RESOURE RECOVERY AND CHARACTERIZATION OF SLUDGE WASTE IN SEVEN-UP BOTTLING COMPANY OLUKU BENIN CITY.

BY

OBASOHAN, Osaikhuwuomwan Osward

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CERTIFICATION

This is to certify that this work was carried out by Obasohan, Osaikhuwuomwan Osward, Matriculation Number ENG2009610, of the Department of Structural Engineering, University of Benin City, Edo State, Nigeria.

SUPERVISOR:

Name: ………………………………………………………………………….

Signature and Date: ………………………………………………………………

HEAD OF DEPARTMENT:

Name: ………………………………………………………………………….

Signature and Date: ……………………………………………………………….

DEDICATION

This project is dedicated to my family, whose encouragement, unwavering moral and financial support throughout my academic journey made this achievement possible. Their belief in my potential provided the foundation upon which this work was built.

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ABSTRACT

This research project investigated sustainable resource recovery and characterization strategies for sludge waste generated by Seven-Up Bottling Company's manufacturing operations in Oluku, Benin City, Edo State, Nigeria. The study comprehensively characterized sludge waste streams from three primary sources within the facility: water treatment plant sludge from clarification processes, cleaning sludge from equipment washing operations, and storage tank sludge from ingredient preparation areas. The research employed systematic sampling and analysis approaches following standard laboratory procedures, with comprehensive physicochemical analysis conducted at the Civil and Structural Engineering Laboratory of the University of Benin. Physical properties including total solids, volatile solids, and moisture content were examined through oven-drying at 105°C and loss on ignition at 550°C.

The results revealed highly favorable characteristics for beneficial reuse applications. The cleaning sludge exhibited a near-neutral pH of 6.9, falling within the optimal range (6.0-7.0) for agricultural crop production, and moderate electrical conductivity of 506 µS/cm, indicating appropriate salt content without salinity risks. The sludge contained valuable plant nutrients including elevated levels of calcium (6.41 mg/L), magnesium (4.71 mg/L), phosphorus (0.241 mg/L), and various nitrogen forms (ammonia nitrogen: 0.330 mg/L, nitrate: 0.283 mg/L), making it suitable as a soil amendment or fertilizer component

The study concludes that Seven-Up Bottling Company's sludge waste possesses excellent characteristics for resource recovery and beneficial reuse, particularly for agricultural applications. The combination of favorable nutrient content, near-neutral pH, low heavy metal concentrations, absence of petroleum contamination, and minimal pathogenic microorganisms demonstrates the sludge's suitability for transformation from an environmental liability into a valuable resource. This research provides the technical foundation for implementing sustainable waste management practices that align with circular economy principles while generating environmental and economic benefits for the company and surrounding agricultural communities.

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ACRONYMS

AAS - Atomic Absorption Spectroscopy

AD - Anaerobic Digestion

AOP - Advanced Oxidation Process

CAGR - Compound Annual Growth Rate

CFU - Colony Forming Unit

COD - Chemical Oxygen Demand

EC - Electrical Conductivity

EPA - Environmental Protection Agency

EPS - Extracellular Polymeric Substances

FBRA - Federal Bureau of Revenue Administration (Nigeria)

HTL - Hydrothermal Liquefaction

ISO - International Organization for Standardization

IWMI - International Water Management Institute

IWRM - Integrated Water Resource Management

LCA - Life Cycle Assessment

NESREA - National Environmental Standards and Regulations Enforcement Agency

TDS - Total Dissolved Solids

THC - Total Hydrocarbon Content

TKN - Total Kjeldahl Nitrogen

TS - Total Solids

TSS - Total Suspended Solids

USD - United States Dollar

VFA - Volatile Fatty Acid

VS - Volatile Solids

WHO - World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

The global beverage industry generates millions of tons of waste annually, with sludge waste representing one of the most challenging byproducts to manage effectively. According to recent industry reports, the global waste management market size was estimated at USD 1,293.70 billion in 2022 and is expected to grow at a CAGR of 5.4%from 2023 to 2030 (Grand View Research 2023), highlighting the growing importance of efficient waste management systems across all industries.

In Nigeria, the beverage manufacturing sector has experienced tremendous growth over the past decade, with companies like Seven-Up Bottling Company leading the market. Seven-Up Bottling Company Ltd is one of the largest manufacturing companies in Nigeria, producing and distributing some of the nation's most-loved beverages in the country like; Pepsi, 7Up, Mirinda, Teem, Mountain Dew, H2oH!, Lipton Ice Tea, Supa Komando Energy Drink and Aquafina premium drinking water. With such large-scale operations across nine bottling plants, the company generates substantial amounts of industrial sludge waste from various manufacturing processes.

The traditional approach to sludge management in many developing countries, including Nigeria, has been disposal in landfills or discharge into water bodies without proper treatment. However, this practice poses serious environmental risks and represents a significant loss of potentially valuable resources. Modern industrial practices worldwide are shifting toward circular economy principles, where waste materials are viewed as resources that can be recovered and recycled rather than simply disposed of.

Recent research in waste management has shown that beverage industry sludge contains valuable organic compounds, nutrients, and energy potential that can be harnessed through appropriate recovery and recycling technologies (EPA, 2018). Municipal solid waste generation is predicted to grow, making resource recovery from industrial waste streams increasingly critical for sustainable development.

The concept of resource recovery from sludge waste involves extracting useful materials, energy, or nutrients from what would otherwise be considered waste. This approach not only reduces environmental impact but also creates economic value for manufacturing companies. In the context of beverage manufacturing, sludge waste typically contains high levels of organic matter, making it suitable for various recovery processes including biogas production, composting, and material recovery.

1.2 STATEMENT OF THE PROBLEM

The rapid expansion of Nigeria's beverage manufacturing sector, exemplified by industry leaders like Seven-Up Bottling Company with its nine production facilities across the country, has brought unprecedented industrial growth but also significant environmental challenges that demand urgent attention. As these facilities continue to meet the growing demand for soft drinks and bottled water, they generate substantial volumes of sludge waste from various production processes including water treatment, equipment cleaning, quality control operations, and wastewater management systems. This industrial byproduct, which contains a complex mixture of organic compounds, suspended solids, chemical residues, and valuable nutrients, currently represents one of the most pressing environmental and economic challenges facing the sector.

The traditional approach to managing this sludge waste in Benin follows outdated practices that treat waste as a burden rather than a resource, leading to widespread environmental degradation that extends far beyond factory boundaries. When sludge containing high levels of organic matter, chemical additives, and processing residues is disposed of in landfills or discharged into water bodies without proper treatment, it creates a cascade of environmental problems (Metcalf & Eddy, 2013) that persist for decades. The organic components decompose under anaerobic conditions, releasing methane and other greenhouse gases that contribute to climate change, while chemical residues seep into groundwater systems, contaminating drinking water sources for surrounding communities. This contamination pattern is particularly concerning in Benin city, where many rural and semi-urban communities depend on groundwater for their daily water needs.

Beyond the immediate environmental impact, the current waste management approach represents a massive economic inefficiency that undermines the financial sustainability of manufacturing operations. Companies like Seven-Up Bottling Company spend millions of naira annually on waste disposal costs, including transportation to disposal sites, landfill fees, treatment charges, and compliance-related expenses, yet receive no value in return for these investments. This economic burden becomes even more significant when considering that the same sludge waste contains valuable resources that could generate revenue through proper recovery and recycling processes. The organic compounds present in beverage industry sludge are ideal for biogas production, which could provide renewable energy for factory operations or be sold to the national grid. Similarly, the nutrient-rich components could be processed into high-quality compost for Nigeria's agricultural sector, while inorganic materials could serve as raw materials for construction applications.

The human dimension of this problem cannot be overlooked, as improper sludge management directly impacts the health and wellbeing of communities surrounding manufacturing facilities. When untreated waste contaminates local water sources, it creates public health risks that disproportionately affect vulnerable populations, including children and elderly residents who are most susceptible to waterborne diseases and chemical exposure. These health impacts create social tensions between manufacturing companies and their host communities, undermining the social license to operate that is essential for long-term business sustainability.

The convergence of these environmental, economic, regulatory, and social challenges creates an urgent need for comprehensive research and practical solutions that can transform sludge waste management from a liability into an asset for Nigerian beverage manufacturers, while contributing to national sustainable development goals and climate commitments.

1.3 AIM AND OBJECTIVES

The aim of this study is to investigate and develop sustainable resource recovery and recycling strategies for sludge waste generated by Seven-Up Bottling Company.

The Objectives are:

a) To comprehensively characterize and quantify sludge waste streams from Seven-Up Bottling Company's manufacturing processes.
b) To investigate the microbiological characteristics and biodegradability potential of beverage industry sludge waste for biological treatment processes.
c) To analyze the physiochemical properties and heavy metal content sludge waste to determine environmental safety and beneficial use applications.
d) To quantify environmental benefits and develop implementation strategies that position Seven-Up Bottling Company as a leader in sustainable manufacturing practices.

1.4 SCOPE OF STUDY

This study focuses specifically on the resource recovery and characterization of sludge waste generated by Seven-Up Bottling Company's manufacturing operations in Benin City, Edo State. The scope encompasses both technical and practical aspects of implementing sustainable waste management solutions within the context of the Nigerian beverage industry.

The study focuses on Seven-Up Bottling Company's operations in Benin City, Edo State, with particular attention to their major production facilities. While the research findings will be specifically applicable to the Nigerian context, the methodologies and principles developed may be adaptable to similar beverage manufacturing operations in other developing countries with comparable industrial and regulatory environments.

i. Laboratory Analysis: Physical and chemical characterization of sludge samples, assessment of organic content, nutrient levels, and contaminant presence, evaluation of biodegradability and treatment potential

ii. Environmental Impact Evaluation: Life cycle assessment comparing current disposal methods with proposed recovery systems, quantification of environmental benefits including greenhouse gas emission reductions, water conservation, and pollution prevention

iii. Technical Evaluation: Primary treatment sludge from initial settling, screening, and flotation processes, secondary biological treatment sludge from activated sludge and trickling filter system, tertiary treatment sludge from advanced treatment processes including chemical precipitation and filtration

1.5 JUSTIFICATION OF STUDY

The justification for this comprehensive study on resource recovery and recycling of sludge waste at Seven-Up Bottling Company emerges from the critical intersection of environmental necessity, economic opportunity, technological advancement, and sustainable development imperatives that define modern industrial operations in Benin City and nationally.

a) Environmental Significance: How the study address pollution, waste reduction, and climate change mitigation.
b) Economic Benefits: Cost savings, revenue generation, and return on investment for the company.
c) Industrial and Technological Advancement: Contributing to industry knowledge and technology transfer.
d) Social and Public Health Impact: Community benefits, job creation, and health protection.
e) Academic Research Contribution: Adding to scientific knowledge and research methodology

CHAPTER TWO

LITERATURE REVIEW

2.1 Water and Its Effect on Life

Water is the most abundant and essential compound on Earth, constituting approximately 71% of the planet's surface and serving as the fundamental basis for all known forms of life (Gleick, 2014). The critical role of water in biological systems extends beyond mere survival, encompassing cellular processes, metabolic functions, and ecosystem dynamics. In industrial applications, particularly in beverage manufacturing, water serves as both a primary ingredient and a processing medium, making its quality and management paramount to operational success and environmental sustainability

The molecular structure of water (H_2O) confers unique properties that make it an ideal solvent, facilitating chemical reactions and nutrient transport in biological systems. These same properties make water indispensable in beverage production, where it typically comprises 85-95% of the final product volume (Chapagain and Hoekstra, 2007). The quality of water directly influences product taste, shelf life, and consumer safety, necessitating stringent treatment and monitoring protocols throughout the manufacturing process.

Water scarcity affects approximately 2.2 billion people globally, with industrial water consumption accounting for 19% of total freshwater withdrawals (UNESCO, 2021). This growing scarcity has intensified focus on water conservation and reuse strategies in manufacturing industries. The beverage industry, being one of the largest industrial water consumers, faces increasing pressure to develop sustainable water management practices that minimize consumption while maintaining product quality standards.

2.2 Groundwater Development and Industrial Applications

Groundwater represents the largest accessible freshwater resource, accounting for approximately 30% of global freshwater reserves (Margat and van der Gun, 2013). Industrial development has historically relied heavily on groundwater extraction due to its generally consistent quality and availability. The development of groundwater resources involves complex hydrogeological assessments, including aquifer characterization, yield determination, and sustainability analysis.

In beverage manufacturing, groundwater often serves as the preferred water source due to its natural filtration through soil and rock layers, which typically results in lower turbidity and microbial contamination compared to surface water sources (Foster et al., 2002). However, groundwater extraction for in/dustrial purposes must be carefully managed to prevent over-exploitation and associated environmental consequences such as land subsidence, saltwater intrusion, and ecosystem disruption.

The sustainable development of groundwater resources requires implementation of integrated water resource management (IWRM) approaches that consider both supply-side and demand-side management strategies. This includes efficient extraction technologies, water recycling systems, and alternative water sources to reduce dependence on primary groundwater reserves (Llamas and Martínez-Santos, 2005).

2.3 Groundwater Location and Quality Assessment

Groundwater occurrence is controlled by geological, topographical, and climatic factors that determine aquifer formation and recharge patterns. The location and assessment of groundwater resources involve geophysical surveys, hydrogeological mapping, and water quality analysis to determine suitability for industrial applications (Todd and Mays, 2005). For beverage manufacturing, groundwater quality parameters of particular importance include total dissolved solids (TDS), hardness, alkalinity, pH, and the presence of organic and inorganic contaminants. The World Health Organization (WHO) and national regulatory bodies establish water quality standards that must be met for potable water production, often requiring additional treatment processes even for high-quality groundwater sources (WHO, 2017).

Groundwater vulnerability assessment has become increasingly important as industrial activities potentially impact aquifer quality through contamination pathways. The implementation of wellhead protection programs and monitoring systems helps ensure long-term sustainability of groundwater resources for industrial use while protecting public health and environmental integrity.

2.4 Beverage Manufacturing Processes and Water Utilization

The beverage manufacturing industry encompasses a diverse range of products including carbonated soft drinks, fruit juices, bottled water, and energy drinks. The production process typically involves several water-intensive stages including ingredient preparation, mixing, carbonation, filling, cleaning, and sanitization (Coca-Cola Company, 2018). Water-to-product ratios in beverage manufacturing typically range from 2:1 to 4:1, meaning that 2-4 liters of water are required to produce 1 liter of finished beverage.

Seven Up Bottling Company, as part of the global soft drink manufacturing sector, employs standardized production processes that include water treatment, syrup preparation, carbonation, filling, capping, and packaging. Each stage generates various waste streams, with sludge production occurring primarily during water treatment, equipment cleaning, and wastewater treatment processes (PepsiCo, 2020).

The complexity of beverage manufacturing processes necessitates multiple water quality specifications for different applications. Process water must meet stringent microbiological and chemical standards, while cleaning and sanitization activities require water with specific temperature and chemical characteristics. This diversity in water requirements creates opportunities for water reuse and recycling within the manufacturing facility.

2.5 Industrial Sludge Generation and Characteristics

Industrial sludge is a semi-solid waste byproduct generated during various manufacturing processes, particularly in water and wastewater treatment operations. In beverage manufacturing, sludge generation occurs through several mechanisms including coagulation-flocculation processes in water treatment, biological treatment of wastewater, and chemical precipitation during cleaning operations (Metcalf & Eddy, 2013).

The characteristics of sludge from beverage manufacturing vary depending on the specific production processes, water treatment methods, and cleaning chemicals used. Typical components include organic matter from fruit concentrates and flavoring agents, inorganic precipitates from water treatment chemicals, microorganisms from biological treatment processes, and residual cleaning agents (Tchobanoglous et al., 2014).

Sludge composition analysis typically reveals moisture content ranging from 95-99%, organic matter content of 60-80% (dry weight basis), and various nutrients including nitrogen, phosphorus, and potassium. Heavy metal concentrations are generally low in beverage industry sludge compared to other industrial sectors, making it potentially suitable for beneficial reuse applications (EPA, 2018).

2.6 Sludge Treatment and Management Technologies

Traditional sludge management approaches in industrial settings have focused on volume reduction and disposal, typically through thickening, dewatering, and landfill disposal or incineration. However, evolving environmental regulations and sustainability considerations have driven development of advanced treatment technologies that enable resource recovery and beneficial reuse (Appels et al., 2008).

Mechanical dewatering technologies including centrifuges, belt filter presses, and screw presses are commonly employed to reduce sludge volume and transportation costs. These technologies can achieve solids concentrations of 15-25%, significantly reducing disposal volumes and associated costs (Mahmoud et al., 2010).

Biological treatment processes such as anaerobic digestion offer dual benefits of volume reduction and energy recovery through biogas production. Anaerobic digestion of organic-rich sludge from beverage manufacturing can achieve volatile solids reduction of 40-60% while producing methane-rich biogas suitable for energy generation (Appels et al., 2011).

2.7 Resource Recovery from Industrial Sludge

The concept of resource recovery from industrial sludge has gained significant attention as part of the circular economy paradigm, which emphasizes waste minimization and material recovery. Resource recovery encompasses the extraction of valuable materials, nutrients, and energy from waste streams that would otherwise be disposed of as waste (Ellen MacArthur Foundation, 2013).

In beverage manufacturing sludge, potential recoverable resources include organic matter for composting or soil amendment, nutrients for fertilizer production, and energy through anaerobic digestion or thermal treatment. The high organic content and relatively low contaminant levels make beverage industry sludge particularly suitable for biological resource recovery processes (Chen et al., 2015).

Phosphorus recovery from sludge has become increasingly important due to the finite nature of phosphate rock reserves and growing demand for agricultural fertilizers. Technologies such as struvite precipitation and thermal treatment can recover phosphorus in forms suitable for agricultural application (Cornel and Schaum, 2009).

2.8 Sludge Recycling Technologies and Applications

Sludge recycling involves the processing of waste sludge into useful products or the reuse of treated sludge within the production process. Recycling approaches can be categorized into direct recycling, where sludge is reused with minimal processing, and indirect recycling, where sludge undergoes significant treatment to produce new materials (Fytili and Zabaniotou, 2008).

Composting represents one of the most widely applied recycling technologies for organic-rich sludge. The controlled decomposition process produces a stable, humus-like material suitable for soil amendment and agricultural applications. Proper composting management ensures pathogen destruction and odor control while producing a valuable end product (Haug, 1993).

Pyrolysis and gasification technologies offer advanced recycling options that can convert organic sludge into valuable products including biochar, syngas, and bio-oil. These thermal treatment processes operate at high temperatures in oxygen-limited environments, breaking down organic compounds into simpler, more valuable forms (Fonts et al., 2012).

2.9 Environmental Impact Assessment of Sludge Management

The environmental impacts of sludge management practices must be carefully evaluated to ensure that resource recovery and recycling activities provide net environmental benefits. Life cycle assessment (LCA) methodologies are commonly employed to quantify environmental impacts across the entire sludge management chain, from generation through final disposal or beneficial use (Corominas et al., 2013).

Key environmental impact categories include greenhouse gas emissions, energy consumption, water usage, land use, and potential for soil and water contamination. Anaerobic digestion of sludge typically results in lower greenhouse gas emissions compared to landfill disposal due to controlled methane capture and utilization (Hospido et al., 2010).

The application of treated sludge to agricultural land can provide environmental benefits through carbon sequestration and reduced need for synthetic fertilizers. However, careful monitoring is required to prevent accumulation of potentially harmful substances and ensure compliance with soil quality standards (Singh and Agrawal, 2008).

2.10 Regulatory Framework for Sludge Management

Sludge management practices are governed by comprehensive regulatory frameworks that vary by jurisdiction but generally address quality standards, treatment requirements, and application restrictions. In Nigeria, the National Environmental Standards and Regulations Enforcement Agency (NESREA) provides guidelines for industrial waste management, including sludge handling and disposal requirements (NESREA, 2007).

International standards such as those developed by the International Organization for Standardization (ISO) provide technical guidance for sludge treatment and beneficial use applications. ISO 14001 environmental management systems standards are increasingly adopted by beverage manufacturers to ensure systematic approach to environmental protection and regulatory compliance (ISO, 2015).

The regulatory framework for sludge management continues to evolve in response to advancing technologies and improved understanding of environmental and health impacts. Recent trends include stricter contaminant limits, enhanced monitoring requirements, and increased emphasis on resource recovery and circular economy principles (EC, 2018).

2.11 Economic Analysis of Sludge Management Options

Economic considerations play a crucial role in determining optimal sludge management strategies for beverage manufacturing facilities. Traditional disposal methods such as landfilling or incineration involve significant costs including transportation, tipping fees, and regulatory compliance expenses. These costs have increased substantially in recent years due to stricter environmental regulations and reduced landfill capacity (Bertanza et al., 2015).

Resource recovery and recycling technologies often require higher initial capital investments but can provide long-term economic benefits through reduced disposal costs, energy generation, and production of valuable byproducts. Cost-benefit analysis methodologies are essential for evaluating the economic viability of different sludge management options (Suh and Rousseaux, 2002).

The development of markets for sludge-derived products is critical for the economic sustainability of resource recovery programs. Successful market development requires product quality assurance, regulatory approval, and customer education to overcome potential resistance to recycled materials (Milieu Ltd., 2008).

2.12 Case Studies in Beverage Industry Sludge Management

Several beverage manufacturing companies have implemented innovative sludge management programs that demonstrate the feasibility and benefits of resource recovery and recycling approaches. The Coca-Cola Company has developed comprehensive water stewardship programs that include sludge minimization and beneficial reuse initiatives across their global operations (Coca-Cola Company, 2019).

PepsiCo's approach to sustainable sludge management includes anaerobic digestion systems at multiple facilities, generating renewable energy while reducing waste disposal volumes. Their integrated approach combines operational efficiency improvements with advanced treatment technologies to achieve environmental and economic benefits (PepsiCo, 2021).

Smaller-scale implementations have also demonstrated success in developing countries, where resource recovery from beverage industry sludge can provide additional environmental and social benefits. Case studies from India and Brazil show how composting and agricultural application of treated sludge can support local food production while reducing industrial waste disposal costs (Kumar et al., 2017; Silva et al., 2019).

2.13 Technology Selection and Implementation Considerations

The selection of appropriate sludge treatment and recycling technologies depends on multiple factors including sludge characteristics, facility constraints, regulatory requirements, and economic considerations. Technology selection frameworks typically involve multi-criteria decision analysis that weighs technical feasibility, environmental impact, economic viability, and social acceptance (Kalbar et al., 2012).

Implementation considerations include available space for treatment systems, utility requirements, skilled labor availability, and integration with existing operations. Phased implementation approaches can help minimize operational disruption while allowing for system optimization and staff training (Tchobanoglous et al., 2014).

Monitoring and control systems are essential for ensuring reliable operation of sludge treatment and recycling systems. Advanced process control technologies including sensors, automation systems, and data analytics can optimize system performance while ensuring regulatory compliance and product quality (Olsson et al., 2005).

2.14 Future Trends and Emerging Technologies

The field of sludge management continues to evolve with emerging technologies and changing regulatory landscapes. Advanced oxidation processes (AOPs) offer potential for enhanced contaminant removal and sludge stabilization, particularly for sludges containing persistent organic compounds (Oller et al., 2011).

Microbial fuel cell technology represents an emerging approach for simultaneous sludge treatment and energy generation. These systems use electrochemically active bacteria to generate electrical current while degrading organic matter in sludge, offering potential for decentralized treatment applications (Logan and Rabaey, 2012).

Nanotechnology applications in sludge treatment include advanced filtration membranes, catalytic treatment processes, and enhanced resource recovery systems. While still in development stages, these technologies offer potential for significant improvements in treatment efficiency and resource recovery rates (Qu et al., 2013).

2.15 Research Gaps and Future Directions

Despite significant advances in sludge management technologies, several research gaps remain that limit widespread implementation of resource recovery and recycling systems. Long-term studies on the environmental fate and effects of sludge-derived products are needed to address regulatory and public acceptance concerns (Harrison et al., 2006).

Economic modeling frameworks that incorporate uncertainty and risk assessment are needed to better evaluate the financial viability of resource recovery investments. Integration of life cycle cost analysis with environmental impact assessment can provide more comprehensive decision-making tools (Yoshida et al., 2013).

Research on optimized treatment process configurations for specific sludge types and local conditions can improve system performance and reduce implementation costs. Development of standardized testing protocols and performance metrics would facilitate technology comparison and selection (IWA, 2008).

The integration of digital technologies including artificial intelligence, machine learning, and Internet of Things (IoT) sensors offers opportunities for improved process optimization and predictive maintenance in sludge management systems. These technologies can enhance operational efficiency while reducing environmental impact and operational costs (Ramin et al., 2019).

2.16 Scale and Characteristics of Beverage Industry Waste

The food and beverage manufacturing sector generates substantial waste streams that require comprehensive management strategies. Recent EPA data indicates that an additional 40 million tons of wasted food was generated in the food and beverage manufacturing and processing sectors, with anaerobic digestion managing the biggest portion (42.6%) of this waste. The beverage bottling industry, in particular, produces various types of sludge waste including biological sludge from wastewater treatment, chemical precipitation sludge from water treatment processes, and organic waste from production operations.

Beverage manufacturing sludge typically contains high organic content, making it suitable for resource recovery applications. The characteristics of this sludge vary depending on the specific beverage type, production processes, and treatment methods employed. Seven Up bottling operations, like other carbonated soft drink manufacturers, generate sludge primarily from cleaning operations, bottle washing, syrup preparation, and wastewater treatment facilities.

2.17 Market Dynamics and Growth Projections

The food and beverage wastewater recovery systems market has experienced significant growth, crossing USD 8.3 billion in 2024 and estimated to grow at a CAGR of 8.4% from 2025 to 2034. This growth is driven by stricter government regulations on wastewater discharge and increasing demand for clean water resources. The expansion of membrane water treatment technology, projected to reach $13.5 billion by 2025 with a CAGR of 7.7% from 2020, underscores the industry's commitment to advanced treatment solutions.

2.18 Thermochemical Conversion Technologies

Recent research has identified thermochemical conversion technologies as promising alternatives for upcycling sludge waste streams. These technologies leverage the high organic content and fairly constant supply of wastewater sludge to implement circular economy strategies. Thermochemical processes including pyrolysis, gasification, and hydrothermal treatment offer potential for converting sludge into valuable products such as biochar, syngas, and bio-oils.

Studies from 2020-2023 have demonstrated that plasma pyrolysis integrated with anaerobic digestion can significantly enhance resource recovery from sewage sludge while addressing environmental concerns related to hazardous substance release. This integrated approach represents a significant advancement in process optimization for industrial applications.

2.19 Anaerobic Digestion and Biogas Production

Anaerobic digestion remains a cornerstone technology for beverage industry sludge treatment. EPA data from 2020-2021 shows that most anaerobic digestion facilities co-digest food waste with other organic waste, including beverage processing wastes. This approach maximizes biogas production while efficiently managing diverse waste streams from bottling operations.

The integration of microalgae-based systems with existing wastewater treatment facilities has emerged as an innovative approach for coupling resource recovery with sludge treatment. Case studies from winery operations demonstrate the feasibility of implementing microalgae systems within existing industrial facilities, providing a model for similar applications in beverage bottling companies.

2.20 Value-Added Material Production

Contemporary research has explored the conversion of sludge and sludge ash into low-carbon construction materials, representing a significant opportunity for structural engineering applications. This approach addresses the dual challenge of waste management and sustainable material production, creating potential revenue streams for beverage manufacturers while reducing environmental impact.

The valorization of sludge through material recovery processes has gained traction as companies seek to implement circular economy principles. These processes can transform waste sludge into products such as aggregates for concrete production, soil amendments, and specialized construction materials.

2.21 Industrial Water Management Strategies

Water resource recovery has become integral to sustainable beverage manufacturing operations. Recent studies demonstrate that specific wastewater generation can be reduced by up to 57.4% through implementation of comprehensive water recycling and reuse systems. A case study from the Turkish soft drink industry showed that water conservation implementations achieved a payback period of approximately 7 months, demonstrating the economic viability of such systems.

The integration of advanced membrane technologies, including reverse osmosis and ultrafiltration, has enabled beverage manufacturers to achieve high-quality water recovery from sludge treatment processes. These technologies support the closed-loop water systems increasingly demanded by regulatory frameworks and corporate sustainability goals.

2.22 Regulatory Compliance and Standards

Industrial facilities across Europe and other regions are implementing new wastewater regulations that directly impact sludge management practices. These regulatory changes are driving innovation in resource recovery technologies and pushing companies toward more comprehensive waste valorization strategies.

The regulatory landscape increasingly favors integrated approaches that combine waste treatment with resource recovery, creating incentives for beverage manufacturers to invest in advanced sludge processing technologies. Compliance with these regulations often requires systematic approaches to waste characterization, treatment optimization, and resource recovery quantification.

2.23 Leading Industry Implementations

Several food and beverage companies have successfully redefined their waste management approach by engineering methods to recover and leverage valuable resources from sludge waste. These implementations have demonstrated that companies can strengthen their bottom line while improving operational sustainability and gaining market differentiation. The brewing industry has pioneered several approaches relevant to beverage bottling operations, recognizing that high-quality clean water is essential for product quality. These companies have implemented comprehensive resource recovery systems that address both water and solid waste streams from their operations.

The waste and recycling industries are embracing "Performance Sustainability" concepts that emphasize measurable environmental and economic benefits from resource recovery initiatives. This approach has particular relevance for beverage manufacturers seeking to demonstrate concrete sustainability achievements while maintaining operational efficiency.

Companies implementing these strategies have positioned themselves as industry leaders by demonstrating quantifiable improvements in resource utilization, waste reduction, and environmental impact mitigation. The integration of advanced monitoring and control systems enables continuous optimization of sludge treatment and resource recovery processes.

2.24 Technical and Economic Barriers

Despite significant technological advances, several challenges remain in implementing comprehensive sludge resource recovery systems in beverage manufacturing. These include the need for specialized equipment, skilled operational personnel, and integration with existing production systems. Economic considerations often require careful analysis of capital investments versus long-term operational savings and regulatory compliance costs.

The variability in sludge characteristics across different beverage products and seasonal production patterns presents additional challenges for system design and optimization. Seven Up bottling operations must consider these factors when developing resource recovery strategies.

2.25 Emerging Technologies and Research Directions

Current research trends indicate growing interest in integrated biorefineries that can process multiple waste streams simultaneously. These systems offer potential for maximizing resource recovery while minimizing treatment costs through economies of scale and process integration.

Advanced process control and artificial intelligence applications are emerging as tools for optimizing sludge treatment and resource recovery operations. These technologies enable real-time adjustment of treatment parameters based on sludge characteristics and recovery objectives.

2.26 Strategic Considerations

For Seven Up bottling operations, the implementation of comprehensive sludge resource recovery systems offers multiple benefits including regulatory compliance, cost reduction, and sustainability leadership. The company's scale of operations provides opportunities for implementing advanced technologies that may not be economically viable for smaller facilities.

The carbonated soft drink manufacturing process generates relatively consistent sludge characteristics compared to other beverage types, potentially simplifying system design and operation. This consistency enables optimization of recovery processes for maximum efficiency and resource yield.

2.27 Sludge Composition and Characterization

The study by Oladejo et al. (2022) examined sludge from a beverage wastewater plant and found it contained 45% C, 3.6% N, 7.3% H, and 0.9% S, with 60% volatile solids and ~27% ash—yielding a high calorific value (5042 kcal/kg). The implication of this study is that high-organic, energy-rich sludge is well-suited for anaerobic digestion or thermal conversion—a fit for Seven-Up's waste, which likely shares similar sugar/organic levels.

The study by Zhu et al. & Tang et al. (2022) and others have highlighted sludge is ~40–60% protein (by organic matter), with recoverable lipids and volatile fatty acids (VFAs). Extraction methods include thermal hydrolysis, alkaline treatment, and co-fermentation. The implication of this study is that Seven-Up sludge could be a source of feedstock proteins/lipids, aligning with circular economy goals.

The study by Studies (e.g.,Wendimagegn et al., Ramya et al.) confirm beverage/agro-industry sludge is nutrient-rich—particularly N, P, K, and minor amounts of heavy metals like Cd, Cu, Ni, Pb, Zn. The implication of this study is that Nutrient recovery (e.g., struvite) presents high-value potential, if metals are within safe limits.

The study by Liang et al. (2025) reviewed pyrolysis-derived adsorbents from sludge, noting increased surface area and pollutant removal efficacy between 300–600 °C. The implication of this study is that After dewatering Seven-Up sludge, pyrolysis could generate biochar adsorbents—another resource stream.

2.28 Energy Recovery from Sludge (Biogas, Briquettes, Biochar)

The study by Rijal et al. (2022) analyzed beverage-waste sludge and reported 45.2% C, 3.6% N, 7.3% H, 60% volatile solids, 27% ash, and a calorific value of 5042 cal/g-highly suitable for both anaerobic digestion (AD) and thermal processes. The implication of this study is that Seven-Up sludge likely exhibits similar energy-rich characteristics, making it ideal for biogas and fuel applications.

The study by Wang et al. (2022) assessed municipal high-ash anaerobic sludge and demonstrated via pyrolysis-kinetics that adding AD as a pre-treatment improved thermal stability and energy yield—supporting a combined biorefinery concept. The project relevance is Combining AD with pyrolysis enhances energy recovery efficiency for sludge like Seven-Up's.

The study by Zhang et al. (2025) studied combined anaerobic digestion followed by pyrolysis of food/bio-sludge. They found that generating biochar from digestate produced energy and reduced CO_2 emissions (3.5%) while offering valuable biochar output. The implication of this study is that For Seven-Up, this integrated route aligns with a circular model: energy (biogas) - biochar.

A 2022 review (Okolie, Epelle et al.) highlighted how AD–pyrolysis for sludge-based feedstocks increases electricity output by ~42% vs standalone systems, and that digestate biochar delivers improved soil properties. The implication of this study is that Applying this sequence could substantially increase the efficiency and yield of the Seven-Up recycling process.

The study by Lalhmunsiami et al. (2023) demonstrated that adding sludge-derived biochar (516 °C pyrolysis) to AD boosted methane yield by 48%, shortened lag time, and enhanced electron transfer. Its relevance is treating Seven-Up sludge with pyrolysis then recycling biochar into AD reactors can dramatically boost biogas production.

2.29 Agricultural Application (Soil Amendment, Composting)

Wikipedia overview (2025) notes sludge commonly harbors pathogens-including parasites like *Cryptosporidium* and *Giardia*-and requires effective sanitization techniques like sonication, quicklime, or thermal methods before reuse. Its relevance to Seven-Up is the

Beverage-industry sludge may be less pathogen-heavy compared to municipal biosolids, but still requires post-treatment (e.g. pasteurization, lime stabilization) before use in soil amendments or feed applications.

A 2024 review by Yi et al. indicates that sewage sludges typically contain 0.5–2% heavy metals (e.g., Al, Pb, Cu, Zn) by dry weight, Surveys (e.g., Poland, China studies) consistently show the sequence Zn > Cu > Pb > Ni > Cr > Cd > Hg in sludge. Its relevance to Seven-Up is even industrial waste streams can accumulate these metals if sourced from cooling water, cleaning supplies, or packaging processes.

The study by Yi et al. (2024) reports that anaerobic bioleaching with iron-oxidizing bacteria can effectively remove metals like Al, Pb, Cu, Zn, and improve dewatering of sludge.

2024 bioleaching review suggests it's an eco-friendly method preserving nutrients—better suited for agriculture-bound sludge. The implication is that while pyrolysis/HTL can provide energy or biochar, heavy metals may end up in the biochar-necessitating use in non-food contexts (e.g., wastewater adsorbent) or further detox.

2.30 Use in Building and Construction Materials

The study by Bubalo et al. (2021) Incorporates 5–20 wt% sewage sludge ash (SSA) into clay bricks. Results include a compressive strength peaked at 5–10 wt% SSA (50–54 MPa vs 50 MPa control); 20% SSA reduced strength but reduced water saturation. The takeaway from this study is that Seven-Up sludge ash could replace a fraction of clay, maintaining structural performance with moderate substitution.

The study by Wu et al. (2022) fired bricks from pure sewage sludge + shale, the findings from the study is that there is an organic content increased porosity (31.6%) and lowered strength (vs clay) but improved insulation (0.51 W/mK). Its implication is that if Seven-Up sludge is similar, it could produce lightweight insulation bricks, even without clay.

The study by Liu et al. (2020) & He et al. (2021) its applications in drinking-water sludge used in concrete paving blocks; alum sludge used in concrete. Its implication is that Seven-Up sludge could be adapted for precast blocks or bricks via geopolymer or cementitious pathways.

2.31Policy, Regulation, and Industry Practice

The study by Chegwe et al., 2024 titled*Efficient Heavy Metal Removal from Industrial Wastewater Effluent Using Low-cost Clay Pellets: Case Study of 7-UP Bottling Company*

Summary: Lab-scale treatment removed heavy metals (e.g., lead, cadmium) from

nitiatives.

2.32 Identified Research Gaps from Literature

Implementation Gaps: Food/beverage systems often treat sludge as waste, lacking circular recovery frameworks. LAT Water notes the absence of closed-loop and nutrient-energy reuse systems, although lab-scale thermal conversion (pyrolysis, HTL), anaerobic digestion, composting has been studied globally, Sludge has emerging pollutants; e.g., HTL can destroy many pharmaceuticals, but effectiveness varies

Standardization Challenges: Unlike 40 CFR Part 503 or EU Sewage Directive, there’s no standard for beverage sludge in Nigeria-leading to inconsistent treatment and reuse, Variability in sludge moisture (up to 95%), nutrient content, ash levels (56%), and contaminant loads.

2.33 Recommended Approach

Based on current literature, a phased implementation approach is recommended for Seven Up bottling facilities. Initial phases should focus on proven technologies such as anaerobic digestion for biogas production, followed by integration of advanced resource recovery technologies as operational experience is gained.

The development of partnerships with research institutions and technology providers can accelerate implementation while reducing technical risks. Pilot-scale studies should be conducted to validate technology performance under specific operating conditions before full-scale implementation.

CHAPTER THREE

METHODOLOGY

3.1 The Study Area

The study was conducted at the Seven Up Bottling Company located in Oluku, Benin City, Edo State, Nigeria. The facility is geographically positioned at approximately 6°28'N latitude and 5°47'E longitude, situated along the Benin-Lagos expressway in the Oluku area. This facility is one of the major soft drink manufacturing plants in the South-South region of Nigeria and produces various carbonated beverages including 7UP, Pepsi, and Mirinda. The plant operates 24 hours daily and has a production capacity of approximately 50,000 bottles per hour.

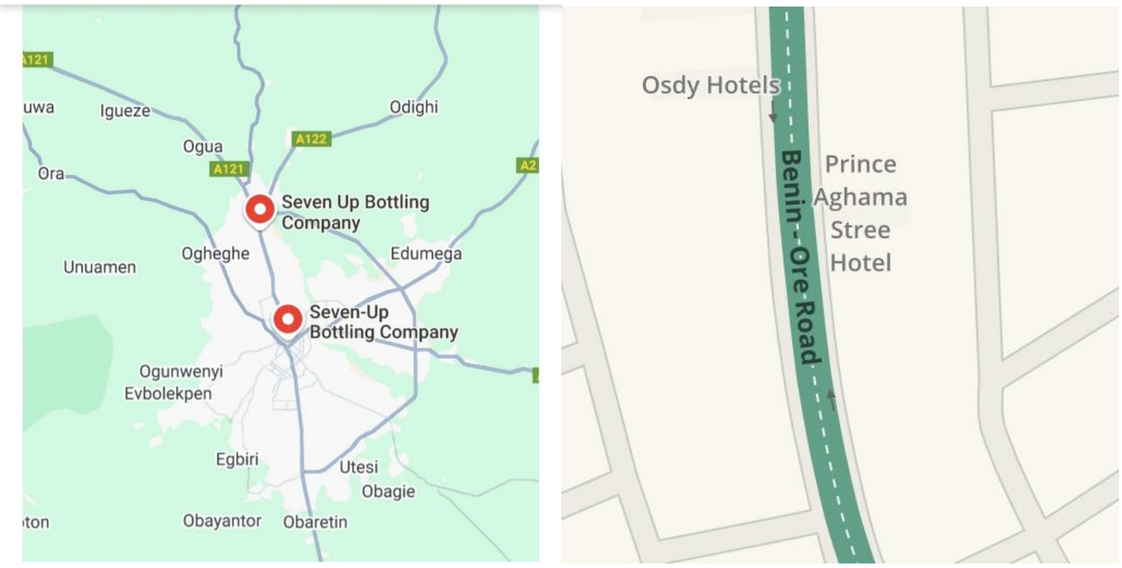

Figure 3.1: A map of the study area.

The factory is situated on a 15-hectare industrial site along the Benin-Lagos expressway in Oluku area of Benin City.\ This location was chosen for the study because it represents a typical beverage manufacturing operation with significant water usage and sludge generation. The plant draws water from both groundwater wells through boreholes and the Edo State water supply system, treating approximately 500,000 liters of water daily for production and cleaning purposes.

Benin City, the capital of Edo State, has a tropical climate with distinct wet and dry seasons. The wet season runs from April to October while the dry season spans November to March. Average temperatures range from 24°C to 32°C throughout the year. Heavy rainfall during the wet season, can impact industrial operations and wastewater management.

The facility generates various types of waste including solid waste, and sludge from water treatment and cleaning operations (bottle and equipment washing). The sludge is currently disposed of through conventional methods, making it an ideal location to study resource recovery and recycling possibilities.

The study area includes the main production hall, water treatment plant, wastewater treatment facility, and temporary sludge storage areas located within the Oluku industrial complex. The surrounding area is characterized by mixed residential and industrial development, making proper waste management particularly important for community relations and environmental protection.

3.2 Sample Collection

Three (3) samples were collected from sources within the Seven Up Bottling Company facility to get a complete picture of sludge generation and characteristics.

Primary Sources of Sample Collection:

i. Water treatment plant sludge from clarification processes

ii. Cleaning sludge from equipment washing operations

iii. Storage tank sludge from ingredient preparation areas

The samples were collected using clean containers provided by the laboratory. Each sampling session involved collecting 1 liters of liquid sludge from each source. All samples were properly labeled with collection date, time, and source location during collection.

Immediately after collection, samples were preserved according to standard procedures. Liquid samples will be stored at 4°C and analyze within 48 hours to prevent changes. Duplicate samples were also collected for quality control purposes.

3.3 Physico-Chemical Analysis

Comprehensive physico-chemical analysis was conducted to determine the composition and characteristics of sludge samples from different sources. The analysis was performed at the Civil and Structural Engineering Laboratory of the University of Benin using standard analytical methods.

3.3.1 Physical Properties Analyzed

a) Total solids (TS): determine dryness by oven-drying at 105°C for 1 hour.
b) Volatile solids (VS): lose ignition at 550°C to estimate organic content.
c) Moisture content
d) Color, odor and visual appearance

3.3.2 Chemical Properties Analyzed

a) pH value and temperature measured using calibrated meters.
b) Chemical oxygen demand (COD) using closed-reflux colorimetric method.
c) Total nitrogen by Kjeldahl method.
d) Heavy metals (lead, cadmium, zinc, copper) by Atomic Absorption Spectroscopy (AAS).

All analyses were performed to ensure accuracy and reliability of results.

Results were recorded in laboratory notebooks and entered into computer databases for statistical analysis. Quality assurance measures included regular checking of equipment calibration, and inter-laboratory comparison.

3.4 Microbiological Analysis.

Microbiological analysis was conducted to determine the presence and concentration of microorganisms in sludge samples. This analysis is important for understanding treatment requirements and potential health risks associated with sludge handling and reuse.

3.4.1 Microorganisms Tested:

a) Total heterotrophic bacterial counts

b) Total coliform counts

c) Total E-coil counts

d) Tentative bacterial isolates

Results were expressed as colony forming units per gram (CFU/g) for solid samples and colony forming units per milliliter (CFU/ml) for liquid samples. Statistical analysis was performed to determine mean values and standard deviations for different sample types

3.5 List of Materials and Equipment

i. Drying oven capable of 105°C

ii. Sample containers

iii. Measuring cylinders

iv. Evaporating dishes (glass or porcelain)

v. Analytical balance (0.1 mg precision)

vi. Muffle furnace (up to 550°C)

vii. Calibrated pH meter

viii. Thermometer

ix. Beakers

x. COD digestion reactor and reflux apparatus

xi. Spectrophotometer

xii. Potassium dichromate, or sulfuric acid for COD

xiii. Kjeldahl distillation setup for TKN

xiv. Mixed indicator or methyl red

xv. Atomic Absorption Spectrometer

xvi. Volumetric flask

xvii. Pipettes

xviii. Nitric acid

xix. Hydrochloric acid

3.6 Laboratory Test Procedures

Total Solid (TS) Determination (APHA, 2017, Method 2540B)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 2540B - Total Solids Dried at 103-105°C.

Principle: Total solids represent the material residue left in a vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. This measurement includes both dissolved and suspended solids.

Procedures

i. Clean and dry evaporating dishes at 105°C for 1 hour

ii. Cool in desiccator and weigh (W1)

iii. Add well-mixed sample (50-100 mL) to dish and weigh (W2)

iv. Place in oven at 105°C for 1 hour

v. Cool in desiccator and weigh (W3)

vi. Calculate: TS (mg/L) = [(W3-W1) × 1000] / [(W2-W1)]

Volatile Solid (VS) Determination (APHA, 2017, Method 2540E)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 2540E - Fixed and Volatile Solids Ignited at 550°C.

Principle: Volatile solids represent the organic fraction of total solids that can be volatilized and burned off when ignited at 550°C in a muffle furnace. The weight loss on ignition provides an estimate of the organic content of the sample.

Procedures

i. Use dried residue from TS determination

ii. Ignite crucible and lid at 550°C for 1 hour in muffle furnace

iii. Cool in desiccator and weigh (W4)

iv. Transfer dried residue to ignited crucible and weigh (W5)

v. Ignite at 550°C for 1 hour

vi. Cool in desiccator and weigh (W6)

vii. Calculate: VS (mg/L) = [(W5-W6) × 1000] / Sample volume (mL)

Moisture Content Determination (ASTM D2216-19)

Standard Reference: ASTM International, D2216-19 - Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

Principle: Moisture content is determined by measuring the weight loss of a sample when dried at 105°C until constant weight is achieved, representing the amount of water present in the sample.

Procedures

i. Weigh clean, dry dish (W1)

ii. Add fresh sample (10-50g) and weigh (W2)

iii. Dry at 105°C for 24 hours (or until constant weight)

iv. Cool in desiccator and weigh (W3)

v. Calculate: Moisture % = [(W2-W3)/(W2-W1)] × 100

pH Measurement (APHA, 2017, Method 4500-H^+ B)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 4500-H^+ B - Electrometric Method.

Principle: pH is measured electrometrically using a glass electrode that is sensitive to hydrogen ion activity. The pH meter measures the potential difference between a pH-sensitive electrode and a reference electrode.

procedures

i. Rinse electrode with distilled water
ii. Immerse electrode in sample
iii. Wait for stable reading
iv. Record pH value
v. Rinse electrode after use

Chemical Oxygen Demand (COD)- Closed Reflux Colorimetric Method (APHA, 2017, Method 5220D)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 5220D - Closed Reflux, Colorimetric Method.

Principle: COD measures the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in water under controlled conditions. In this method, the sample is heated with a strong oxidizing agent (potassium dichromate) in acidic solution, and the amount of dichromate consumed is measured colorimetrically.

Procedures

i. Add 2.0 mL sample to digestion tube

ii. Add 1.0 mL potassium dichromate solution

iii. Add 3.0 mL sulfuric acid reagent (with silver sulfate)

iv. Mix and cap tubes

v. Heat at 150°C for 2 hours in COD reactor

vi. Cool to room temperature

vii. Measure absorbance at appropriate wavelength

viii. Calculate COD from calibration curve

Total Nitrogen- Kjeldahl Method (APHA, 2017, Method 4500-Norg C)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 4500-Norg C - Macro-Kjeldahl Method.

Principle: The Kjeldahl method converts organic nitrogen to ammonium sulfate through acid digestion with concentrated sulfuric acid and a catalyst. The ammonia in the digest is then distilled and measured by titration or other methods.

Procedures

i. Add 25 mL sample to Kjeldahl flask

ii. Add catalyst mixture (K_2SO_4 + $CuSO_4$)

iii. Add 25 mL concentrated H_2SO_4

iv. Heat until solution becomes clear (2-4 hours)

v. Cool digested sample

vi. Add 300 mL distilled water

vii. Add NaOH solution until strongly alkaline

viii. Distill ammonia into boric acid solution

ix. Titrate collected ammonia with standard HCl

x. Calculate: Total N (mg/L) = (mL HCl × N × 14 × 1000) / mL sample

Atomic Absorption Spectroscopy (AAS)

Procedures

i. Take 100 mL filtered sample
ii. Add 5 mL concentrated HNO_3
iii. Heat gently to reduce volume to 15-20 mL
iv. Cool and dilute to 100 mL with distilled water
v. Prepare calibration standards for each metal
vi. Typical range: 0.1, 0.5, 1.0, 2.0, 5.0 ppm
vii. Install appropriate hollow cathode lamp
viii. Set wavelength (Pb: 217.0 nm, Cd: 228.8 nm, Zn: 213.9 nm, Cu: 324.8 nm)
ix. Optimize flame conditions
x. Run standards and samples
xi. Calculate concentrations from calibration curves

Microbiological Analysis - Heterotrophic Plate Count (APHA, 2017, Method 9215B)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 9215B - Pour Plate Method.

Principle: This method determines the number of viable heterotrophic bacteria capable of growing on nutrient agar under specified conditions of temperature and incubation time.

Coliform and E. coli Detection (APHA, 2017, Method 9221B and 9221E)

Standard Reference: American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 23rd Edition, Method 9221B - Multiple-Tube Fermentation Technique for Total Coliforms and Method 9221E - Fecal Coliform Procedure (E. coli).

Principle: These methods detect and enumerate coliform bacteria and E. coli using selective media and biochemical tests based on lactose fermentation and gas production at specific temperatures.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 PHYSIO-CHEMICAL AND MICROBIOLOGICAL ANALYSES

4.1.1 Physical Properties Analysis

i. Visual Appearance and Color

The cleaning sludge sample showed distinct physical characteristics that were different from the other samples. Fresh sludge collected from the treatment area appeared as a thick, semi-solid material with a brownish color.

ii. Odor

The fresh cleaning sludge had a mild organic smell, which is typical of wastewater treatment sludge. However, the odor was not offensive or extremely strong, indicating that the waste was relatively fresh and had not undergone significant anaerobic decomposition.

4.1.2 Chemical Properties Analysis

Table 4.1: Chemical Properties Test Results

S/N	TEST DESCRIPTION	STANDARD UNITS	BOREHOLE	CLEANING SLUDGE	STORAGE TANK
1	pH		5.3	6.9	5.0
2	EC	µS/cm	233	506	247
3	TDS	mg/L	117	254	124
4	COD	mg/L	11.3	36.2	18.1
5	HCO_3	mg/L	44.3	80.3	51.0
6	Na	mg/L	0.74	1.40	0.82
7	K	mg/L	0.21	0.54	0.33
8	Ca	mg/L	3.14	6.41	3.88
9	Mg	mg/L	1.93	4.71	3.88
10	Cl	mg/L	66.3	101.3	80.4
11	P	mg/L	0.061	0.241	0.085
12	NH_4N	mg/L	0.088	0.330	0.121
13	NO_2	mg/L	0.007	0.015	0.009
14	NO_3	mg/L	0.073	0.283	0.101
15	SO_4	mg/L	0.053	0.181	0.064
16	Fe	mg/L	0.217	0.813	0.240
17	Mn	mg/L	0.070	0.480	0.088
18	Zn	mg/L	0.113	0.666	0.181
19	Cu	mg/L	0.053	0.140	0.060
20	Cr	mg/L	0.021	0.081	0.038
21	Cd	mg/L	0.001	0.015	0.005
22	Ni	mg/L	0.001	0.011	0.003
23	Pb	mg/L	0.003	0.020	0.009
24	V	mg/L	0.001	0.008	0.009
25	THC		ND	ND	ND

26	Water Hardness	mg/L	15.7	35.4	21.4

4.1.3 Microbiological Analyses

Table 4.2: Microbiological Test Results

S/N	TEST DESCRIPTION	STANDARD UNITS	BOREHOLE	CLEANING SLUDGE	STORAGE TANK
1	Total Heterotrophic Bacterial Counts	CFU/mL	0×10^3	1×10^3	1×10^3
2	Total Coliform Counts	CFU/mL	0×10^3	0×10^3	0×10^3
3	Total E-Coil Counts	CFU/mL	0×10^3	0×10^3	0×10^3
4	Tentative Bacterial Isolates	CFU/mL	Nil	Enterobacter sp. Bacillus sp.	Enterobacter sp. Bacillus sp.

4.2 ANALYSIS OF PHYSIO-CHEMICAL AND MICROBIOLOGICAL TEST RESULTS

4.2.1 Interpretation of Physical Observations

The semi-solid, paste-like consistency of the fresh cleaning sludge indicates high moisture content, which is typical of wastewater treatment sludge (Metcalf & Eddy, 2014). The brownish color is typical of organic waste materials and suggests the presence of decomposed organic matter (Tchobanoglous et al., 2003). The mild odor indicates that the beverage manufacturing process doesn't introduce strong-smelling chemicals or compounds into the waste stream.

4.2.2 Detailed Interpretation of Chemical Results

pH Levels

The pH test results showed:

Borehole water: pH 5.3 (slightly acidic)

Cleaning sludge: pH 6.9 (nearly neutral)

Storage tank: pH 5.0 (moderately acidic)

The cleaning sludge pH of 6.9 is particularly significant because it falls within the acceptable range for most agricultural applications. Most agricultural soils have pH values between 5.5 and 7.5, with the optimal range for most crops being 6.0 to 7.0 (Brady and

Weil, 2016).The cleaning sludge pH of 6.9 falls right within this optimal range. A pH close to neutral (7.0) means the sludge would not drastically change soil pH when applied to farmland. This is important because extreme pH levels can harm plants and soil organisms (Havlin et al., 2014).

Electrical Conductivity (EC)

Electrical conductivity measures the ability of water or solution to conduct electricity, which indicates the amount of dissolved salts present (Rhoades et al., 1999):

Borehole water: 233 µS/cm

Cleaning sludge: 506 µS/cm

Storage tank: 247 µS/cm

The cleaning sludge showed the highest electrical conductivity at 506 µS/cm. The electrical conductivity (EC) value of 506 µS/cm in the cleaning sludge provides important information about dissolved salt content. To understand what this means, we need some context (Ayers & Westcot, 1985):

EC below 250 µS/cm: Low salt content, excellent for all crops

EC 250-750 µS/cm: Moderate salt content, suitable for most crops

EC 750-2000 µS/cm: Moderately high, may affect sensitive crops

EC above 2000 µS/cm: High salt content, may damage many crops

The cleaning sludge EC of 506 µS/cm falls in the moderate range. This moderate EC value indicates that the sludge contains dissolved salts and minerals (FAO, 1992).

Total Dissolved Solids (TDS)

TDS measures the total amount of dissolved materials in the sample (APHA, 2017):

Borehole water: 117 mg/L

Cleaning sludge: 254 mg/L

Storage tank: 124 mg/L

The cleaning sludge had the highest TDS value at 254 mg/L, this indicates that the sludge contains substantial amounts of dissolved organic and inorganic materials from the beverage manufacturing process. These dissolved solids include sugars, minerals, organic compounds, and nutrients that were washed off during equipment cleaning and production processes (Cheremisinoff, 1995).

.**Chemical Oxygen Demand (COD)**

COD measures the amount of oxygen required to chemically break down organic matter in the sample (APHA, 2017):

Borehole water: 11.3 mg/L

Cleaning sludge: 36.2 mg/L

Storage tank: 18.1 mg/L

The cleaning sludge showed a COD value of 36.2 mg/L, this elevated COD indicates the presence of organic materials that can be broken down by chemical oxidation. The COD value confirms that the sludge contains organic materials that came from the beverage manufacturing process. These likely include sugars, starches, proteins, and other organic compounds washed from equipment during cleaning (Eckenfelder, 2000).

Compared to sewage sludge (which typically has much higher COD) or sludges from food processing industries (typically 5,000-20,000 mg/L), the Seven Up sludge has relatively low organic content (Metcalf & Eddy, 2014). This is actually advantageous because high organic content can create odor problems and attract pests during handling and storage.

Bicarbonate (HCO_3)

Bicarbonate levels were measured as follows:

Borehole water: 44.8 mg/L

Cleaning sludge: 80.3 mg/L

Storage tank: 51.0 mg/L

The higher bicarbonate content in the cleaning sludge (80.3 mg/L) indicates good buffering capacity (Stumm & Morgan, 1996).

Major Cations (Sodium, Potassium, Calcium, Magnesium)

These elements are essential plant nutrients and important for soil health (Marschner, 2012):

Sodium (Na):

Borehole water: 0.74 mg/L

Cleaning sludge: 1.40 mg/L

Storage tank: 0.82 mg/L

The sodium content is relatively low in all samples, which is good because high sodium can damage soil structure and harm plants (Brady & Weil, 2016).

Potassium (K):

Borehole water: 0.21 mg/L

Cleaning sludge: 0.54 mg/L

Storage tank: 0.33 mg/L

Potassium is one of the three major plant nutrients (along with nitrogen and phosphorus). The cleaning sludge contains more potassium than the control samples, though the concentration is not very high. Potassium helps plants with disease resistance, water regulation, and fruit quality (Havlin et al., 2014).

Calcium (Ca):

Borehole water: 3.14 mg/L

Cleaning sludge: 6.41 mg/L

Storage tank: 3.88 mg/L

Calcium content in the cleaning sludge is notably higher at 6.41 mg/L. Calcium is important for cell wall structure in plants and helps improve soil structure by promoting the formation of stable soil aggregates (Marschner, 2012).

Magnesium (Mg):

Borehole water: 1.93 mg/L

Cleaning sludge: 4.71 mg/L

Storage tank: 3.88 mg/L

Magnesium is a component of chlorophyll and is essential for photosynthesis (Havlin et al., 2014).

Chloride (Cl)

Chloride concentrations were:

Borehole water: 66.3 mg/L

Cleaning sludge: 101.3 mg/L

Storage tank: 80.4 mg/L

The cleaning sludge showed elevated chloride levels at 101.3 mg/L. While chloride is needed by plants in small amounts, high concentrations (typically above 350 mg/L) can be harmful (Ayers & Westcot, 1985). However, the level found in this sludge is not excessively high and should not pose problems for most crops.

Phosphorus (P)

Phosphorus is a critical plant nutrient:

Borehole water: 0.061 mg/L

Cleaning sludge: 0.241 mg/L

Storage tank: 0.085 mg/L

The cleaning sludge contains nearly four times more phosphorus than the borehole water. Phosphorus is essential for root development, flowering, and fruit formation in plants (Brady & Weil, 2016).

Nitrogen Compounds

Ammonia Nitrogen (NH_4N)

Borehole water: 0.088 mg/L

Cleaning sludge: 0.330 mg/L

Storage tank: 0.121 mg/L

Nitrite (NO_2):

Borehole water: 0.007 mg/L

Cleaning sludge: 0.015 mg/L

Storage tank: 0.009 mg/L

Nitrate (NO_3):

Borehole water: 0.073 mg/L

Cleaning sludge: 0.283 mg/L

Storage tank: 0.101 mg/L

The cleaning sludge contains higher levels of all nitrogen forms compared to the control samples. Nitrogen is the most important nutrient for plant growth, promoting leaf and stem development (Havlin et al., 2014).

Sulfate (SO_4):

Borehole water: 0.053 mg/L

Cleaning sludge: 0.181 mg/L

Storage tank: 0.064 mg/L

The sulfate level (0.181 mg/L) is low and poses no concerns. Sulfate actually provides sulfur, which is an essential plant nutrient often overlooked. Sulfur is important for protein synthesis and is needed for proper nitrogen utilization by plants (Marschner, 2012).

Heavy Metal Analysis

Iron (Fe):

Borehole water: 0.217 mg/L

Cleaning sludge: 0.813 mg/L

Storage tank: 0.240 mg/L

Iron is an essential micronutrient for plants and is not considered a toxic heavy metal. The elevated iron in the cleaning sludge (0.813 mg/L) is actually beneficial for plant growth, as iron is involved in chlorophyll production and enzyme functions (Marschner, 2012).

Manganese (Mn):

Borehole water: 0.070 mg/L

Cleaning sludge: 0.480 mg/L

Storage tank: 0.088 mg/L

Manganese is another essential micronutrient that plants need in small amounts, it's involved in photosynthesis and helps plants resist diseases. The level in the cleaning sludge (0.480 mg/L) is elevated but not toxic, and would be beneficial for crops (Havlin et al., 2014).

Zinc (Zn):

Borehole water: 0.113 mg/L

Cleaning sludge: 0.666 mg/L

Storage tank: 0.181 mg/L

Zinc is essential for plant growth and is commonly deficient in tropical soils. The cleaning sludge contains 0.666 mg/L, which is higher than the control samples but still within safe limits for agricultural use zinc toxicity typically occurs above 300-400 mg/kg in soil (Alloway, 2013).

Copper (Cu):

Borehole water: 0.053 mg/L

Cleaning sludge: 0.140 mg/L

Storage tank: 0.060 mg/L

Copper is an essential micronutrient involved in plant enzyme systems. It is needed by plants in trace amounts. The level in the cleaning sludge (0.140 mg/L) is low and safe for agricultural applications (Marschner, 2012).

Chromium (Cr):

Borehole water: 0.021 mg/L

Cleaning sludge: 0.081 mg/L

Storage tank: 0.038 mg/L

Chromium levels are very low in all samples. The cleaning sludge contains only 0.081 mg/L, which is well below safety limits for agricultural use. Regulatory limits for chromium in biosolids range from 1000-3000 mg/kg (US EPA, 1993; European Union, 1986).

Cadmium (Cd):

Borehole water: 0.001 mg/L

Cleaning sludge: 0.015 mg/L

Storage tank: 0.005 mg/L

Cadmium is one of the most toxic heavy metals and can accumulate in food chain, eventually causing kidney damage and bone disease in humans (Alloway, 2013). However, the level in the cleaning sludge (0.015 mg/L) is extremely low and far below regulatory limits for agricultural applications. The WHO guideline for agricultural biosolids is typically 20-40 mg/kg, while US EPA limits are 39 mg/kg for land application (US EPA, 1993).

Nickel (Ni):

Borehole water: 0.001 mg/L

Cleaning sludge: 0.011 mg/L

Storage tank: 0.003 mg/L

Nickel can be toxic at high levels but is actually required by some plants in trace amounts. Nickel levels are very low across all samples, the cleaning sludge contains only 0.011 mg/L, indicating minimal contamination with this metal. Regulatory limits for nickel in biosolids are typically 420 mg/kg (US EPA, 1993; European Union, 1986).

Lead (Pb):

Borehole water: 0.003 mg/L

Cleaning sludge: 0.020 mg/L

Storage tank: 0.009 mg/L

Lead is a toxic heavy metal of particular concern because it can cause serious health problems including neurological damage, particularly in children (Alloway, 2013). However, the level in the cleaning sludge (0.020 mg/L) is very low and well within safe limits for agricultural use. Regulatory limits for lead in biosolids typically range from 300-840 mg/kg (US EPA, 1993; European Union, 1986).

Vanadium (V):

Borehole water: 0.001 mg/L

Cleaning sludge: 0.008 mg/L

Storage tank: 0.002 mg/L

Vanadium levels are negligible in all samples, indicating this element is not a concern for the sludge waste (Kabata-Pendias).

Total Hydrocarbon Content (THC):

Borehole water: ND (Not Detected)

Cleaning sludge: ND (Not Detected)

Storage tank: ND (Not Detected)

The absence of detectable hydrocarbons in all samples is an excellent finding. It indicates that the beverage manufacturing process does not introduce petroleum products or oils into the waste stream, which could have limited reuse options (US EPA, 2000).

Water Hardness:

Borehole water: 15.7 mg/L

Cleaning sludge: 35.4 mg/L

Storage tank: 21.4 mg/L

Water hardness is caused primarily by calcium and magnesium. The cleaning sludge shows higher hardness (35.4 mg/L) due to its elevated calcium and magnesium content. This is classified as "soft" water as hardness below 60 mg/L is considered soft, which is suitable for most applications (Sawyer et al., 2003).

4.2.3 Detailed Interpretation of Microbiological Results

The microbiological tests were conducted to assess the presence of bacteria and other microorganisms in the samples (APHA, 2017).

Total Heterotrophic Bacterial Counts

This test measures the total number of bacteria that can grow on standard laboratory media:

Borehole water: 0×10^3 CFU/mL (no bacteria detected)

Cleaning sludge: 1×10^3 CFU/mL (1,000 bacteria per milliliter)

Storage tank: 1×10^3 CFU/mL (1,000 bacteria per milliliter)

The presence of bacteria in both the cleaning sludge and storage tank samples is expected and normal for wastewater materials. The count of 1×10^3 CFU/mL (1,000 colony-forming units per milliliter) indicates a moderate bacterial population (Bitton, 2011). These bacteria are primarily involved in breaking down organic matter and are not necessarily harmful. The absence of bacteria in the borehole water confirms it was a clean control sample.

Total Coliform Counts

Coliform bacteria are used as indicators of fecal contamination and general sanitary quality (APHA, 2017):

Borehole water: 0×10^3 CFU/mL (none detected)

Cleaning sludge: 0×10^3 CFU/mL (none detected)

Storage tank: 0×10^3 CFU/mL (none detected)

The absence of coliform bacteria in all samples, including the cleaning sludge, is a very positive finding. Coliform bacteria are commonly found in wastewater and their absence suggests that the beverage manufacturing process maintains good sanitary conditions (Bitton, 2011). This also indicates that the wastewater is not contaminated with fecal matter from sewage or other sources.

Total E. coli Counts

E. coli (Escherichia coli) is a specific type of coliform bacteria that indicates fecal contamination (APHA, 2017):

Borehole water: 0×10^3 CFU/mL (none detected)

Cleaning sludge: 0×10^3 CFU/mL (none detected)

Storage tank: 0×10³ CFU/mL (none detected)

The absence of E. coli in all samples is excellent news from a public health perspective. E. coli is the primary indicator of fecal contamination, and its absence means the sludge waste is not contaminated with human or animal feces (US EPA, 2003). This significantly reduces health risks associated with handling and reusing the sludge.

Tentative Bacterial Isolates

The laboratory identified specific types of bacteria present in the samples:

Borehole water: Nil (no bacteria isolated)

Cleaning sludge: Enterobacter sp., Bacillus sp.

Storage tank: Enterobacter sp., Bacillus sp.

The cleaning sludge and storage tank samples contained two types of bacteria:

Enterobacter species: These are common environmental bacteria found in soil, water, and plant materials. While some Enterobacter can be opportunistic pathogens (causing infections in people with weakened immune systems), they are generally not considered highly dangerous (Holt et al., 1994). Their presence in beverage manufacturing waste is not unusual.

Bacillus species: These are widespread bacteria found in soil, water, and many environments. Most Bacillus species are harmless, and some are actually beneficial. For example, certain Bacillus bacteria are used in biological fertilizers because they help plants absorb nutrients and protect against diseases (Logan & De Vos, 2009). Bacillus bacteria can form spores that survive harsh conditions, which explains why they were found in the sludge.

The identification of these specific bacterial types is important because neither is considered a serious pathogen. The absence of dangerous bacteria like Salmonella, Shigella, or pathogenic E. coli strains indicates that the sludge is relatively safe from a microbiological standpoint US EPA, 2003; Gerba & Pepper, 2009).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study successfully investigated and developed sustainable resource recovery for the sludge waste, concluding that the sludge waste is safe for the environment and can be converted to fertilizers which is good for the agricultural sector.

The microbiological analysis revealed highly favorable characteristics for biological treatment processes. The presence of moderate bacterial populations (1×10^3 CFU/mL) comprising primarily Enterobacter species and Bacillus species indicates natural biodegradation potential. The complete absence of coliform bacteria, E. coli, and dangerous pathogens such as Salmonella and Shigella confirms that the sludge is microbiologically safe for handling and beneficial reuse applications.

The physicochemical analysis demonstrated that the cleaning sludge possesses properties highly favorable for agricultural applications. The near-neutral pH of 6.9 falls within the optimal range for most crops (6.0-7.0), while the moderate electrical conductivity of 506 µS/cm indicates appropriate salt content suitable for agricultural use without risk of salinity damage. The sludge contains essential plant nutrients including elevated levels of calcium (6.41 mg/L), magnesium (4.71 mg/L), phosphorus (0.241 mg/L), and various nitrogen forms, making it a potential soil amendment or fertilizer component. The presence of beneficial micronutrients including iron (0.813 mg/L), manganese (0.480 mg/L), and zinc (0.666 mg/L) further enhances its agricultural value.

Critical to environmental safety, all potentially toxic heavy metals are present at concentrations far below regulatory limits for agricultural biosolids application. Cadmium (0.015 mg/L), lead (0.020 mg/L), chromium (0.081 mg/L), nickel (0.011 mg/L), and copper (0.140 mg/L) pose no risk to human health, environmental quality, or food chain contamination. The complete absence of detectable total hydrocarbon content confirms that petroleum products are not introduced into the waste stream.

The characterized sludge waste presents multiple opportunities for resource recovery that align with circular economy principles. Potential applications include direct use as soil amendment, composting to produce stabilized organic fertilizer, and development of value-added products for horticultural markets. Implementing these resource recovery strategies would divert significant waste volumes from landfills, reduce the company's environmental footprint, displace synthetic fertilizers, and generate economic value from materials previously considered waste. This positions Seven-Up Bottling Company as a leader in sustainable manufacturing practices within the beverage industry, demonstrating commitment to environmental stewardship and circular economy principles while creating both environmental and economic benefits.

5.2 RECOMMENDATIONS

Develop a formal sludge management plan incorporating standard operating procedures for collection, storage, treatment, and beneficial reuse with clear quality control measures to ensure consistency and safety.

Establish regular monitoring schedule including monthly physicochemical analysis of key parameters, quarterly microbiological testing, annual comprehensive analysis, and maintenance of detailed records for regulatory compliance and quality assurance.

Establish partnerships with local farmers and agricultural cooperatives to distribute the treated sludge or compost for agricultural use

The technical foundation established through this study provides a solid basis for confident implementation of these resource recovery strategies.

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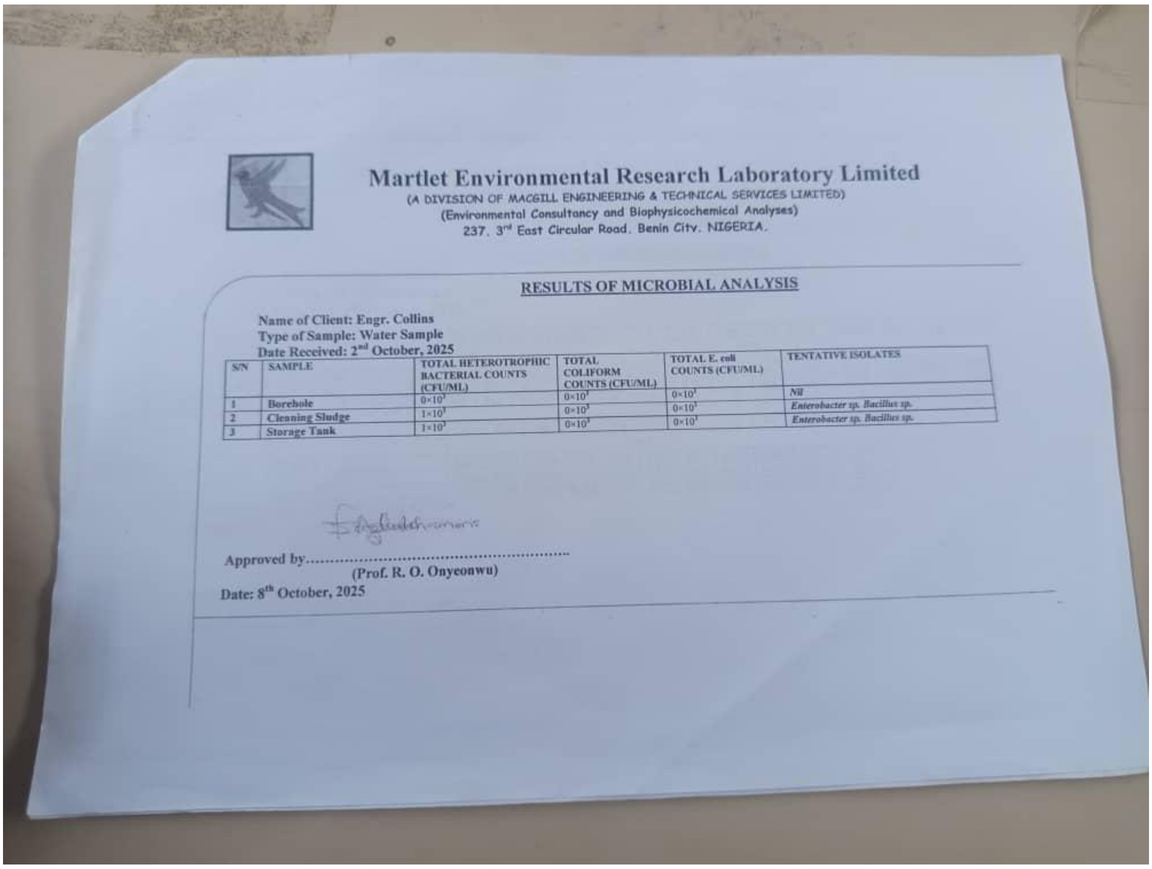
APPENDIX

APPENDIX A



Martlet Environmental Research Laboratory Limited
(A DIVISION OF MACGILL ENGINEERING & TECHNICAL SERVICES LIMITED)
(Environmental Consultancy and Biophysicochemical Analyses)
237. 3rd East Circular Road. Benin City. NIGERIA.

RESULTS OF MICROBIAL ANALYSIS

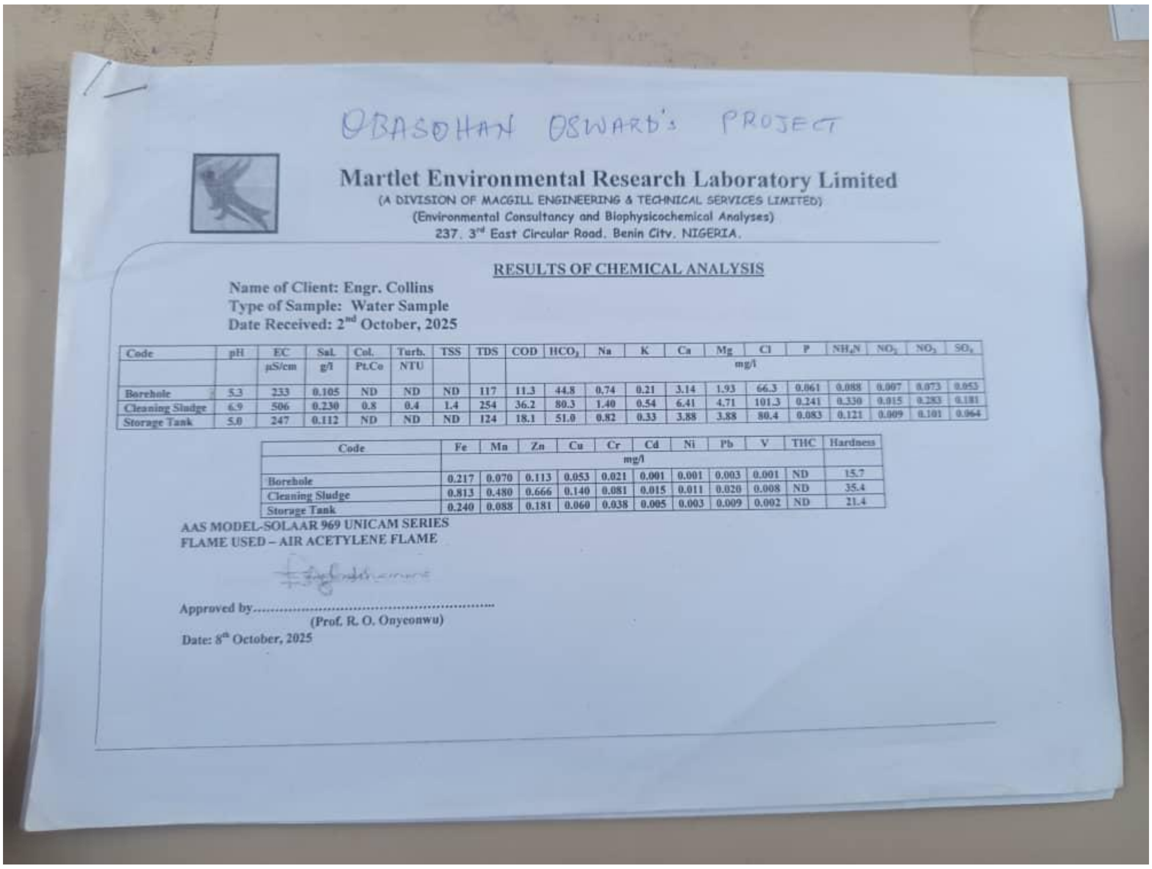
Name of Client: Engr. Collins
Type of Sample: Water Sample
Date Received: 2nd October, 2025

S/N	SAMPLE	TOTAL HETEROTROPHIC BACTERIAL COUNTS (CFU/ML)	TOTAL COLIFORM COUNTS (CFU/ML)	TOTAL E. coli COUNTS (CFU/ML)	TENTATIVE ISOLATES
1	Borehole	0×10^3	0×10^3	0×10^3	*Nil*
2	Cleaning Sludge	1×10^3	0×10^3	0×10^3	*Enterobacter sp. Bacillus sp.*
3	Storage Tank	1×10^3	0×10^3	0×10^3	*Enterobacter sp. Bacillus sp.*

Approved by……………………………………………
(Prof. R. O. Onyeonwu)
Date: 8th October, 2025

PLATE A-1. Microbiological laboratory result

APPENDIX B



OBASOHAN OSWARD's PROJECT

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(A DIVISION OF MACGILL ENGINEERING & TECHNICAL SERVICES LIMITED)
(Environmental Consultancy and Biophysicochemical Analyses)
237, 3rd East Circular Road, Benin City, NIGERIA.

RESULTS OF CHEMICAL ANALYSIS

Name of Client: Engr. Collins
Type of Sample: Water Sample
Date Received: 2nd October, 2025

Code	pH	EC	Sal.	Col.	Turb.	TSS	TDS	COD	HCO_3	Na	K	Ca	Mg	Cl	P	NH_4N	NO_2	NO_3	SO_4
		µS/cm	g/l	Pt.Co	NTU			mg/l											
Borehole	5.3	233	0.105	ND	ND	ND	117	11.3	44.8	0.74	0.21	3.14	1.93	66.3	0.061	0.088	0.007	0.073	0.053
Cleaning Sludge	6.9	506	0.230	0.8	0.4	1.4	254	36.2	80.3	1.40	0.54	6.41	4.71	101.3	0.241	0.330	0.015	0.283	0.181
Storage Tank	5.0	247	0.112	ND	ND	ND	124	18.1	51.0	0.82	0.33	3.88	3.88	80.4	0.083	0.121	0.009	0.101	0.064

Code	Fe	Mn	Zn	Cu	Cr	Cd	Ni	Pb	V	THC	Hardness
	mg/l										
Borehole	0.217	0.070	0.113	0.053	0.021	0.001	0.001	0.003	0.001	ND	15.7
Cleaning Sludge	0.813	0.480	0.666	0.140	0.081	0.015	0.011	0.020	0.008	ND	35.4
Storage Tank	0.240	0.088	0.181	0.060	0.038	0.005	0.003	0.009	0.002	ND	21.4

AAS MODEL-SOLAAR 969 UNICAM SERIES
FLAME USED – AIR ACETYLENE FLAME

Approved by……………………………………………………
(Prof. R. O. Onyeonwu)
Date: 8th October, 2025

PLATE B-1. Physiochemical laboratory test

APPENDIX C

PLATE C-1. A Typical borehole section

APPENDIX D

PLATE D-1. A Storage tank