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Industrial Wastewater Loads and Pretreatment Performance of Beverage Industries Discharging to Mbeya Municipal Waste Stabilisation Ponds

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ABSTRACT

Industrial wastewater is a growing threat to municipal Waste Stabilisation Ponds (WSPs) in rapidly urbanising Sub-Saharan cities. This study evaluated the pretreatment efficiency and quantified pollutant loads from three major beverage industries—Tanzania Breweries Limited (TBL), Coca-Cola Kwanza, and Pepsi—that discharge into the Kalobe WSP in Mbeya, Tanzania. Weekly grab samples were collected over a one-month period (n = 12 per industry), and physicochemical parameters, including BOD_5, COD, TSS, nutrients, and pH, were analysed following Standard Methods. Daily pollution loads (kg/day) were calculated from measured flows and concentrations, and statistical differences were tested using one-way ANOVA and Pearson correlation at a 95% confidence level. Results showed significant variation in wastewater quality among the industries ($p < 0.05$). In terms of treatment efficiency, Coca-Cola consistently maintained the lowest pollutant concentrations, demonstrating effective pretreatment and compliance with national standards. TBL recorded elevated suspended solids due to brewing by-products, while Pepsi exhibited the poorest pretreatment performance, discharging the highest organic loads (BOD: 124.81 kg/day; COD: 245.46 kg/day) despite moderate flow. Collectively, Pepsi accounted for 71% of BOD and 76% of COD loads entering the WSP, underscoring that industries with insufficient pretreatment disproportionately stress municipal systems. The findings underscore the urgent need for targeted upgrades to Pepsi's pretreatment facility, stricter enforcement of load-based discharge permits, and improved industry–utility collaboration. This study is the first in Tanzania to apply a mass-based load assessment framework for industrial discharges, providing a replicable model for regulatory action. The results support implementation of Tanzania's Industrial Wastewater Regulations (2020) and contribute to achieving SDG 6.3 on reducing untreated wastewater.

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1.0 Introduction

Wastewater management is a persistent environmental and public health concern in developing countries, where treatment systems are often underfunded and subject to mixed influent streams (Mara and Pearson, 2013). Waste Stabilisation Ponds (WSPs) are the most widely used wastewater treatment technology in warm-climate regions, valued for their simplicity, low cost, and natural removal of pathogens and biodegradable organics (El-Fadel et al., 2020; WHO, 1987).

However, WSPs were not designed to handle high-strength industrial effluents. Increasing urbanisation and industrialisation in Sub-Saharan Africa have introduced a new stressor to these systems, namely, unregulated industrial discharges. Effluents from beverage and brewing industries often contain high biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and nutrients that overwhelm biological treatment capacity, leading to shock loading, rapid sludge accumulation, odours, and eventual treatment failures (Garcia et al., 2019; Chakraborty and Ghosh, 2015; Müller et al., 2018).

Evidence from across the region illustrates these impacts. In Kenya and India, beverage effluents contributed over 65% of organic loads to municipal ponds despite being a minor portion of total flow, causing treatment breakdowns (Musyoka et al., 2021; Ramaswamy et al., 2020). In Tanzania, Dar es Salaam WSPs treating mixed hospital and domestic wastewater experienced sludge buildup and effluent quality deterioration (Kaseva et al., 2008). Kabeto et al. (2020) reported influent CODs of 1200–1400 mg/L and BOD above 600 mg/L in Hawassa University WSPs. Likewise, Kaseva (2008) recorded influent TSS exceeding 500 mg/L and COD greater than 1000 mg/L in Dar es Salaam WSPs, reflecting significant stress from mixed wastewater inputs. These cases underscore the vulnerability of WSPs to industrial inputs and the weak enforcement of pretreatment standards across East Africa (Khan et al., 2021).

Nationally, the Environmental Management Act (URT, 2004) and the Industrial Wastewater Discharge Standards (URT, 2020) require industries to implement effective on-site pretreatment before releasing effluent into municipal sewers. Nonetheless, in many Tanzanian cities, weak monitoring and limited data hinder enforcement. In Mbeya, the Kalobe WSP was designed for 28,800 m^3/day of domestic wastewater but now receives significant inputs from Tanzania Breweries Limited (TBL), Coca-Cola Kwanza, and Pepsi. Spot sampling by the utility has suggested elevated pollutant levels, but comprehensive, load-based industrial contributions have never been quantified.

While previous Tanzanian studies have described wastewater stabilisation pond performance in general (Pearson et al., 1996; Kaseva et al., 2008), none have systematically applied a mass-based load approach to quantify industrial contributions. Most monitoring focuses only on concentration values (mg/L), which do not account for flow and therefore underestimate the true pollution burden of industries with large discharges. Mass-based assessment (kg/day) provides a clearer picture of the environmental impact and aligns with modern regulatory approaches that emphasise pollution loads rather than volumes. Applying this framework for the first time in Tanzania offers an innovative contribution to wastewater governance and supports more effective enforcement of discharge standards.

This study evaluates the wastewater quality and pollutant loads from three beverage industries in Mbeya City, quantifies their contributions to the Kalobe WSP, and assesses pretreatment effectiveness against national standards. The findings aim to:

i. Generate baseline data on industrial pollutant loads,
ii. Identify industries contributing disproportionately to organic and solids loading, and
iii. Provide evidence for regulators to strengthen enforcement and promote sustainable wastewater management.

By filling this data gap, the study contributes to national regulatory practice, informs infrastructure planning, and supports Sustainable Development Goal 6.3 on reducing untreated wastewater.

Materials and Methods

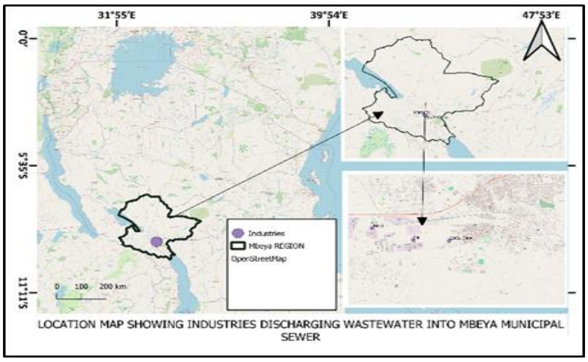
2.1 Study Area

The study was conducted in Mbeya City, located in the Southern Highlands of Tanzania (coordinates: 8°55′S, 33°27′E). The city lies at elevations of 1,700–2,400 m above sea level, with a subtropical highland climate characterised by mean annual rainfall of 1,000–2,700 mm and temperatures ranging from 12–25°C. The current urban population is approximately 550,000. Wastewater from the city is treated at the Kalobe Waste Stabilisation Ponds (WSP), operated by the Mbeya Urban Water Supply and Sanitation Authority (Mbeya UWSA). The system was originally designed for 28,800 m^3/day of domestic wastewater but now also receives industrial effluents. This study focused on three major beverage industries—Tanzania Breweries Limited (TBL), Coca-Cola Kwanza, and Pepsi (SBC Tanzania Ltd)—which are among the largest contributors of industrial effluents in Mbeya.

Annual wastewater generation was estimated from production logs and discharge reports: TBL (~2,500–3,000 m^3/day), Coca-Cola (~1,500–2,000 m^3/day), and Pepsi (~2,000–2,500 m^3/day). These volumes represent substantial shares of the total inflow to the municipal system and underscore the potential environmental burden of industrial discharges.

Figure 1

A map showing the location of the three industries, their discharge points, and the Kalobe WSP



2.2 Wastewater Sampling and Analysis

Wastewater grab samples were collected weekly over one month (April–May 2025), resulting in 12 samples per industry (n = 36). Grab sampling was chosen due to logistical constraints and industry access restrictions. Sampling was conducted during peak beverage production weeks, providing a representative picture of pollutant levels. Although composite sampling would capture daily variability, grab sampling at consistent times ensured comparability among industries. Samples were collected in sterilised 1-L HDPE bottles, pre-rinsed with sample water, sealed, and stored at 4°C. They were transported to the Mbeya Water Quality Laboratory within two hours. Sampling was done between 9:00 and 11:00 AM during peak production to ensure comparability.

Parameters analyzed included:

i. Organic matter: BOD_5 (BODTrack system), COD (HACH DR2800 photometer),
ii. Solids: TSS (gravimetric filtration),
iii. Nutrients: TN (Kjeldahl digestion/distillation), NH_4^+, NO_3^-, PO_4^{3-} (HACH DR2800), TP (persulfate digestion + spectrophotometry),
iv. General: pH (portable pH meter),

Analytical methods followed the APHA Standard Methods for the Examination of Water and Wastewater (2017). (Table 1)

Table 1

Standard Methods for the Examination of Water and Wastewater

Parameter	Analytical Method	Standard Method Reference	Instrument Used	Detection Wavelength/Output
BOD_5 (mg/L)	5-Day Incubation, Dilution Method	5210 B (APHA, 2017)[17]	BOD Incubator + DO Meter (HANNA HI9147)	DO depletion (mg/L)

Parameter	Analytical Method	Standard Method Reference	Instrument Used	Detection Wavelength/Output
COD (mg/L)	Closed Reflux, Colorimetric	5220 D (APHA, 2017)[17]	COD Reactor (Lovibond®) + Spectrophotometer	600 nm
TSS (mg/L)	Gravimetric (Drying at 105°C)	2540 D (APHA, 2017) [17]	Glass Fiber Filters + Analytical Balance	Mass difference (mg)
Ammonia–N (mg/L)	Nesslerization	4500-NH_3 C (APHA, 2017) [17]	UV–Vis Spectrophotometer (Hach DR 6000)	425 nm
Nitrite–N (mg/L)	Diazotization	4500-NO_2 B (APHA, 2017) [17]	UV–Vis Spectrophotometer (Hach DR 6000)	543 nm

2.3 Flow Measurement and Load Calculation

Industrial discharge flows (m^3/day) were determined using a combination of methods:

i. On-site flow meters where functional,
ii. Daily production logs cross-checked against water consumption records, and
iii. Reported discharge volumes from industry staff.

Reliability was enhanced by triangulating these sources and excluding inconsistent records. Daily pollutant loads (kg/day) were calculated as:

Equation 1

$$Load\left(\frac{kg}{day}\right) = Concentration\left(\frac{mg}{L}\right) \times Flow\left(\frac{m^3}{day}\right) \times 0.001$$

Mean values were expressed with standard deviations, and outliers were identified using boxplot analysis

2.4 Contribution Analysis

The contribution of each industry to total system loading was computed as follows*:*

Equation 2

$$Contribution\ (\%) = \left(\frac{Industry\ Load}{Total\ Load}\right) \times 100$$

2.5 Compliance Assessment

Effluent quality from each industry was compared with the Tanzania Industrial Wastewater Discharge Standards (URT, 2020) and WHO guidelines. Parameters assessed included COD, BOD, TSS, TN, TP, and pH. Compliance tables were generated to present side-by-side comparisons of measured values and regulatory thresholds.

2.6 Statistical Analysis

Statistical analyses were performed using IBM SPSS v26. One-way ANOVA was applied to test for differences in pollutant concentrations between industries, with Tukey's post-hoc test identifying pairwise significance ($p < 0.05$). Pearson correlation was applied to examine relationships between flows and pollutant concentrations. Graphical outputs (radar charts, scatter plots) were generated in Excel 365 and SPSS to illustrate industrial variation and pollutant profiles. Statistical significance levels are reported in the Results section alongside relevant tables and figures.

3.0 Results

3.1 Industrial Wastewater Quality

Significant variation was observed in the quality of effluents among the three beverage industries (Table 1). Pepsi discharged the highest organic pollutant concentrations, with COD (1875.4 ± 205.8 mg/L) and BOD (1042.6 ± 142.3 mg/L) significantly higher than TBL and Coca-Cola ($p < 0.05$). Coca-Cola recorded the lowest pollutant concentrations across most parameters (COD: 710.3 ± 96.5 mg/L; BOD: 456.9 ± 54.1 mg/L; TSS: 230.1 ± 28.3 mg/L), reflecting effective pretreatment. Both COD and BOD were measured because COD captures total oxidisable organic matter (biodegradable + non-biodegradable), while BOD reflects only the biodegradable fraction. Together they provide a comprehensive assessment of wastewater strength.

TBL exhibited the highest TSS (520.8 ± 74.6 mg/L), despite moderate COD (970.5 ± 110.4 mg/L) and BOD (590.1 ± 80.2 mg/L). This anomaly likely reflects the presence of brewing by-products such as yeast, grains, and other suspended solids that contribute to TSS but not necessarily to organic oxygen demand. Nutrient levels were moderate across all industries, though Pepsi's TN and TP were consistently higher than Coca-Cola's, raising potential eutrophication concerns.

Table 2
Raw wastewater quality (Mean ± SD, n = 12 per industry)

Parameter	TBL	Coca-Cola	Pepsi
COD (mg/L)	970.5 ± 110.4	710.3 ± 96.5	1875.4 ± 205.8
BOD (mg/L)	590.1 ± 80.2	456.9 ± 54.1	1042.6 ± 142.3
TSS (mg/L)	520.8 ± 74.6	230.1 ± 28.3	310.6 ± 45.2
TN (mg/L)	32.4 ± 6.7	21.2 ± 5.4	28.9 ± 6.2
TP (mg/L)	7.6 ± 1.4	4.8 ± 1.0	6.3 ± 1.5
pH	7.1 ± 0.4	6.9 ± 0.2	7.2 ± 0.3

3.2 Pollution Loads Entering the WSP

Pollution load analysis (Table 2) confirmed that Pepsi contributed the highest BOD (124.81 kg/day) and COD (245.46 kg/day), despite a moderate hydraulic discharge compared to TBL. TBL contributed the highest TSS load (94.49 kg/day), consistent with the observed high suspended solids concentration. Coca-Cola contributed the lowest loads across all parameters, reflecting its superior pretreatment performance.

Table 3
Average Daily Pollution Load (kg/day)

Industry	BOD	COD	TSS	TN	TP
TBL	32.55	65.11	94.49	8.1	1.9
Coca-Cola	25.51	12.76	8.87	3.15	0.89
Pepsi	124.81	245.46	8.32	6.93	1.6

3.3. Industry Contribution to Total WSP Load

Relative contributions (Table 3) revealed that Pepsi dominated organic loading, accounting for 71% of BOD and 76% of COD entering the WSP. By contrast, TBL dominated solids loading (48% of TSS), while Coca-Cola's contribution was minimal. This demonstrates that industries with high-strength effluents can exert disproportionate pressure on municipal treatment systems, regardless of flow volumes. Correlation analysis showed a strong positive relationship between industrial flow and COD load ($r = 0.82$, $p < 0.05$), confirming that flow directly influenced pollutant loading.

Table 4
Percentage Contribution to Total WSP Load

Industry	Hydraulic (%)	BOD (%)	COD (%)	TSS (%)
TBL	27	16	20	48
Coca-Cola	19	13	4	5
Pepsi	24	71	76	4

3.4 Compliance with Tanzanian Standards

When compared against Tanzania's Industrial Wastewater Discharge Standards (URT, 2020), Coca-Cola effluents were fully compliant across all parameters. TBL was borderline for TSS, while Pepsi exceeded allowable thresholds for COD, BOD, and nutrients, underscoring its underperforming pretreatment system.

Table 5
Compliance assessment against Tanzanian standards (URT, 2020).

Parameter	Standard Limit	TBL	Coca-Cola	Pepsi	Compliance
COD (mg/L)	60	970.5	710.3	1875.4	Non-compliant (all)
BOD (mg/L)	30	590.1	456.9	1042.6	Non-compliant (all)
TSS (mg/L)	100	520.8	230.1	310.6	TBL borderline
TN (mg/L)	20	32.4	21.2	28.9	Exceeds in all
TP (mg/L)	5	7.6	4.8	6.3	Pepsi, TBL exceed

3.4. Visual Representations

Figure 2

Hydraulic Load Contribution Showing Industries Collectively Contribute 70% Of Total WSP Inflow

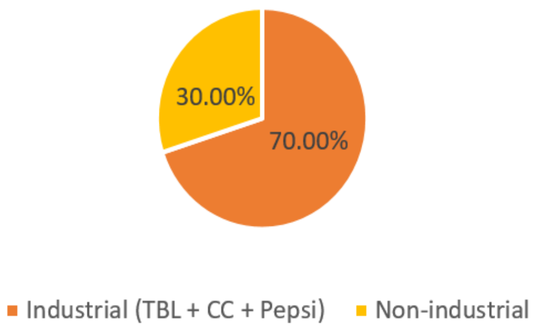


Figure 3

Pollution Load Comparison Industrial Sources Contribute the Majority of BOD and COD Loads

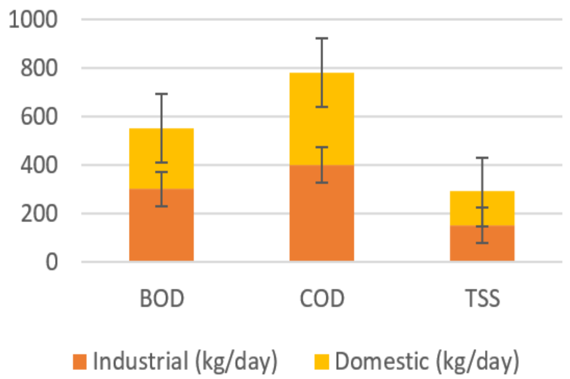


Figure 4

Flow vs. COD Concentration Indicates Pollution is Not Directly Proportional to Flow

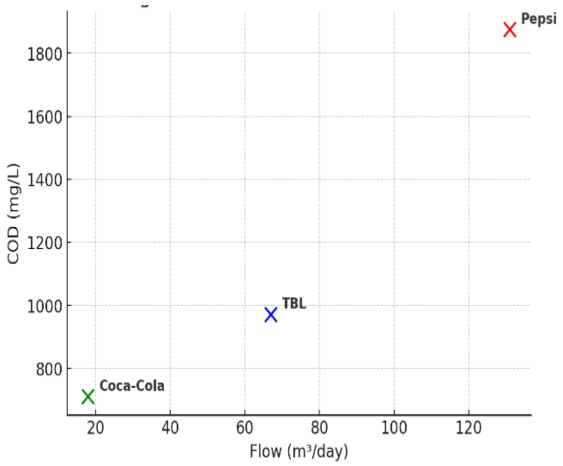
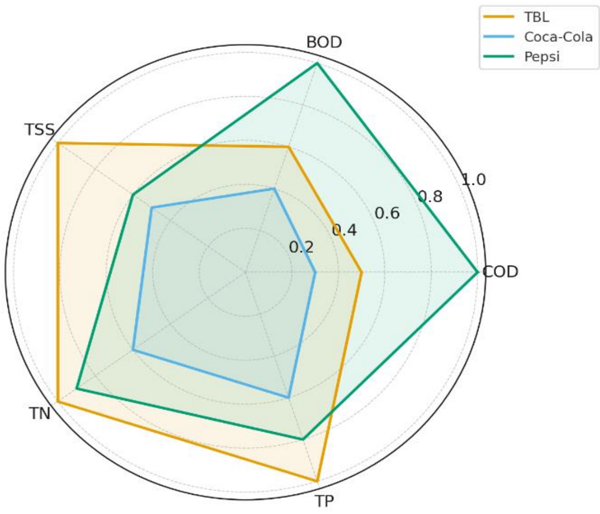


Figure 5

Radar Chart Normalized Pollutant Profiles Show Pepsi as the Dominant Polluter



These results confirm that industrial wastewater, particularly from Pepsi, is the dominant source of pollution entering the Kalobe WSP, despite its lower volumetric contribution.

4.0 Discussion

4.1 Industrial Pretreatment Performance and Variability

The three beverage industries exhibited markedly different wastewater profiles (Table 1). Coca-Cola consistently maintained the lowest concentrations of COD (710.3 ± 96.5 mg/L), BOD (456.9 ± 54.1 mg/L), and TSS (230.1 ± 28.3 mg/L), reflecting effective pretreatment and compliance with national standards. In contrast, TBL showed high suspended solids (TSS: 520.8 ± 74.6 mg/L) despite moderate organic loads, consistent with findings from other breweries where residual grains and yeast contribute to elevated solids (Chakraborty and Ghosh, 2015; Adewumi *et al.,* 2021). Pepsi discharged the highest organic concentrations (BOD: 1042.6 ± 142.3 mg/L; COD: 1875.4 ± 205.8 mg/L), suggesting deficiencies in design capacity or operational management of its pretreatment system. These differences arise because industries discharging stronger effluents reduce effective retention times and disturb oxygen transfer in WSPs. Pepsi's high-strength discharges therefore stressed the system more than Coca-Cola's lower-strength effluents.

4.2 Industrial Contributions to WSP Overloading

Pollution load calculations revealed that Pepsi accounted for 71% of BOD and 76% of COD entering the Kalobe WSP, despite contributing only 24% of the hydraulic flow (Table 3). This disproportionality confirms that pollutant loads, rather than volumes, are the key determinant of system stress. Such shock loading shortens retention times, disrupts microbial activity, and accelerates sludge accumulation (El Samad *et al.,* 2020; Müller *et al.,* 2018). In this study, Pepsi contributed 124.81 kg/day of BOD and 245.46 kg/day of COD, accounting for over 70% of the total organic load. This result result result result confirms severe underperformance of its pretreatment system. Comparable overload effects have also been reported in India and East Africa (Ramaswamy *et al.,* 2020; Musyoka *et al.,* 2021).

TBL's dominance in TSS load (48%) highlights a different challenge: suspended solids increase sludge build-up, raising desludging costs and reducing pond capacity. By contrast, Coca-Cola's minimal contribution confirms that well-maintained pretreatment plants can substantially reduce industrial impacts.

4.3 Ecological and Public Health Risks

Exceedances of BOD, COD, TN, and TP pose significant ecological risks. Organic overload reduces dissolved oxygen in receiving waters, impairing aquatic life and increasing the risk of fish kills (Garcia *et al.,* 2019). High nitrogen and phosphorus levels promote eutrophication, leading to algal blooms, oxygen depletion, and poor pathogen removal efficiency in ponds (Kabeto *et al.,* 2020). Nutrient-rich downstream discharges can also contaminate water supplies, increasing the risk of diarrhoea and other waterborne illnesses in nearby communities (WHO, 1987). These findings highlight that industrial non-compliance is not only an engineering problem but also an ecological and public health threat.

4.4 Compliance Context

The compliance assessment (Table 4) showed that Coca-Cola met all Tanzanian discharge standards, TBL was borderline for TSS, and Pepsi exceeded limits for COD, BOD, TN, and TP. These results echo broader challenges in East Africa, where weak monitoring and enforcement have allowed industries to persistently exceed effluent standards (Khan *et al.,* 2021). A direct comparison with national standards contextualises the severity of non-compliance and strengthens the case for regulatory action.

4.5 Policy and Economic Implications

Addressing these industrial loads requires both technical and policy measures. First, targeted upgrades to Pepsi's pretreatment system are urgent, with an emphasis on equaliser tanks, anaerobic treatment units, and sludge handling. Second, regulators should adopt load-based permits (kg/day) rather than volume-only limits, ensuring that industries with stronger discharges bear responsibility for their true environmental impact (Mara and Pearson, 2013).

Economic feasibility is central to policy uptake. Incentives such as tax relief for investments in pretreatment technology, low-interest loans, or shared-cost schemes through public–private partnerships could motivate industries to improve compliance. Conversely, penalties for non-compliance—such as pollution levies scaled to excess load discharged—would deter negligence. These approaches balance enforcement with support, making sustainable wastewater management more attainable for both industry and regulators.

4.6 Regional Comparisons and Contribution to Knowledge

This study reinforces regional evidence that beverage industries are major contributors to municipal WSP overloads (Adewumi *et al.,* 2021; Musyoka *et al.,* 2021; Ramaswamy et al., 2020). However, its unique contribution lies in applying a mass-based pollutant load framework for the first time in Tanzania. Unlike conventional concentration monitoring, this method captures the real environmental burden by integrating flow with pollutant strength. As such, it provides a more accurate and policy-relevant basis for enforcement and regulatory decision-making.

4.7 Limitations and Future Directions

The study was limited to one month of monitoring, which may not capture seasonal variations in production or rainfall-related dilution. Flow estimation partly relied on production records and reported values, which could introduce uncertainties despite cross-verification. In addition, the study assessed only physicochemical parameters; microbial contaminants and emerging pollutants (e.g., pharmaceuticals, microplastics) were not included. Future research should therefore expand monitoring across wet and dry seasons, incorporate microbial and toxicological assessments, and evaluate the long-term performance of industrial pretreatment facilities.

5.0 Conclusion

This study evaluated industrial wastewater quality and pollutant loads from three major beverage industries—TBL, Coca-Cola, Kwanza, and Pepsi—discharging into the Kalobe Waste Stabilisation Pond (WSP) in Mbeya, Tanzania. By applying a mass-based pollutant load framework, for the first time in Tanzania, the study quantified each industry's contribution to organic and solids overloading in a municipal treatment system.

Results indicated that Coca-Cola maintained effective pretreatment and compliance with discharge standards, TBL contributed the highest suspended solids due to brewing by-products, and Pepsi discharged excessive BOD and COD loads (71% and 76% of total, respectively), highlighting critical underperformance in its pretreatment system. These disproportionate contributions confirm that pollutant loads, not just flow volumes, determine system stress, threatening WSP performance, effluent quality, and downstream ecological health.

The findings emphasise three urgent actions: (i) (i) (i) (i) (i) (i) targeted upgrades to Pepsi's pretreatment facility, (ii) adoption of load-based permits (kg/day) instead of volume-only regulation, and (iii) introduction of incentive mechanisms and stronger enforcement to align industrial practices with national standards. These recommendations support the implementation of Tanzania's Industrial Wastewater Regulations (2020) and advance SDG 6.3 on reducing untreated wastewater. This study provides the first empirical evidence in Tanzania that industrial discharges can be accurately apportioned using a mass-based framework. This methodological contribution enhances regulatory enforcement capacity and offers a replicable model for other Sub-Saharan cities facing similar challenges. Longitudinal monitoring across wet and dry seasons, inclusion of microbial and emerging pollutants, and economic feasibility assessments of pretreatment options are recommended. These directions will provide a more comprehensive understanding of industrial wastewater impacts and guide sustainable policy interventions.

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8.0 Conflict of Interest

The authors declare that there are no conflicts of interest for the publication of this manuscript. The information, analysis, and conclusions expressed in this study are exclusively the authors' and do not necessarily reflect the opinions or policies of the institutions concerned.

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