Higher conductivity levels often indicate increased pollution from anthropogenic sources, such as industrial discharges or agricultural runoff. Monitoring EC can help identify changes in water quality and detect potential contamination events. EC is often correlated with other water quality indicators, such as total dissolved solids (TDS) and turbidity. High EC values can be associated with elevated TDS, which may negatively impact aquatic organisms by altering osmoregulation and reducing habitat quality (López *et al.,* 2018).

Chloride ion: -

The analysis of chloride ion concentrations across seven samples during summer and winter seasons revealed notable variations in relation to WHO standards, which define a normal range of 1–100 ppm for freshwater. Samples 3 (industrial wastewater), 6 (domestic wastewater), and 7 (industrial wastewater) exhibited concentrations exceeding 100 ppm in both seasons, resulting in higher conductivity values. In contrast, samples 1, 2, 4, and 5 remained within the acceptable range, though slight seasonal variations were observed. Most samples showed higher chloride levels during winter compared to summer, except for samples 1, 4, and 5, where summer concentrations were slightly higher. These results indicate that industrial and domestic wastewater are significant contributors to elevated chloride ion levels, with seasonal factors influencing the observed variations (Table-7).

Table-7 Chloride ion concentrations in summer and in winter season

Sample No.	Sample Type	Summer Season (mg/L)	Winter Season (mg/L)
1	Tap Water	74.33	67.8
2	Domestic Wastewater	89.53	94.96
3	Industrial Wastewater	148.5	164.43
4	Tap Water (Standard)	66.06	57.73
5	Tap Water	84.3	72.7
6	Domestic Wastewater	136.93	140.93
7	Industrial Wastewater	175	177

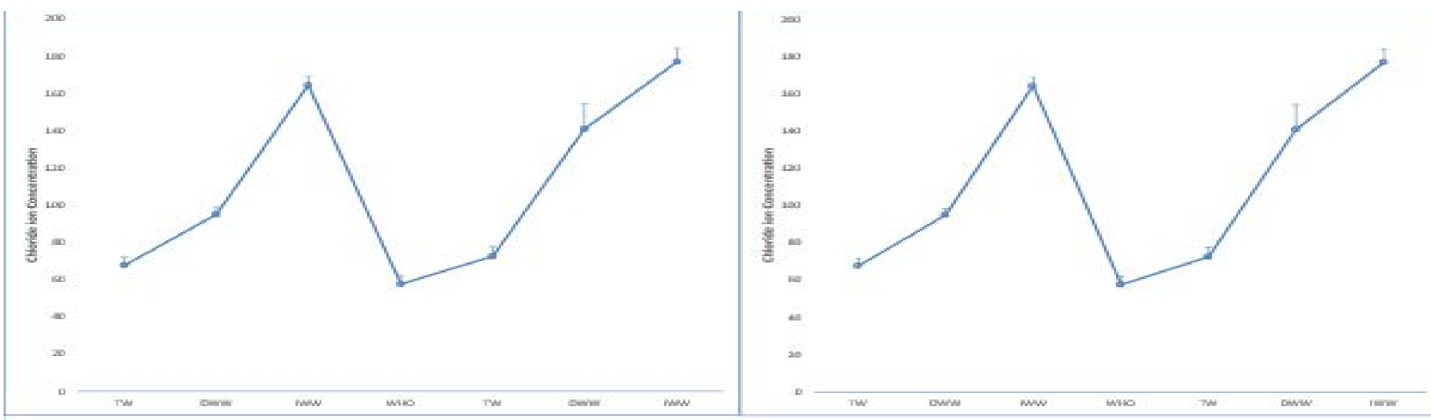

Fig-3: The results show similarities and also some differences for the two seasonal analyses of winter and summer season.

Chloride ions (Cl^-) are important indicators of water quality, particularly in freshwater systems. They can originate from natural sources such as mineral dissolution or anthropogenic activities, including industrial discharges and agricultural runoff. Elevated chloride concentrations can indicate pollution and may have detrimental effects on aquatic ecosystems (Hatt et al., 2004). Seasonal variations in chloride concentrations can be influenced by factors such as precipitation, temperature, and evaporation. For instance, rainfall can dilute chloride levels in surface waters, while dry conditions may concentrate salts (Kumar et al., 2016). Industrial and domestic wastewater often contains elevated chloride concentrations due to the discharge of salt-laden effluents. This can lead to significant increases in conductivity and overall water salinity, affecting aquatic life and water quality (Alder et al., 2006).

Calcium hardness

Total hardness represents the combined concentrations of calcium and magnesium, expressed as calcium carbonate in milligrams per liter (mg/L). Levels below 75 mg/L are typically classified as soft.The total hardness of two (2) samples which are (3) Industrial wastewater and (6) Industrial wastewater are relatively high and are considered hard which are 90.3mg/L to 105mg/L respectively. And also, sample (2) Domestic wastewater also shown a considerably high with 77.7 mg/L. The calcium hardness was compared for the two seasons; winter and summer seasons. The calcium content present in all the water samples were measured for the two seasons, and all the results were recorded accordingly. All the samples measured during the winter season were higher than that of the summer season. And the samples including the standard sample was measured for both the seasons and was within the normal range of soft water according to the world health organization (Fig-4).

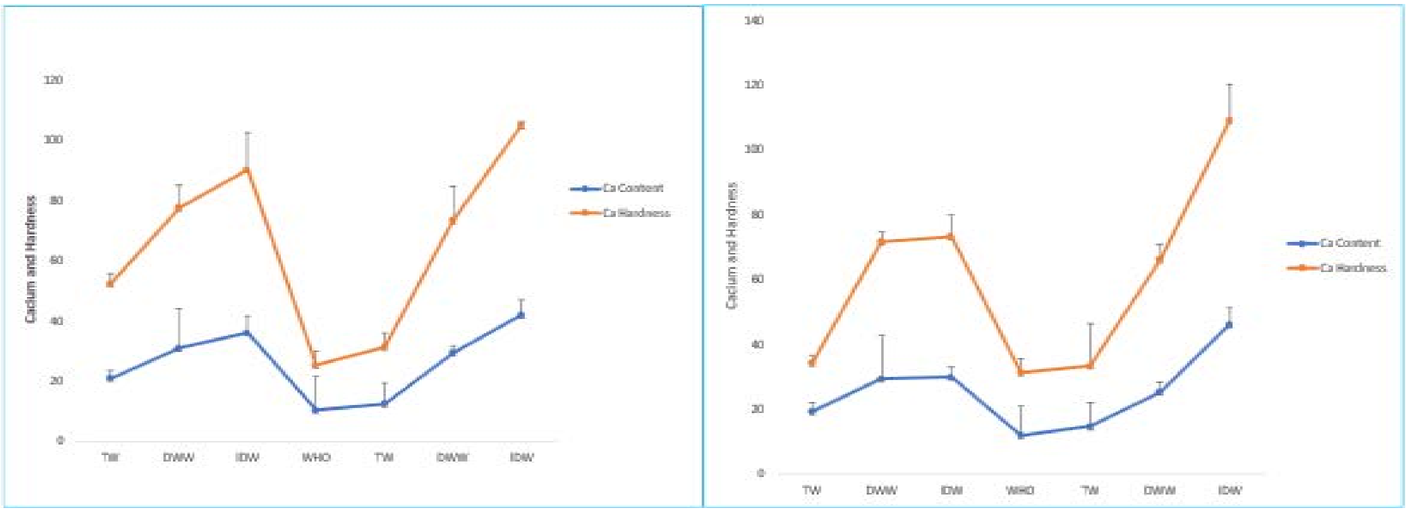

Fig-4 Comparison of calcium hardness in winter and summer season

Total hardness is primarily determined by the presence of calcium (Ca^{2}) and magnesium (Mg^{2}) ions in water. It is typically expressed in terms of $CaCO_3$ equivalents. Hardness is an essential water quality parameter, influencing not only the aesthetic quality of water but also its suitability for various domestic, agricultural, and industrial applications (Mason, 1992). Water hardness is classified as soft, moderately hard, hard, or very hard based on its concentration. Soft water (below 75 mg/L) is generally preferred for household uses, while hard water (above 75 mg/L) can lead to scale formation in pipes and appliances, potentially increasing maintenance costs (Lehr et al., 2010). Seasonal changes can significantly impact the hardness of water bodies. Factors such as rainfall, evaporation, and temperature variations can influence the dissolution of minerals. Studies have shown that hardness tends to increase during dry periods due to reduced water levels and higher concentrations of dissolved ions (Gupta & Gupta, 2011). High levels of total hardness can affect the palatability of drinking water and its suitability for industrial processes. It can also influence the effectiveness of soaps and detergents, as hard water requires more soap to achieve the same lather as soft water (Murray *et al.*, 2013).

Conclusions

The physico-chemical analysis of wastewater is paramount for understanding the environmental challenges posed by urban agglomerations in India and Nigeria. This study highlights the pressing need for effective wastewater management practices in these rapidly urbanizing regions, where population growth and industrialization significantly impact water quality. The analysis of various parameters, including pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), dissolved oxygen, turbidity, total dissolved solids (TDS), electrical conductivity, chloride concentrations, and total hardness, reveals critical insights into the state of wastewater in these urban settings.High levels of BOD and COD indicate substantial organic pollution, which can lead to severe ecological consequences if not addressed. The low levels of dissolved oxygen found in many samples point to the degradation of aquatic ecosystems and the potential for adverse effects on public health. Furthermore, the significant turbidity levels in domestic and industrial wastewater samples underscore the need for immediate intervention to reduce particulate pollution. Seasonal variations in water quality parameters reflect the dynamic nature of urban wastewater, influenced by factors such as rainfall, temperature, and industrial discharge. The comparative analysis between India and Nigeria reveals distinct differences in wastewater quality, underscoring the diverse challenges faced by each country in managing their water resources effectively. To achieve sustainable development, it is crucial to implement robust wastewater treatment technologies and policies tailored to the specific needs of each urban agglomeration. This includes promoting the adoption of green technologies, enhancing community awareness, and engaging stakeholders in the decision-making process. Improved infrastructure and investment in advanced treatment methods can significantly mitigate the adverse effects of wastewater on the environment and public health.The findings of this study underscore the importance of continuous monitoring of wastewater quality to ensure compliance with environmental standards and public health regulations. Policymakers must prioritize wastewater management in their urban development strategies to promote sustainable growth. In conclusion, effective wastewater management is not only essential for protecting water resources but also for fostering resilient urban environments that can thrive in the face of increasing population pressures and climate change. By addressing the challenges of wastewater management, India and Nigeria can pave the way for sustainable urban agglomerations that support economic growth while safeguarding public health and the environment.

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M A. Jajere. All authors have read and agreed to the published version of the manuscript.

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