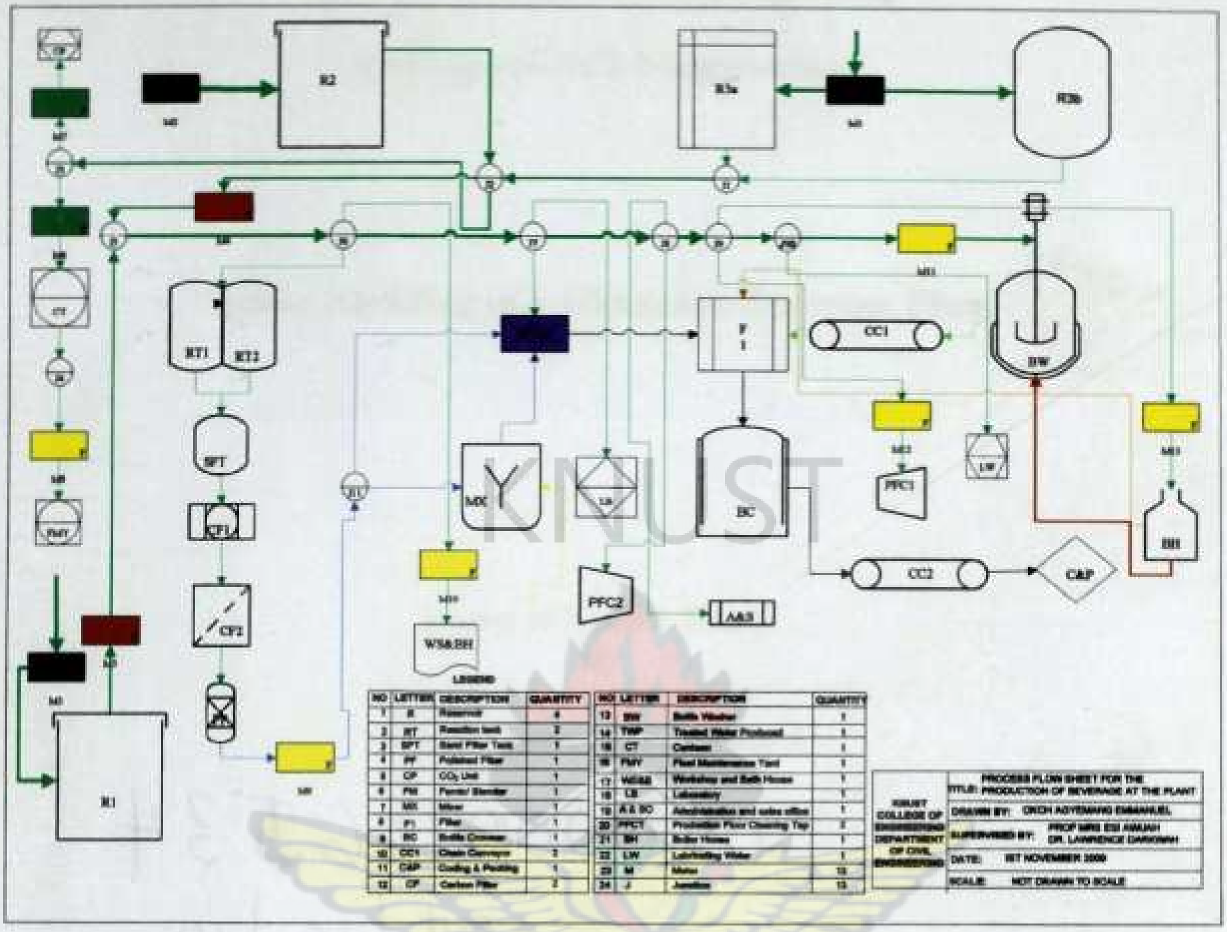
# Kwame Nkrumah University of Science and Technology
# Kumasi, Ghana




## Water Auditing of a Ghanaian Beverage Plant


Okoh Agyemang Emmanuel


MSc. Thesis
February 2010

Kwame Nkrumah University of Science and Technology

**WRESP – KNUST**

Faculty of Civil and Geomatic Engineering

**Department of Civil Engineering**

# Water Auditing of a Ghanaian Beverage Plant

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Master of Science Thesis
By

**Okoh Agyemang Emmanuel**

Supervisors

**Prof. (Mrs.) Esi Awuah**

**and**

**Dr. Lawrence Darkwah**

**Kumasi**
**February 2010**

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# Water Auditing of a Ghanaian Beverage Plant

by

Okoh Agyemang Emmanuel, BSc. (Hons)

KNUST

Thesis submitted to
The Department of Civil Engineering,
Kwame Nkrumah University of Science and Technology
in Partial Fulfilment of the Requirements for the Degree of

**MASTER OF SCIENCE**

**In**

**(Water Supply and Environmental Sanitation)**

**Faculty of Civil and Geomatic Engineering**
**College of Engineering**

**February 2010**

# CERTIFICATION

I hereby declare that this submission is my own work towards the M.Sc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

| | | |
|---|---|---|
| E. Okoh Agyemang | | 23/04/2010 |
| **(20067583)** | Signature | Date |

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**Certified by:**

| | | |
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| Prof. Mrs. Esi Awuah | | 20th April 2010 |
| **(Principal Supervisor)** | Signature | Date |
| Dr. L. Darkwah | | 23/04/2010 |
| **(Second Supervisor)** | Signature | Date |
| Prof. S. I. K. Ampadu | | 04/05/2010 |
| **(Head of Department)** | Signature | Date |



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# DEDICATION

*I dedicate this work to my family especially Grace Okyem, my mother.*

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# ABSTRACT

A water audit (quantity and quality) was carried out at The Coca-Cola Bottling Company of Ghana, Kumasi Plant. The specific objectives were to determine the water consumption pattern of the plant in the last five years, to determine the current water usage at the metered stages of the plant, to determine the specific water consumption of the plant and to assess the performance of the wastewater ( does not include black water ) treatment plant. Primary data on the daily volumes of input water from the main reservoirs of the plant, daily volumes of beverage produced and the water consumed at the eight (8) metered stages of the plant out of a total of twelve (12) stages identified were recorded over a period of four (4) months. Furthermore, limited composite influent and effluent wastewater samples were analyzed for a period of three (3) months and compared with EPA (Ghana) guidelines for beverage industries discharging into receiving water bodies. Parameters analysed for include colour, temperature, turbidity, TSS, TDS, conductivity, pH, BOD, COD, DO, ammonia, nitrate, nitrite, phosphate, sulphate, copper, lead and cadmium. Secondary data on the plant's monthly water consumption was obtained from Ghana Water Company Limited billing records for the period January 2005 to December 2009. The study revealed that, the average monthly water consumption is 9,825m$^3$ with a standard deviation of ($\pm$1,399) for the last five years. Stages (Units) with high water usage in the plant were the Syrup and Beverage Preparation (55%) and the Bottle Washer (34%). Furthermore, the plants specific water consumption determined was 3.5:1 which is better than the company's target of 4:1. This indicates that the plant's current water use efficiency is good and therefore encouraging. Even though most of the effluent wastewater parameters such as temperature, TDS, pH, DO, Colour, BOD, Copper and Sulphates met the EPA (Ghana) guidelines for discharges from beverage industries into receiving water bodies, others such as COD, TSS, and Lead, Cadmium, Total Coliforms and Faecal Coliforms were unacceptable compared to EPA guidelines. The ability of the wastewater treatment plant to effectively deal with some key parameters suggests that the treatment plant is efficient. The parameters that showed high removal efficiency were: BOD (93%), Ammonia (82%), and COD (82%). It is therefore recommended that sand filters be introduced to improve on the final effluent wastewater quality. Also de-sludging of the various treatment units of



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the treatment plant must be done as soon as possible in order to improve on the quality of the final effluent that is discharging into the environment.

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## List of Abbreviations and Acronyms

| | |
|---|---|
| GWCL | Ghana Water Company Limited |
| CWSA | Community Water and Sanitation Agency |
| KNUST | Kwame Nkrumah University of Science and Technology |
| KBL | Kumasi Brewery Limited |
| GGL | Guinness Ghana Limited |
| CCBC | Coca- Cola Bottling Company |
| TCCBCKP | The Coca-Cola Bottling Company, Kumasi Plant |
| TSS | Total Suspended Solids |
| TDS | Total Dissolved Solids |
| BOD | Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| EPA | Environmental Protection Agency |
| INF | Influent |
| EFF | Effluent |
| STD DEVTN | Standard Deviation |
| N/A | No Activity |

## ACKNOWLEDGEMENTS

First of all, I owe a great gratitude to the Almighty God for sustaining me to accomplish this task. Without Him, this work would not have been realized. My gratitude is highly expressed to the Department of Civil Engineering and the Water Resources and Environmental Sanitation Project for making the necessary resources available for me to carry out this work successfully.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 BACKGROUND

Water is vital for human survival, health and dignity and is a fundamental resource for human development. Even though most of the world's freshwater resources have been explored, yet many lack access to adequate water supply for their basic needs. Growth in population, increased economic activity and improved standards of living has led to increased competition for the limited freshwater resource.

The increasing cost of supply, scarcity of untapped source of surface water, limitation of groundwater because it's a finite resource and the possibility of its contamination as well as the growing concern on environmental issues in relation to waste water released into the environment, lead many countries and water utilities to explore alternatives such as water conservation and water use efficiency, to manage municipal water system (Griggs, 1999). With the increasing demand on the limited freshwater resources, water conservation and efficiency improvements methods need to be assessed as long-term measures and consequently implemented to reduce municipal water use (Andren, 2004).

In Ghana, the principal uses of water are categorized into domestic, commercial, public, institutional, agricultural and industrial. Although most industries have made significant improvements in reducing their operational and process consumption of water, of which the brewery and beverage industries are no exception, an opportunity



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still exist to engage beyond the fence line and work with respective supply chains to improve water use efficiency in order to mitigate the risk of disruption to business.

The Coca-Cola Bottling Company, Kumasi Plant, is part of a multi-national beverage industry which uses water as the main ingredient in all of its products and therefore represents one of the major requirements to the success of the business.

Sustainable water management practices and improved water use efficiency is vital to its business. The Company views protection of the environment as a journey not a destination and began the journey years ago and it continues today. Each employee of the plant has a responsibility for stewardship of natural resources and to conduct business in ways that protect and preserve the environment. The company's employees, business partners, suppliers and consumers must all work together to continuously find innovative ways to foster the efficient use of natural resources, prevention of waste and the sound management of water.

Also the protection of surface waters is essential to prevent eutrophication and oxygen depletion in order to maintain fish and other aquatic life. Contaminated surface waters may put at risk those urban and peri-urban dwellers that depend on these waters for domestic and personal hygiene. Though wash water must not comply with drinking water standards, contacts with water carrying high pathogenic loads may potentially lead to the transmission of enteric infections.

Hence the need to determine the water usage pattern of the plant, investigate the water use efficiency and determine the quality of the treated effluent.

## 1.2 PROBLEM STATEMENT

Water is a cross-cutting element of the Growth and Poverty Reduction Strategy (GPRS II) of the Republic of Ghana and is linked to all eight of the Millennium Development Goals (MDGs). Hence, with water as a finite resource and Ghana's population increasing in urban centres, while the cost of new water sources is rising steadily, it is paramount to use water more efficiently and conserve where possible. This will consequently lead to the minimization of waste water released into the environment. Since conservation and efficient use are critical elements of any future water management strategy, there is the need for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives as well as efficient use and improved conservation effort by all water users in order to ensure an adequate supply now and in the future. It is in this light that this work aims at determining water usage pattern of the plant, investigate the efficiency of water use and quality of the treated effluent wastewater that is discharged into the environment.

## 1.3 JUSTIFICATION

By reducing water consumption through water conservation where possible and efficient use, without impacting negatively on production quantity, quality or yield, or affecting the quality of water involved in beverage preparation, optimized resource utilisation can be a realistic and cost-effective strategy.

Building water conservation and efficient utilization awareness and education among employees while maintaining good water housekeeping practices cannot only save water, but also save money on operational and production costs and boost the profit margin of businesses.

## 1.4 OBJECTIVE

The main objective of this work is to conduct a water audit (quantity and quality) at a Ghanaian beverage plant.

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## 1.5 SPECIFIC OBJECTIVES

The specific objectives of the study include,

- To determine the water consumption pattern of the plant in the last five years.
- To determine the current water usage at the metered stages of the plant.
- To determine the specific water consumption of the plant.
- To assess the performance of the wastewater treatment plant.

## 1.6 SCOPE OF STUDY

Due to logistical problems 10 out of 14 points identified in the plant were metered for the water consumption study. Only, five years monthly water consumption records were collected and analyzed. Furthermore, the study was restricted to collecting limited wastewater samples from the study site for physical, chemical and biological analysis.

## 1.7 STUDY LIMITATION

For security reasons picture taking during the data collection stage in the plant was not allowed during the course of the study.

## 1.8 STRUCTURE OF THE REPORT

The structure of the report is organised into five main chapters. Chapter one covers the introduction of the study which comprises background of the study, problem statement, justification, objectives and specific objectives and operational definition. Chapter two mainly consists of the literature review of the study. The study site and research methodology is addressed in chapter three and the results and discussion of the study are highlighted in chapter four. Finally, conclusion and recommendations are outlined in chapter five.



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# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 WATER USE/CONSUMPTION

Water use refers to the utilization of water for a wide diversity of desirable purposes, some of which are drinking, cooking, washing, cleaning, washing of cars, watering of gardens and at times watering of animals. Due to the increasing consumption patterns, water is becoming scarce and this scarcity is an emerging treat to the global population. Global consumption of water is doubling every 20 years, more than twice the rate of human population growth (Sampath, 2002). The principal uses of water are categorized into domestic, commercial, public, institutional, industrial and agricultural water use.

#### 2.1.1 Domestic Water Use

Generally the end use of water for domestic purposes may be subdivided into various categories such as food preparation, drinking, washing, bathing, garden watering, lawn sprinkling, house cleaning and car washing.

#### 2.1.2 Institutional Water Use

This represents water use in hospitals, schools, government offices, universities and military establishments.

**2.1.3 Commercial Water Use**

This represents water use for shops, hotels, railway stations, small trades, restaurants and workshops, etc. This quantity varies with the nature of the city and the number and types of commercial establishments.

**2.1.4 Agricultural Water Use**

Agricultural use is for the irrigation of farm lands, horticultural and greenhouse purposes.

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**2.1.5 Public Water Use**

Public use is for public parks, street watering, sewer flushing, green areas, fire fighting and water mains.

**2.1.6 Industrial Water Use**

This represents water for factories, industries, power stations and docks, etc. The quantity used of which varies for different types of industries. Industrial water use is divided into four categories.

**2.1.6.1 Cooling water**

This is usually abstracted from rivers or estuaries and returned to same with little loss. Public water supply is excluded.

**2.1.6.2 Major industrial uses**

This category includes industries which use close to and above 1000 $m^3$ of water, in a day. These large supplies are often not met from the public supply, but rather obtained



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from private sources. Supplies are not intended for drinking or culinary uses and may therefore undergo no treatment by the water supplier, or it may receive precautionary disinfection in case it is inadvertently used by someone for drinking. Depending on the type of industry served, a user may apply extensive treatment to the supply since some industries require very low suspended or dissolved solids in the water. Factories that usually fall under this category include paper making, steel and iron producing, chemical manufacturing and oil refining industries.

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#### 2.1.6.3 Small industrial uses

This category includes factories and all kinds of small manufacturers that use less than 50 $m^3$ of water in a day. A greater majority of industries that fall in this category rely on public supply.

#### 2.1.6.4 Medium industrial uses

The medium category includes factories that use between 100-500 $m^3$ of water in a day for food processing, vegetable washing, drinks bottling and chemical products manufacturing. These demands are often met from the public supply.

### 2.2 DETERMINANTS OF INDUSTRIAL WATER USE

Determinants of industrial water use refer to the factors that influence water use in industries. Water use varies considerably for different industries and these variations depend on various factors. These factors includes

**2.2.1 Cost of water**

The rising cost of chemicals employed in raw water treatment as well as the energy for its transportation has consequently lead to high rates for water. In order to reduce the total cost of production and maximize the profit of businesses, most industries, especially the beverage and brewery, have made significant improvements by reducing their operational and process consumption of water through the application of water conservation and efficient use practices.

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**2.2.2 Type and size of industry**

The type and size of an industry greatly influence its water use. For instance industries such as the beverage and brewery among others depend solely on water since it's the main ingredient in all of their products. Also major industries whose operations are water-intensive in nature require large volumes of water whereas water required by small to medium industries is minimal.

**2.2.3 Availability/Relative price of alternative sources**

Water used from alternative source(s) is strongly influenced by the cost and the distance through which it is transported. Thus the nearer the source(s) to industries, the greater the possibility to use water from these sources(s) because of proximity and the reduction in the cost of transport. Again if water from theses source(s) is also cheap, people will generally be less interested to displace their current source(s).



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**2.2.4 Quality and reliability of supply**

In situations where the existing water supply system provides a fully satisfactory service to industries connected, others not connected will generally be interested to connect in order to enjoy better conditions of service.

**2.2.5 Cost of treatment and disposal of wastewater**

Due to the rising cost of wastewater treatment, most industries have resolved to employ efficient water use as well as water conservation mechanism to reduce the quantity of wastewater generated and the subsequent treatment cost before releasing into the environment.

## 2.3 AUTHORITIES IN CHARGE OF WATER SUPPLY IN GHANA

### 2.3.1 Ghana Water Company Limited (GWCL)

The body responsible for urban water management is the Ghana Water Company Limited, established as a limited liability company in 1999 and emerged from the then Ghana Water and Sewerage Corporation. GWCL is responsible for the management of 86 water supply systems nationwide, owns the water supply infrastructure and is responsible for planning and investment in capital projects. Presently the responsibility for operation and maintenance lies with Aqua-Vitens Rand Ltd.

**Mandate of GWCL**

GWCL is mandated by the government of Ghana (GOG) to provide the following services: (September 2009)

a) Production of water at various corporate headworks/treatment plants
b) Transmission of water by pumps to reservoir and/overhead tanks over varying distances
c) Distribution of water to customers through smaller ( 4''& 6'') pipelines

**GWCL Mission Statement**

Ghana Water Company Limited (GWCL) Mission Statement is a "commitment to continuously improve our water supply to our customers as it relates to Reliability, Quality, Sustainability and Cost effectiveness. Corporate policy is geared towards treating customers with courtesy and respect and to encourage partnership between GWCL and other stakeholders in the water supply industry''

**Water Supply in Kumasi**

The city of Kumasi, the capital of Ashanti Region of Ghana consist of eight water districts and includes Central, Eastern, Western, North-East, North-West, South-East, Northern and Southern districts. In the water districts are located a number of suburbs some of which are Ahinsan, Adum and Asokwa, etc. In the city of Kumasi, GWCL/AVRL operates two headworks that supply water to all of these districts.

The firstly built Owabi headworks, has a design capacity of 14,100 $m^3$/day and the second, Barekese, has a design capacity of 84,600 $m^3$/day. Due to problems such as obsolete equipments, Owabi and Barekese headworks produce on the average 9,400 $m^3$ and 47,000 $m^3$ respectively of treated water in a day. Currently two projects are on-going and at the end, Barekese is expected to increase its supply to 112,800 $m^3$/day and Owabi will be brought to its initial design capacity.

Treated water from Owabi plant is pumped through two steel transmission mains of sizes 350 mm and 450 mm, along a 12 km distance into a circular concrete cistern, of capacity 4,700 $m^3$ at Suame distribution point. Also, treated water from Barekese plant is pumped along a 17 km distance through 900 mm steel transmission main to Suame distribution point and other high pressure zone areas in the city. Part of the treated water from Barekese empties into a rectangular concrete cistern of capacity 9400 $m^3$ at Suame distribution point.

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The water distribution system in the city is categorized into high and low pressure zone areas. Areas in the high pressure zone are supplied directly from Barekese headworks and consist of the Eastern and Western districts of the city. The Eastern district includes suburbs such as Mampong, Offinso, Oforikrom, and KNUST whereas the Western district includes Bantama, Santase and Kwadaso.

The remaining water districts are found in the low pressure zone area and are fed from main Suame distribution point. Suburbs within the low pressure zone include Kejetia, Adum, Asafo, Amakom, Ahodwo, Kaase, Atonsu, Gyinase and Ahinsan. The Coca-Cola Bottling Company, Kumasi Plant is located at Ahinsan in the Southern water district and solely relies on GWCL for all of its water supply. Other industries located at Ahinsan in the Southern water district include Kumasi Brewery Limited, Guinness Ghana Limited, Stivo Timber Company Limited, etc.

### 2.3.2 Community Water and Sanitation Agency (CWSA)

The Community Water and Sanitation Agency, was established in 1944 (CWSA Act 564 of 1998), to facilitate the provision of safe water and related sanitation services to village communities and small towns. CWSA is responsible for managing Ghana's Community Water and Sanitation Programme for accelerated and equitable delivery of potable water and improved sanitation facilities as well as providing hygiene education to village communities and small towns. CWSA defines small towns as communities of between 2,000 and 50,000 population who require improved water supplies and related sanitation facilities. These communities must be prepared to manage their piped water supply systems in an efficient and sustainable manner (CWSA, 2000).

## 2.4 CATEGORIES OF METERS USED TO MEASURE WATER

### 2.4.1 Displacement type

Such metres contain a vessel of known volume and the number of times it is filled and emptied is automatically recorded. This type of metre is useful in small installations to measure relatively small quantity of flow as in hotels, residential buildings, etc.

### 2.4.2 Velocity type

Such metres are turbine or venturi type and contain a device by which a vane or propeller turns in direct ratio to the quantity of flow passing through the propeller. This type of metre is useful for big installations such as on pumps, water main lines, etc.



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## 2.5 SPECIFIC WATER CONSUMPTION

Specific water consumption is the ratio of the total volume of water used over a period to the total volume of beverage produced during that same period. Beverage production is intrinsically a water intensive industry. Commonly available best practice technologies require an excess of four litres of raw water for every litre of beverage produced (4:1). Older technologies that are inefficiently operated may easily double or triple this consumption, to the detriment of neighbouring communities and add additional cost to the company itself (Desta, Girum and Ellen, 2007). High water consumption due to inefficient use may also means higher energy use, as much of the excess water has to be heated during the beverage production period and cleaning processes.

In a study conducted to investigate the effect of personnel water use minimization practices on the specific water consumption of a Ghanaian brewery plant, employees of the brewery were taken through a training programme for water use minimization. Personnel input and options identified during the training sessions were then applied to the operations of the brewery over a 12-week period. A total savings of 55,340 $m^3$ on an annual basis in the overall water use in the brewery as well as a reduction of 13.3% (from 7.5 to 6.5) in the specific water consumption (volume of water consumed per volume of beverage produced) were achieved. The key factors contributing to the success of the water use minimisation programme include employee awareness of the importance of water conservation and a commitment of employees to saving water (Puplampu and Siebel, 2003).



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Specific water consumption may be influenced by the conditions of process equipments, pipelines and personnel water minimization and water use efficiencies.

## 2.6 FINANCIAL IMPLICATION OF WATER USAGE PATTERN

Financial implication of water usage pattern refers to the cost result as a consequence of water use. Given that freshwater resource is limited and the cost of new water sources is rising steadily, most beverage industries have embarked on an effort to measure water usage, identify opportunities to reduce water consumption and wastewater production and improve operating efficiency at their production facilities. These efforts once achieved could ultimately lead to a significant reduction in the total cost of production and consequently boost up the profit margin of businesses.

## 2.7 WATER CONSERVATION

The use of water by man, plants and animals is universal. As a matter of fact, every living soul requires water for its survival. It is the principal raw material for food production and for many other uses outside the home and on the farm. Man can live without food for two months, but hardly can he survive for three to four days without water. In a similar way, a shortage of water could lead to a decline in food and beverage production, just like a shortage of steel will lead to the decrease in the production of automobiles (Rangwala, 2007).

In addition to the direct consumption of water at homes and on farms, there are many indirect ways in which water affects daily life. Water plays an important role in the manufacture of essential commodities, generation of electric power, transportation, recreation, industrial activities, etc. Water is considered the most important raw material of civilization because without it, man cannot live and industry cannot operate.

With the growing population and industrial development, the demand for water is also increasing day by day and hence most countries as well as water utilities have taken preventive measures to avoid careless pollution and contamination of the available and limited freshwater resources (Odoyo, 1998).

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Water consumption can be reduced without purchasing expensive equipment or being inconvenienced through efficient use. Reducing water use mean substantial savings on water, sewage, energy and wastewater treatment cost. Thus the proper management, conservation and efficient use of the freshwater resources will definitely avoid the chances of water famine for future generations for an indefinite period and prevent adverse effects on industries and businesses.

## 2.8 WATER DEMAND MANAGEMENT

Managing water supply more efficiently and effectively has become essential, especially in developing countries. Given the escalating cost of new infrastructure development and the recent emphasis on demand management as well as the social obligation to provide water services to the urban population, water providers are faced with one important choice, thus whether to go the demand management route or proceed with new infrastructure development.

Water demand management is defined as the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a finite resource (Savenije and van der Zaag, 2002). Water demand management is not necessarily the same as decreasing water demand or water use; in certain situation managing the demand may mean to simulate the demand that has been suppressed. For instance, in some parts of urban centres in Ghana water use is undesirably low; in such situation there is the need to improve water services and increase water consumption.

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Water demand management is also not necessarily the same as pricing of water. Water demand management uses technical, legal, economic incentives in combination with awareness raising, information provision and education; in order to achieve more desirable consumption patterns, both in terms of distribution between sectors and quantities consumed, coupled with an increased reliability of supply (Savenije and van der Zaag, 2002).

## 2.9 WATER QUALITY

Water is often ranked by its quality. However, there are many different measures of water quality and the quality of water often depends on its use. Water quality, especially freshwater quality, is often classified by it uses which are usually for recreational, drinking, fishing etc. It is important to understand how the water upstream and downstream is being used because the downstream use will often dictate the overall water quality and that will affect the discharge criteria for water discharge (Russell, 2006).



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## 2.10 CHARACTERISTICS OF WASTEWATER

According to Tchobanoglous, Burton and Stensel (2003), wastewater is characterized by physical, chemical and biological constituents.

### 2.10.1 Physical Characteristics

The physical constituents of wastewater include temperature, turbidity, colour, suspended solids, conductivity, total dissolved solids, settleable solids and total chemical solids, etc. These characteristics are used to assess the reuse potential of wastewater and to determine the most suitable type of operation and processes for its treatment.

#### 2.10.1.1 Colour

The colour of water is the result of the different wavelengths that is not absorbed by the water itself or the result of particulate and dissolved substances present (Chapman and Kimstach, 1992). Fresh water is usually of a light brownish grey colour. However, as the travel time in the collection system increases and more anaerobic conditions develop, the colour of the wastewater changes sequentially from grey to dark grey and ultimately to black (Tchobanoglous, Burton and Stensel 2003).

Colour is partly due to suspended solids (apparent colour) and partly due to dissolved solids (true colour). Hence natural minerals such as ferric hydroxide and manganese oxide impact colour to water (Annang, 2000).In most cases the grey, dark grey and black colour of the wastewater is due to the formation of metallic sulphides, which form as the sulphides produced under anaerobic conditions react with the metals in the wastewater. Colour is measured by the Lovibond Nesslerizer disc.

#### 2.10.1.2 Temperature

The temperature of wastewater is an important parameter because of its effects on chemical reactions and reaction rates, aquatic life and the suitability of the water for beneficial uses. Temperature varies with climatic fluctuations and responds to factors such as seasons, time of day, air circulation, cloud cover and depth and flow of water in the natural system (Annang, 2000). Wastewater temperatures, as high as 30 to 35°C have been reported for countries in Africa and Middle East (Tchobanoglous, Burton and Stensel, 2003). Increased temperature, for example, could cause a change in the species of fish that could exist in the receiving water body.

In addition, oxygen is less soluble in warm water than in cold water and this could result in serious depletion of dissolved oxygen concentration in the dry season or summer months. It is realized that a sudden change in temperature could result in high rate of mortality of aquatic life and abnormal growth of undesirable water plant and wastewater fungus. Temperature is measured using a thermometer.

#### 2.10.1.3 Total Dissolved Solids (TDS)

Total dissolved solids mainly consist of inorganic salts like carbonates, bicarbonates, chlorides, sulphates as well as small amounts of organic matter and dissolved gases. It is noted that mere determination of the dissolved solids does not give a clear picture of the type of pollutant present in the water. However many dissolved substances are undesirable in water and they impact displeasing colour, taste and odour.

Water with a high content of dissolved solids has a laxative or sometimes reverse effect on the human body and it takes time for people to adjust to it. The estimation of total dissolved solids is useful in determining the suitability of water for drinking, cleaning purpose as well as agriculture and other processes.

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**2.10.1.4 Total Suspended Solids (TSS)**

All waste streams have some suspended solids. The suspended solids are a collection of organic and inorganic materials of various sizes and density. The size and density ranges are from 3-5 mm to 0.001 mm and from 0.8-2.65 gm/cm$^3$ and higher. Some wastes streams, including paper plants, food wastes, and some petrochemical processes, have total suspended solids (TSS) loads in excess of 1000 mg/L.

The solids generally have a biodegradable component and may have active biomass. The particles could be large and others could be smaller and tend to be indistinguishable and invisible in the water (Russell, 2006). Total suspended solids test results are used routinely to assess the performance of conventional treatment processes and the need for further effluent filtration for reuse applications (Tchobanoglous, Burton and Stensel, 2003).

### 2.10.1.5 Turbidity

Turbidity is a measure of light transmitting properties of water. It is another test used to indicate water quality of waste discharges and natural waters with respect to colloidal and residual suspended matter. The measurement of turbidity is based on comparison of intensity of light scattered by a reference suspension under the same conditions (Greenberg et al, 1992). Turbidity measurements are reported as Nephelometric turbidity units (NTU). Colloidal matter would scatter or absorb light and thus prevent its transmission (Tchobanoglous, Burton and Stensel, 2003).

### 2.10.1.6 Conductivity and Salinity

Conductivity is the ability of water to conduct electrical current. Conductivity increases as the concentration of ions increases, since electrical current is transported by ions in solution. Abrupt changes in conductivity might indicate that water or wastes are being diverted into the stream from a new source.

Conductivity could be used as a measure of total dissolved solids. Conductivity is also a good measure of salinity in water. The measurement detects chloride ions from the salt. Salinity affects the potential dissolved oxygen levels in water. The greater the salinity level, the lower the saturation point. Salinity is the total amount in grams of inorganic materials dissolved in 1kg water when all the carbonate has been converted to oxide, all the bromide and iodine have been replaced by chlorine and all organic matter have been completely oxidized (Annang, 2000).

**2.10.1.7 Dissolved Oxygen (DO)**

Oxygen is very essential to all aquatic life. The oxygen concentration of natural waters bodies varies with temperature, atmospheric pressure, salinity, turbulence and photosynthetic activity of algae and plants. The solubility of oxygen decreases as temperature and salinity increases and as pressure decreases (Annang, 2000).

Waste discharges high organic matter and nutrients and this could cause a decrease in DO due to respiration during breakdown of organic matter. Determination of DO is very important in water quality assessments as it influences most chemical and biological processes in aquatic environments. Concentrations below 5mg/l may affect the functioning and survival of biological communities and below 2mg/l may lead to death of most fishes (Chapman and Kimstach, 1992).

**2.10.2 Chemical Characteristics**

The chemical constituents of wastewater include nutrients such as free ammonia, nitrates, nitrites, total phosphorus, etc. These parameters are used to measure the nutrients present and the degree of decomposition in the wastewater. Alkalinity, pH, chlorides, sulphates, biochemical oxygen demand and chemical oxygen demand metals such as cadmium, copper, lead, arsenic etc are all chemical constituents of wastewater. To assess the suitability of wastewater reuse and for toxicity effects in treatment and also to measure the acidity or basicity of the wastewater, these characteristics are considered.



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#### 2.10.2.1 pH

pH, also a potential of hydrogen is defined as the negative logarithm of hydrogen-ion concentration (Pankratz, 2000). The hydrogen-ion concentration is an important quality parameter of both natural waters and wastewaters. The usual means of expressing the hydrogen-ion concentration is pH. On the 0 to 14 pH scale, a value of 7 at 25°C represents a natural condition. Decreasing values indicate increasing hydrogen ion concentration (acidity) and increasing values indicate decreasing hydrogen ion concentration (alkalinity).

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Tchobanogolous, Burton and Stensel (2003) observed that the concentration range suitable for the existence of most biological life is quite narrow and critical; it is from 6 to 9. Wastewater with an extreme concentration of hydrogen-ion is difficult to treat by biological means. If the concentration is not altered before discharge, the wastewater effluent may alter the concentration in the natural water. Most organisms have adapted to live in water at a specific pH and may die if it changes slightly. The toxicity level of ammonia to fish, for example, varies tremendously within a small range of pH values. pH is measured using a portable pH meter in the field or at an investigation site.

#### 2.10.2.2 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

$BOD_5$ is a measure of the quantity of dissolved oxygen used by microorganisms in the oxidation of organic matter. Micro-organisms utilize dissolved oxygen in water to oxidize polluting biodegradable organic matter, thereby giving an indication of the pollution load present. By measuring the initial concentration of a sample and the concentration after five days of incubation at 20°C, the BOD can be determined (Greenberg et al, 1992). The most serious limitation is that the five days period may or may not correspond to the point where the soluble organic matter that is present has been used.

COD measures biodegradable and non biodegradable organic matter of wastewaters. Some organic substances are resistant to biological degradation (e.g. tannic, cellulose, benzene). COD test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in acid solution. COD is attractive as the test yield results within two hours.

**2.10.2.3 Ammonia-Nitrogen, Nitrite-Nitrogen and Nitrate-Nitrogen**

Nitrogen occurs in natural waters as nitrate ($NO_3$), nitrite ($NO_2$), ammonia ($NH_3$), and organically bound nitrogen. As aquatic plants and animals die, bacteria break down large protein molecules containing nitrogen into ammonia. Sewage is the main source of nitrates added by humans to water bodies. Another important source is fertilizer, which could be carried into natural waters by storm water runoff.

Excessive nitrate stimulate growth with algae and other plants, which later decay and increase biochemical oxygen demand as they decompose. When ammonia oxidizes to nitrate, it requires substantial amounts of oxygen. The first oxidation is to nitrite by *Nitrosomonas* bacteria. The second groups of bacteria take the nitrite and oxidize it to nitrate.

Nitrite concentration in a viable bacterial population is seldom above 0.1mg/l in surface water or 1mg/l in wastewater (Tchobanoglous, Burton and Stensel, 2003). Nitrite is extremely toxic to most fishes and other aquatic species so usually present in low concentrations. Nitrite concentration in wastewater effluent is from 15 to 20mg/l as N. Ammonia, nitrite, nitrate and organic nitrogen concentrations are determined by colorimetric method (Tchobanoglous, Burton and Stensel, 2003).

#### 2.10.2.4 Phosphorus

Phosphorus is usually present in natural water as phosphates. In aqueous solution, phosphorus exists as orthophosphate, polyphosphate and organic phosphate. The orthophosphate, $H_2PO^{4-}$, $H_3PO_4$, $HPO_4^{2-}$ are available for biological metabolism without further breakdown. Phosphorus is a plant nutrient needed for growth and a fundamental element in the metabolic reactions of plants and animals hence its use in fertilizers.

Sources of phosphorus include human and animal wastes (i.e. sewage), industrial waste, soil erosion and fertilizers. Excess phosphorus causes extensive algal growth called "blooms," which are a classic symptom of cultural eutrophication and lead to decrease oxygen levels in natural water.

#### 2.10.2.5 TRACE METALS

Heavy metals are important because they are often toxic and they impede or interfere with the biological treatment process when in excessive quantities. Depending upon the metal and the species, all the reactions are pH dependent (Russell, 2006).

#### 2.10.2.5.1 Cadmium

In Ghana cadmium is introduced into the aquatic environment through waste streams from mining activities, refuse and sewage sludge disposal in urban areas and manufacturing industries such as steel and iron. Cadmium is usually considered as a contaminant in many chemical fertilizers. Phosphate contains 5-100mg Cd $kg^{-1}$. Storm water runoffs carry these fertilizers in receiving water bodies. Concentration as low as 0.1mg/l is potential for accumulation in plants and soils to concentrations that may be harmful to humans (Tchobanoglous, Burton and Stensel, 2003).

#### 2.10.2.5.2 Copper

Copper is an essential micro-nutrient, but at high doses has been shown to cause stomach and intestinal distress, liver and kidney damage, and anaemia. Copper is a reddish-brown metal, often used in plumbing of residential and commercial structures that are connected to water distribution systems. Copper containing water occurs as the result of the corrosion of copper pipes that remain in contact with water for a prolonged period (Shelton, 2005). Copper is toxic to a number of plants at 0.1 to 1.0mg/l in nutrient solution. Recommended maximum concentration for irrigation is 0.2mg/l (Tchobanoglous, Burton and Stensel, 2003).

#### 2.10.2.5.3 Lead

Lead is one of the commonest metals that are used in industry for a wide variety of purposes, including pipes, paint pigment, alkyl compounds for gasoline, lead acid accumulators, brass and bronze fixtures and cable sheathing. Lead is a heavy metal that can cause a variety of adverse health effects in humans. At relatively low levels of exposure, these effects may include interferences in red blood cell chemistry, delays in normal physical and mental development in babies and young children, deficits in the attention span, hearing, and learning abilities of children and increases in blood pressure of some adults (Shelton, 2005).

Plants growing near high ways often absorb this lead as do some grasses that grow near abandoned lead mines. Concentration of water above 5mg/l lead can inhibit plant growth. Materials that contain lead have frequently been used in the construction of water supply distribution system and plumbing systems in private homes other buildings. Lead in these materials contaminates water and natural water as a result of the corrosion that takes place when water comes into contact with that material.

### 2.10.3 Biological Characteristics

Biological constituents of wastewater include Coliforms, specific microorganisms and toxicity. These characteristics are used to assess the presence of pathogenic bacteria, specific organisms present and to detect the level of toxicity, whether acute toxic unit or chronic toxic unit.

#### 2.10.3.1 Coliforms and Faecal Coliforms

Wastewater usually contains bacteria. Some bacteria are harmful and are called pathogenic bacteria whereas others are not and are referred to as non-pathogenic bacteria. Pathogenic bacteria cause typhoid, cholera, dysenteries, etc. Because it is difficult to isolate pathogenic bacteria in the laboratory, simple tests are carried out to



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determine the possible presence of intestinal organisms. These are termed as the coliforms groups of bacteria, some of which are non-pathogenic.

The presence of intestinal bacteria indicates the presence of pathogenic bacteria also. Coliforms are good indicators of pollution too. Hence, the presence of pathogenic bacteria is detected by testing for the coliforms group of bacteria. In the total count test, the sample of water with chromo cult agar added is placed in an incubator at 37°C for 24hours. The bacteria in the water grow and form colonies which can be seen and counted.

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The most common risk of human health associated to wastewater comes from the presence of pathogenic microorganisms. Tchobanoglous, Burton and Stensel (2003) reported that each person discharges from 100 to 400 billion bacteria per day, in addition to other kinds of bacteria. Coliforms in environmental samples, is an indication that pathogenic organism associated with faecal contamination may be present.

Poorly treated greywater, leachate from sanitary landfills and urban solid waste disposal sites, which contain human faecal matter are potential sources of pathogens. Detection of all possible pathogens is rather complex, costly and time consuming, hence *Escherichia coli* is used as indicator organism for detecting the presence of pathogens. Methods commonly used are multiple tube fermentation and membrane filtration techniques.

## 2.11 FACTORS INFLUENCING WATER QUALITY

The quality of water is influenced directly or indirectly by three major factors (Myebeck, 1992). These include:

- The geological factors of the catchment: including topography, relief, lithology, pedology, climate, land use, hydrology, hydro-geology, etc.
- Water use: including dams, canals, water withdrawals for cities and industries, agriculture, navigation, recreation, fisheries etc.
- Pollution source: (present and expected): including domestic, industrial and agriculture.

## 2.12 SAMPLING

Sampling deals with the collection of a portion of a material that represents the actual sample composition. The quality of the analyzed data depends on activities such as formulating the particular objective for a sampling program, collecting representative samples, proper sample handling, sample preservation and properly analyses of the samples. Sampling techniques used in wastewater survey ensure that representative samples are obtained, since the data from the analysis of the samples, ultimately serve as a basis for decision making and planning. Usually sampling programs are tailored to fit a particular scenario since there are no laid down universal procedures. The following types of samples have been listed.

### 2.12.1 Grab sample

Grab sample is an individual sample, collected at a particular time and place. This type of sample represents conditions at the time it was collected. Very often, a grab sample is usually not used as a basis for decision making. However, in certain scenarios some sources are quite stable and may be represented well by a single grab sample.

### 2.12.2 Composite sample

Composite sample refers to a mixture of grab samples collected at the same point at different times. Usually a series of smaller samples are collected in a single container and blended for analysis. The mixing process averages the variation in sample composition and minimizes analytical effort and expense. In scenarios where a time interval is being considered, grab samples are collected within suitable sampling intervals and chosen according to the expected changes. Also in scenarios where composition depends on location, grab samples are collected from appropriate source. Composite samples reflect the average characteristics during the sampling period and in most cases, a 24 hour period is standard. The volume of samples taken must be constant (for example, 200mls each time) in constant time intervals (for example every hour), and mixed well at the end of the composite period.

### 2.12.3 Duplicate sample

Duplicate samples are collected for checking the preciseness of the sampling process.

### 2.12.4 Split sample

Split samples are taken for checking analytical performance. Usually the sample is taken into one container mixed thoroughly, and halved into another properly cleaned container. Both samples are preserved as needed and represent the same sampling point and are referred to as split samples.

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**CHAPTER THREE**

# 3.0 RESEARCH METHODOLOGY

## 3.1 DESCRIPTION OF STUDY SITE

Kumasi Metropolis is the regional capital of Ashanti region in the central part of the republic of Ghana and lies within latitudes 6° 35' N and 6° 40' N, longitudes of 1° 30' W and 1° 25' W, with an area of 254 $km^2$. The unique central location of the city as a traversing point from all parts of the country makes it a special place in terms of the social, economic, cultural and political life of the country. It has a good network of roads, with the Central business district in the city centre, and other infrastructures like telephones (both mobile and landlines), electricity and water facilities being present also.

Kumasi is the second largest city in the country, comprising ten (10) sub-metros namely Asawase, Bantama, Tafo, Kwadaso, Manhyia, Nhyiaeso, Oforikrom, Suame, Subin and Asokwa. Asokwa sub-metro, located in the southern part of the Kumasi metropolis is popularly called the industrial area of Kumasi because the majority of industries are situated there. Pertinent amongst these industries is The Coca-Cola Bottling Company of Ghana, Kumasi Plant which is part of the multi-national beverage industry.

A plant is the sequential arrangement of process equipment as well as other ancillary units in order to produce a product.

The Coca-Cola Bottling Company of Ghana, Kumasi plant is located at the southern part of Asokwa sub-metro, has a total land area of approximately 2 $km^2$ and a core staff strength of 230 out of which 223 are males and 7 females. The plant consists of the Production block, Administration block, Sales block, Depot, Wastewater Treatment block, Canteen block and the Fleet Maintenance block. The plant has a single 330ml bottling line and produces a wide variety of products including Coke, Sprite, Fanta, Fanta Lemon, Fanta Orange, Fanta Cocktail, etc.

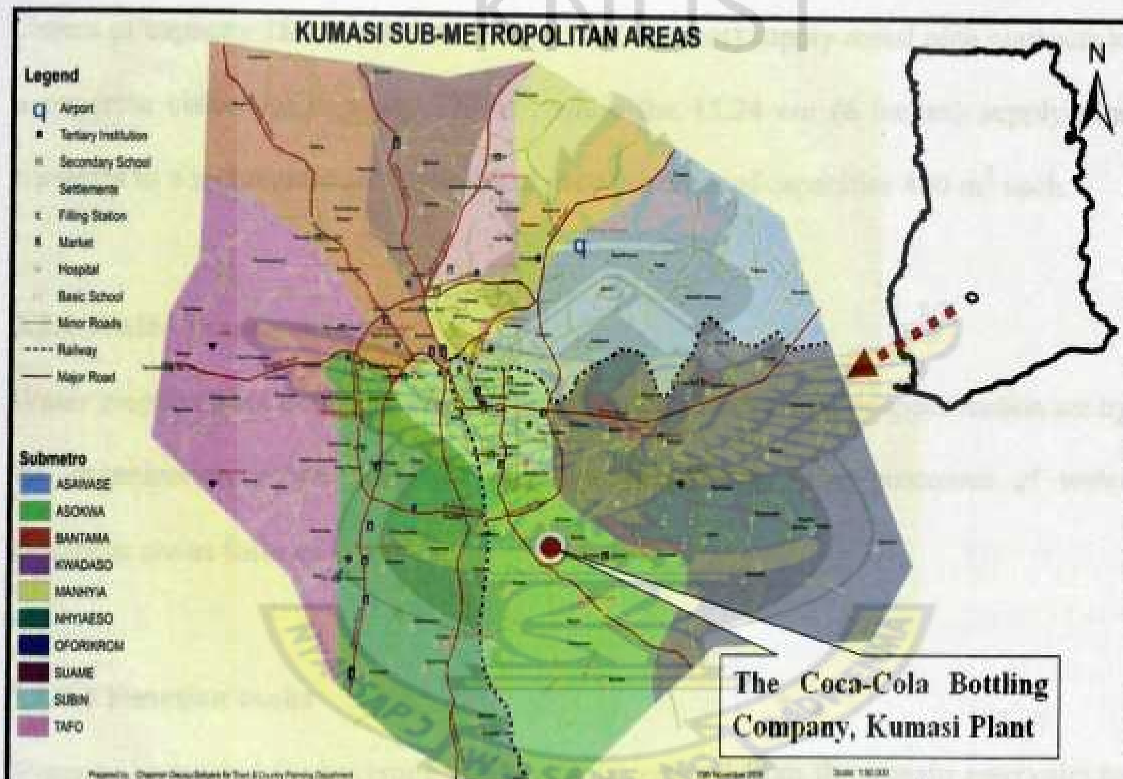


**Figure 3. 1: Study Site**

## 3.2 BEVERAGE PROCESSING STAGES AT THE COCA-COLA BOTTLING COMPANY KUMASI PLANT (TCCBCKP)

### 3.2.1 Water Storage

TCCBCKP relies on Ghana Water Company Limited (GWCL) for all of its water needs. Water supply from trunk mains, at different locations around the plant is achieved through two metal pipes and a PVC pipe of sizes 10.16 and 15.24 cm (4 and 6 inches) respectively, equipped with velocity type meters to measure the flow of water through them. Connected to the 10.16 cm (4 inches) supply pipe is a concrete cistern of capacity 180 $m^3$, the other10.16 cm (4 inches) supply metal pipe connects to a concrete cistern of capacity 270 $m^3$, while the 15.24 cm (6 inches) supply pipe connects to a rectangular and cylindrical metal cisterns of capacities 450 $m^3$ each.

### 3.2.2 Water Treatment unit

Water employed for beverage production is treated to meet quality specification set by the organization before used for beverage preparation. The processes of water treatment are as follows

#### 3.2.2.1 Reaction tanks

Water to be treated for beverage production is pumped from three main reservoirs to the water treatment unit. Incoming water is stored in reaction tanks made of concrete and having capacities of 45 $m^3$ each, with one used at a time. First and foremost, the raw water quality is determined and based on results from analyzed samples, a calculated amount of lime is dosed to remove hardness and reduce the alkalinity of the water, calcium hypochlorite is also dosed to kill microorganisms present in the water



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and ferrous sulphate is dosed to enhance the coagulation of suspended and dissolved particles present after which water flows by gravity to the sand filter tank.

**3.2.2.2 Sand filter tank**

This is a cylindrical metallic tank containing sand and gravel layers with a capacity of 15 $m^3$. The sand filter tank is employed to filter water from the reaction tanks.

**3.2.2.3 Carbon purifier tank I**

It is a cylindrical metallic tank with a capacity of 15 $m^3$ and contains layers of gravel, sand and activated carbon, which are employed to remove chlorine, iron, odour and corrects the taste of the water from the carbon purifier tank I.

**3.2.2.4 Carbon purifier tank II**

This is a cylindrical metallic tank of capacity of 20 $m^3$ containing layers of gravel, sand and activated carbon, employed to treat water by further removing chlorine, iron and odour from the carbon purifier tank I.

**3.2.2.5 Polished filter**

The polished filter consists of layers of cartridges employed to filter water from the carbon purifier tank II. From the polished filter, filtered water is channelled to the syrup preparation and blending units.

### 3.2.3 Syrup Unit

The syrup unit is charged with the responsibility of preparing syrup from concentrate and water in their right proportions for beverage production. The unit is equipped with three large tanks each with a capacity of 80 $m^3$ in which dissolution of sugar, mixing of concentrate and water are achieved. Preparation of syrup is done according to the specifications of the production manager.

### 3.2.4 Laboratory

The laboratory is the hub of the plant. Laboratory personnel are charged with the responsibility of ensuring that both incoming raw material and outgoing products are well within the range of the required standards. Task undertaken in the laboratory include testing the contents of bottles to ensure that brix, carbonation, colour, appearance and taste are within standards, and ensuring that bottles are not scoffed, coding is legible and crown corks meet required standards. Other responsibilities include ensuring that the temperatures of the caustic solution in the caustic tank I, the concentration of caustic as well as the chlorine concentration of the washer meet desired standards. Also inspection of all raw materials is done to ensure that certificate of analysis and certificate of conformation meet standards.

### 3.2.5 Carbon Dioxide Plant

In the presence of filtered air and electrical sparks burning of diesel is achieved in a reaction chamber known as a reactivator. The reactivator contains tubes in which the heat generated as a result of burning moves into and eventually heats up a mixture of water, monoethanolamine, soda ash and antifoam flowing around it. The heated mixture is automatically pumped out of the reactivator through a control system and consequently heats up a similar mixture pumped from an absorber tank through a heat exchanger arrangement.

The heated mixture from the absorber has a high affinity for $CO_2$ and is therefore pumped to the stripper to attract $CO_2$ from the effluent gas from the reactivator. The trapped $CO_2$ contained in a gaseous mixture is liberated by washing the mixture in a scrubber. Consequently liberated $CO_2$ is cooled and is sent to a purifier containing layers of soda ash and $KMnO_4$ to be purified. Purified $CO_2$ is compressed and sent to a drier, after which it is liquefied and stored.

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### 3.2.6 Blending and Filling unit

The Famix is employed to blend syrup and treated water to form beverage. It has a number of components which performs several operations and these includes a metering pump which functions as to measure the amount of water and syrup in their right proportions before blending, a chiller which cools the treated water through a heat exchanger arrangement in order to enhance the absorption of $CO_2$, a flow server which injects $CO_2$ automatically into the beverage to preserve it and enhance the taste and a vacuum pump which deaerates the beverage to prevent the growth of microorganisms after bottles are crowned.

After blending, the beverage produced is further chilled through a second heat exchanger arrangement and finally transported to the bottling bowl where filling of beverage into bottles is done. At this stage clean bottles, having gone through various inspection are carried on a chain conveyor to the bottling bowl where a sniffing valve sniffs out air present in the bottle and charging valve with a vent tube connection directs the beverage to the inner walls of the bottles to prevent foaming. From the filler, bottles are crowned and coded after which it is packed into crates and palleted.

### 3.2.7 Bottle washer

The bottle washer is employed in washing of bottles and consists of five distinct sections. It has a total of 276 carriers, with 206 loaded at a time and operates at a maximum speed of 19 rev/min. The first compartment, the pre-rinse section, has a nozzles arrangement which sprays water in the form of jets to remove dirt and other materials contained in and on the incoming bottles.

The second compartment, the caustic tank I, contains caustic solution of concentration between 2.5-3 ppm and temperature range of 70-80°C and is particularly employed to kill microorganisms present in the bottles. The third compartment, the caustic tank II contains raw water, which is employed to reduce the caustic concentration of the solution on the bottles from the caustic tank I by further washing. The fourth compartment, the cold water tank, removes caustic stains and dirt and prepares it's for final rinsing. The fifth compartment, the final rinse section, contains raw water having a chlorine concentration of about 3 ppm and is employed to finally clean the bottles to complete the bottle washing process. After cleaning bottles are inspected and carried on a chain conveyor to the bottling bowl.

### 3.2.8 The boiler house

The boiler house consists of the Scotch Marine Firetube Boiler and a Screw Compressor.

### 3.2.8.1 Scotch Marine Boiler

The Scotch marine boiler is employed to generate steam and consists of a combustion chamber, burner, heat exchanger, controls and an enclosure. In the presence of filtered air generated by the operation of a blower, and electrical sparks provided by an ignition system, the diesel valve opens through a sensing arrangement resulting in the burning of diesel. Heat generated from burning moves through firetubes which subsequently heats up water flowing around it, generating steam. Steam generated is transported through pipes contained in heat retaining materials to the syrup preparation, washing and filling units and subsequently used in beverage production. The scotch marine boiler is popular for commercial heating services and is widely used due to its compactness, low cost and reliability.

### 3.2.8.2 Screw Compressor

The screw compressor is employed to generate compressed air and consists of a motor, compressing gear, filter and chamber. In its operation, the rotation of the compressing gear is accomplished by the action of a motor which sucks the surrounding air into a chamber. As the air passes through the compressed gear, it is compressed, after which it moves to a second compressing gear where it is further compressed. Next the compressed air produced is passed through a two filter arrangement in series and finally into a storage tank. The compressed air is used at the filling unit during the filling stage of beverage production. The choice for the screw compressor is obvious due to its reliability, efficiency and cost.

### 3.2.9 The Wastewater Treatment Plant

The wastewater treatment plant is the batch type and consists of four main components; the pre-treatment tank, balancing equalizing and neutralization basin, the sequential batch reactor 1 and sequential batch reactor 2.

#### 3.2.9.1 Pre-Treatment Tank

The pre-treatment tank is an underground rectangular concrete tank with the capacity of 180 $m^3$ and consists of three main chambers. In the first chamber, preliminary wastewater treatment is achieved by the removal of wastewater constituents that may cause maintenance or operational problems with the treatment operations, processes and ancillary systems. Examples are screening for the removal of debris, crown corks, straw and rags, grit removal for the elimination of coarse suspended matter that may cause wear or clogging of equipment, and flotation for the removal of small quantities of oil and grease. The second chamber, the neutralization basin is equipped with an automatic pH meter which corrects the pH of the wastewater by dosing sulphuric acid as and when it becomes necessary. It also contains mechanical agitators which continuously stir the wastewater to ensure a uniform pH within the chamber. The third chamber, the neutralized tank, has submersible pumps (pump immersed in the wastewater) that automatically pump the wastewater when it gets to a set maximum limit.

#### 3.2.9.2 Balancing Neutralization and Equalization Basin

The balancing, neutralization and equalization basin is the second component of the wastewater treatment plant. It is circular in shape, has a capacity of 780 $m^3$ and is



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made of stainless steel. It is employed to neutralize the wastewater pumped from the pre-treatment tank and to receive and balance shocks such as high pH and temperature. The basin is automatically controlled.

#### 3.2.9.3 Sequential Batch Reactor 1

The sequential batch reactor 1 is the third component of the wastewater treatment plant and receives neutralized wastewater from the balancing neutralizing and equalizing basin. It is circular in shape, has a capacity of 780 $m^3$ and is made of stainless steel. It contains bacteria employed to remove or reduce the concentration of organic and inorganic compounds. The removal of carbonaceous biochemical oxygen demand, coagulation of nonsettleable colloidal solids and stabilization of organic matter are accomplished biologically through the activities of bacteria. Bacteria convert the colloidal and dissolved carbonaceous organic matter into various gases and cell tissue. Because cell tissue has a specific gravity slightly greater than that of water, the resulting cells are removed from the treated water by gravity settling. The reactor is automatically operated and desludging is done periodically.

#### 3.2.9.4 Sequential Batch Reactor 2

The sequential batch reactor 2 is the final component of the wastewater treatment plant. It is similar in shape and size to the sequential batch reactor 1 and is also made of stainless steel. It is employed to further breakdown organic and inorganic compounds present in the wastewater from the sequential batch reactor 1. It is automatically operated. Discharge of effluent wastewater as well as desludging is done periodically.

## 3.3 METHODOLOGY

### 3.3.1 Desk study

Desk study was carried out and data as well as information were obtained from the following sources: TCCBCKP, GWCL, Textbooks, Previous theses the internet and journals. Also other related works that have been done were reviewed.

### 3.3.2 Data Collection

Various interviews were conducted with the distribution engineer and technicians of the GWCL to collect first hand information about water supply to the plant. Engineers, technicians and Managers of the plant were also interviewed to have a fair idea of the existing state of water supply to the plant, water use and the current wastewater treatment situation.

## 3.4 APPROACHES FOR THE STUDY

### 3.4.1 Water Use and Beverage Produced

Appendix E.1 shows the process flow sheet for the production of beverage in the plant. The black rectangular boxes labelled M1, M2 and M3 represents service meters that records water pumped from GWCL, Suame distribution point to the plant. The red rectangular boxes labelled M4 and M5 represent the main input water from the main reservoirs (R1, R2, R3a, and R3b) to all the stages (units) in the plant. The green rectangular boxes labelled M6 and M7 doubles as the main input water from the main reservoirs of the plant as well as the metered stages of the plant. The yellow rectangular boxes labelled M8, M9, M10, M11, M12 and M13 represent the metered stages of the plant. Therefore a total of four (4) main meters represent the input water from the main water reservoirs of the plant to all the twelve (12) stages (units) of the plant and eight (8) represent the metered stages of the plant. Out of the total of twelve (12) stages identified in the plant, eight (8) were used for the study of the current water consumption at the metered stages, the single reason being that the other areas (4 stages) could not be metered for the study. The metered stages include the Bottle Washer (M11), Boiler House (M13), Production Floor Cleaning Area 1(M12), Fleet Maintenance Yard (M8), Syrup and Beverage Preparation Units (M9), Workshop and Bath House (M10), Carbon Dioxide Plant (M7) and the Canteen (M6-M8). The unmetered stages include the Laboratory, the Production Floor Cleaning Area 2, Lubricating Water and the Administration and Sales Office. Input water from the reservoirs R1, R2, 3b and 3a to all the metered stages of the plant was recorded each day at 6am from the 1 August – 30 November 2009. Beverage produced within that same period was also recorded against each day. Also monthly water consumption for the period between January 2005 and December 2009 were collected and has been tabulated in Table D.9 in Appendix D. Tables D.1 to D.8 in Appendix D summarises the results of the general input water and the water used at the eight (8) stages of the plant as well as the beverage produced for the period under study.

### 3.4.2 Sampling procedure and analysis

Sampling was done during the first weeks in the months of August, September and October. In all nine (9) influents composite samples representing the 1st, 2nd and 3rd shifts and 6 effluent composite samples representing 1st and 2nd discharges from the wastewater treatment plant sampled at regular times were analyzed. E.2 in appendix E is the process flowsheet for the treatment of wastewater in the plant and shows areas (2 main points) where the influent and effluent wastewater samples were collected.

At all times, grab samples for the influent wastewater were collected at the start, middle and the end of the eight hour shift by dipping the sampling bottles (1.5 litres each) into the influent wastewater against the direction of flow and thereafter composited, after which 1.5 litre of the composite sample was used for the analysis. Parameters that were analysed includes BOD, COD, Turbidity, Colour, pH, Temperature, Total Dissolved Solids, Total Suspended Solids, Conductivity, Coliforms, Faecal Coliforms, Nutrients and Trace metals.

Table 3.1 shows the method and type of instruments used for the analysis of the various parameters considered above.

Samples for bacteriological analysis were collected in sterilized plain glass bottles and stored under ice. These were transported to the laboratory for analysis. The membrane filtration method was used, incubating at 37°C for 18-24 hours and counting the colonies developed. For trace metals, about 75 ml of samples were digested with 5 ml concentrated nitric acid and the concentration of the metal measured directly with Atomic Absorption Spectrophotometer ( 220 model).

**Table 3. 1: Methods and Instruments used for the Water Quality Analysis**

| Parameter | Method Used | Instrument |
|---|---|---|
| BOD | Winkler Modification | Appendix 1 |
| COD | Closed Tube Method | Appendix 1 |
| Turbidity | APHA Standard Method (USEPA) | HACH Model 2100P Turbidimeter |
| Conductivity | Cyberscan PC 300 Series | Cyberscan PC 300 Series |
| Total Dissolved Solids | Cyberscan PC 300 Series | Cyberscan PC 300 Series |
| Total Suspended Solids | Gravimetric Method | Appendix 1 |

| | | |
|---|---|---|
| Ammonia-Nitrogen | Titrimetric Method | Micro Kjeldhal Method |
| Nitrate-Nitrogen | Cadmium Reduction method (Nitra via Powder Pillow) | HACH Type DREL/2010 Spectrophotometer |
| Nitrite-Nitrogen | Diazotization Method (Powder Pillow) | HACH Type DREL/2010 Spectrophotometer |
| Phosphorus | Orthophosphate Phos Ver 3 (Ascorbic Acid) Method {Pillow Powder} | HACH Type DREL/2010 Spectrophotometer |
| Sulphates | | HACH Type DREL/2010 Spectrophotometer |
| Trace metals | | A.A.S 220 model |
| Temperature | | Thermometer |
| pH | | Cyberscan PC 300 series pH meter |
| Colour | | Nesselerizer |
| Coliforms | Membrane Filtration Method | Membrane Filter |
| Faecal Coliforms | Membrane Filtration Method | Membrane Filter |
| DO | | Oximeter |

**3.5 Flow measurement**

Wastewater flow rate measurement was carried out with the aid of a weir constructed across the rectangular concrete drain that empties its content into the pre-treatment tank of the wastewater treatment plant. The height of the water above the weir was measured using a point gauge on an hourly basis for a period of 4 days and the flow computed. Appendix B gives a sample calculation of flow rate computation and the results are tabulated in Table B.1

**CHAPTER FOUR**

# 4.0 RESULTS AND DISCUSSION

## 4.1 WATER CONSUMPTION PATTERN OF THE PLANT IN THE LAST FIVE YEARS

The monthly water consumption of the plant was obtained from GWCL billing records from January 2005 to December 2009 and has been tabulated in appendix D Table D.9 The figure 4.1 is a plot of water consumption against the various months of the years (2005-2009).

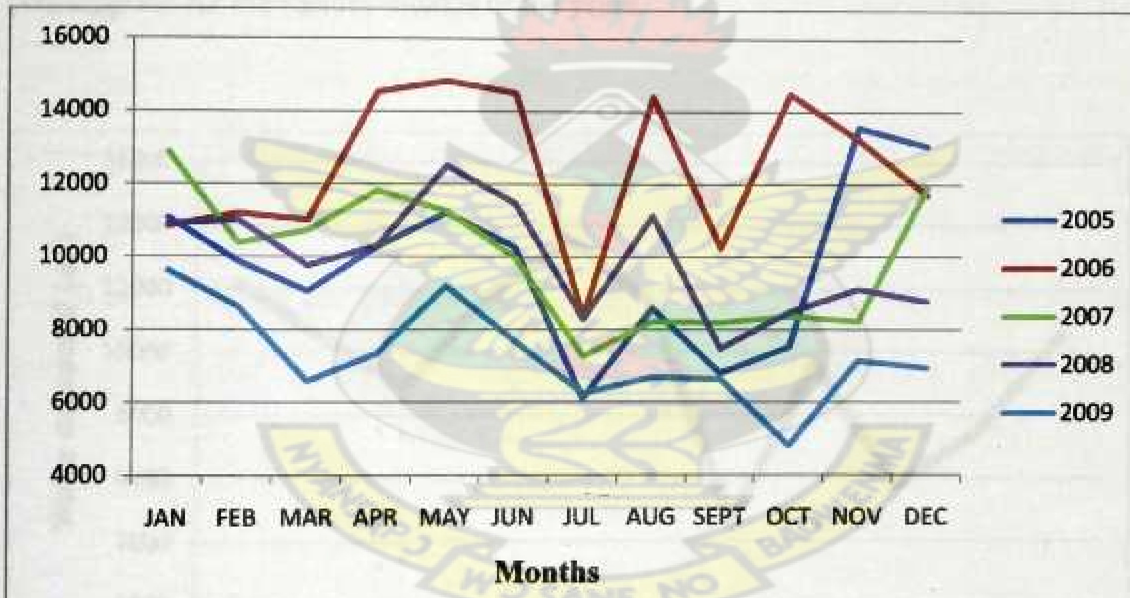


**Figure 4. 1: Monthly water consumption pattern for the five years**

The figure 4.1 shows similar trends of monthly water consumption for the various years under study. Even though 2005 was expected to register the highest average yearly water consumption for the study period, the case was not so. This could be attributed to the low demands of the products (beverage) of the plant in that year.

The highest average yearly water consumption for the study occurred in 2006 followed by 2007 and 2008 in that order with the lowest average yearly water consumption being registered in 2009. The decreasing trends in water consumption from the period between 2006 and 2009 were consistent with a corresponding decrease in beverage produced in those years. This trend could be due to a decrease in demand of the plant products (beverage) resulting from competition from similar beverage products on the market. Figure 4.2 is a plot of the average water consumption for the various months of the years.

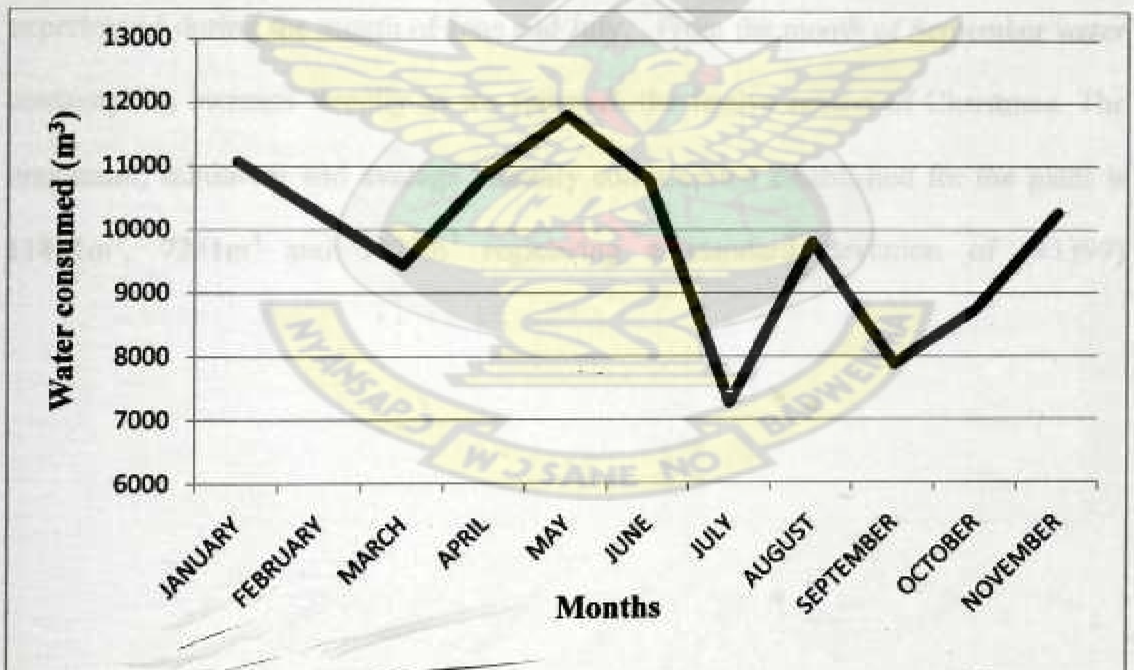


**Figure 4. 2: Average monthly water consumption for the five year period**



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From figure 4.2, it is evident that from the month of January which marks the end of the festive season Christmas and New Year celebration, the water consumption of the plant declines until March where it eventually increases from April to May. The decrease in water consumption is due to the low patronage of beverage from the plant after the festive season while the subsequent increase in water consumption in the months of April and May could be due to Easter Celebration which is mostly marked by merrymaking which consequently leads to an increase in the demand of the products (beverage) of the plant.

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From the month of May water consumption declines once again registering the lowest monthly water consumption in July. The decline in water consumption may be attributed to a fall in demand of the plant product (beverage) due to the wet season experienced during the month of June and July. From the month of September water consumption increase steadily as we approach the festive season of Christmas. The maximum, minimum and average monthly consumption established for the plant is $11801m^3$, $7251m^3$ and $9825m^3$ registering a standard deviation of (±1399)

## 4.2 THE CURRENT WATER USAGE AT THE METERED STAGES OF THE PLANT

In all, a total of 8 metered stages out of 12 indentified in the plant were used for the current water usage at the metered stages of the plant study. The metered stages include the Bottle Washer, Boiler House, The Production Floor Cleaning Area I, The Fleet Maintenance Yard, Syrup and Beverage Preparation Units, Workshop and Bath House, Carbon Dioxide Plant and Canteen.

The daily and monthly volumes of water consumed at these metered stages of the plant were recorded for the period under study (4 months). The results have been tabulated in appendix D Tables D.1, D.2, D.3, D.4. Plots of the monthly water consumption of the metered stages of the plant for the months of August, September, October and November have been presented in appendix D, figures D.1, D.2, D.3 and D.4. Figure 4.3 is a plot of the average water consumption pattern at the 8 metered stages of the plant for the period under study.

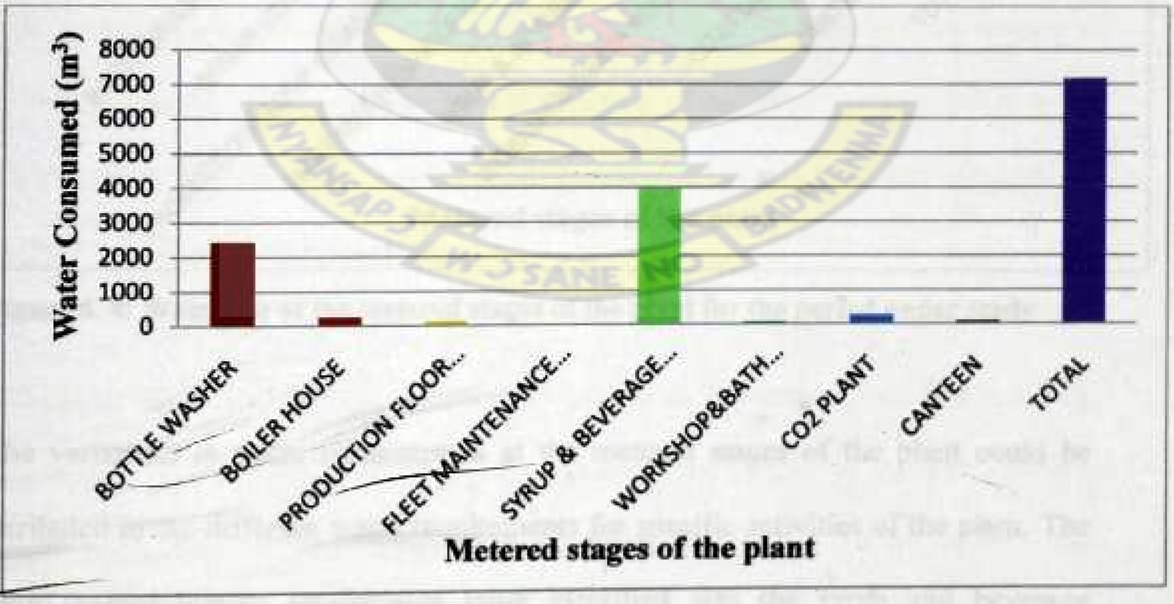


**Figure 4. 3: Average water use at the metered stages of the plant**

In the plot above, the highest water consumption was registered at the syrup and beverage preparation units (55.47%), followed by the bottle washer equipment (33.96%), Production floor cleaning (1.59%), Fleet maintenance yard (0.21%), Boiler house (3.40%), Workshop and bath house (0.77%), Carbon dioxide plant (3.78%) and Canteen (0.81%) of the total water used in that period.

Generally the water consumption pattern at the various stages of the plant showed similar trends for the other months under study. Figure 4.4 is a plot of the water consumption pattern for all the months under study.

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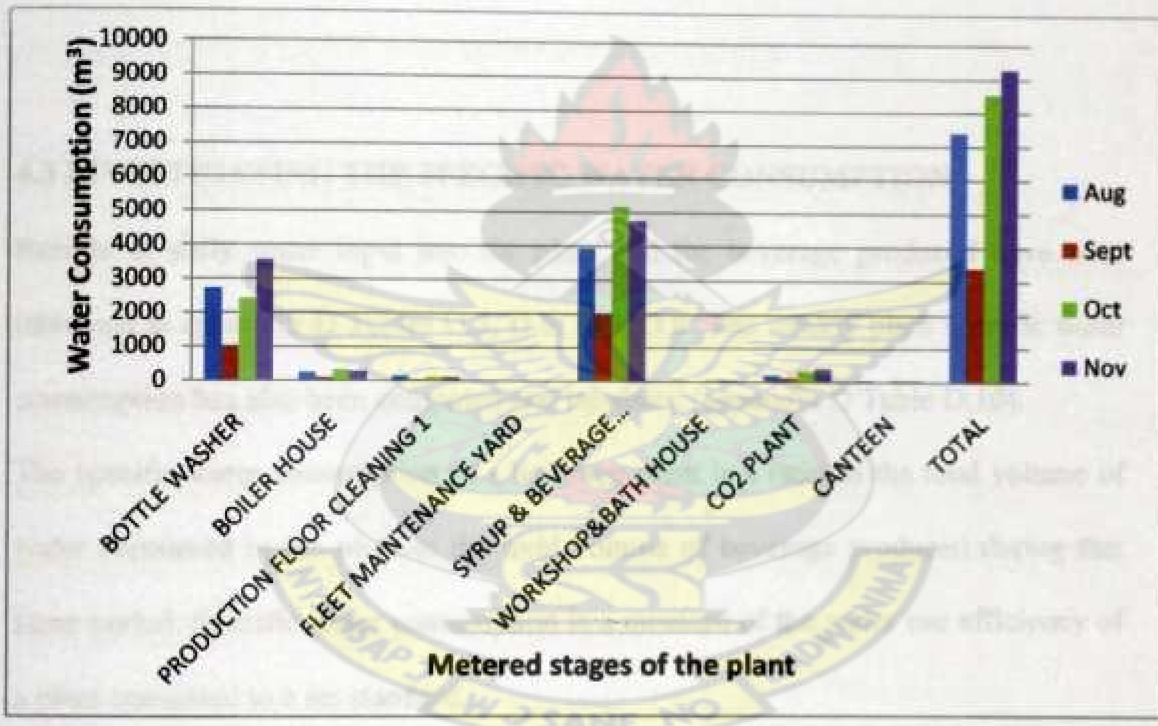


**Figure 4. 4: Water use at the metered stages of the plant for the period under study**

The variations in water consumption at the metered stages of the plant could be attributed to the differing water requirements for specific activities of the plant. The most water-intensive requirement stage identified was the syrup and beverage preparation units and the bottle washer equipment. The high consumption of water in these areas may be due to the simple reason that the syrup and beverage preparation stage as well as the bottle washing stage requires more water during the beverage manufacturing process.

Again judging from the plot of water consumption against the period under study for the various stages above, it was quite evident that water consumption kept on increasing from the month of August to the month of November. The gradual increase could be attributed to the fact that from the month of August to September the plant gradually enters its peak season and therefore experiences high market demand of its products.

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## 4.3 INVESTIGATING THE SPECIFIC WATER CONSUMPTION

Results of daily water input into the plant and the beverage produced have been tabulated in appendix D Tables D.5, D.6, D.7, D.8. The weekly plant specific water consumption has also been computed and tabulated (appendix D Table D.10).

The specific water consumption of a beverage plant is a ratio of the total volume of water consumed in the plant to the total volume of beverage produced during that same period. Specific water consumption is a measure of the water use efficiency of a plant compared to a set standard.

The plant under study like other conventional Africa Beverage Plants has a specific water consumption standard ~~of (4:1)~~ which is explained as follows for each 4 litres of water consumed, 1 litre of beverage must be produced. Figure 4.5 is a plot of specific water consumption against the 12 week period under study.

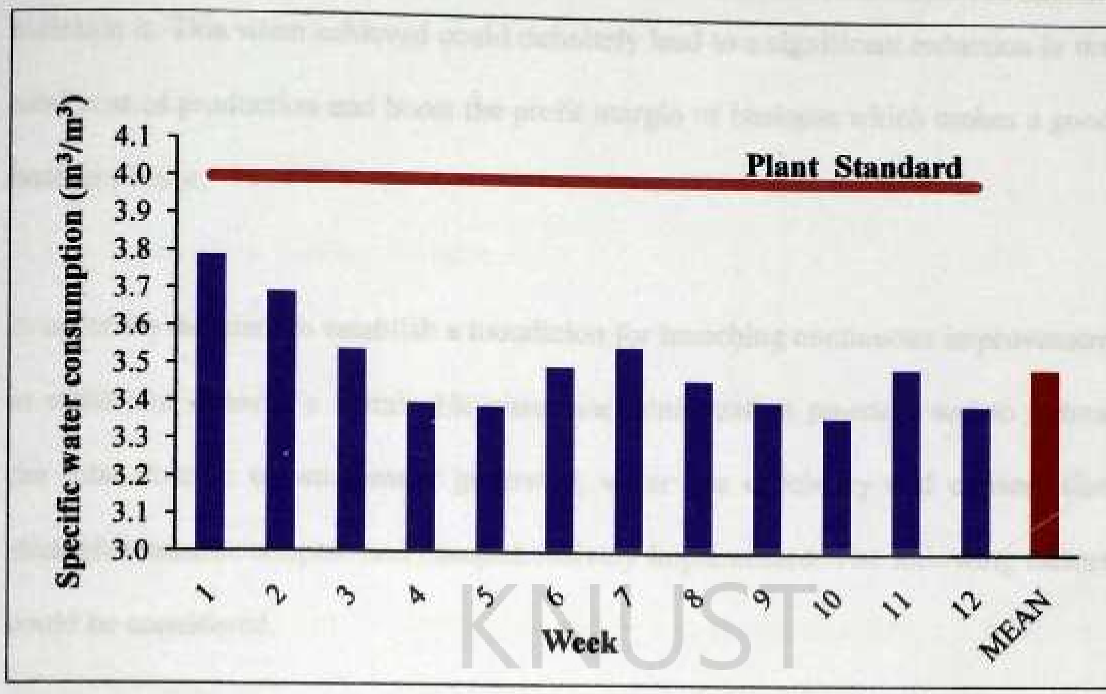


**Figure 4. 5: Weekly specific water consumption computation**

During the period of the study, the maximum, minimum and mean specific water consumption recorded was 3.8, 3.4 and 3.5 respectively with a standard deviation of (±0.1). With reference to the plot above, the specific water consumption measured in the first week was 3.8 and then it dropped gradually from 3.7 to 3.4 between the second to the fourth week. From the fifth to the seventh week, the specific water consumption rose from 3.4 to 3.6 and then dropped again during the eighth and ninth week remaining fairly constant to the twelve week.

The variation in the specific water consumption pattern during the period could be attributed to factors such as personnel water use minimization and efficiency practices, conditions of process equipments and pipelines. Registering a mean of 3.5 against the 4 as set by the plant, it was quite obvious that the plant is operating within its set standard. Even though the plant is within its water use efficiency standard, opportunities exist to reduce the current specific water consumption figure or maintain it. This when achieved could definitely lead to a significant reduction in the total cost of production and boost the profit margin of business which makes a good business sense.

In order for the plant to establish a foundation for launching continuous improvement in water use, achieve a sustainable water use minimization practices and to reduce the total volume of wastewater generated, water use efficiency and conservation strategies must be adopted and comprehensively implemented. The following factors could be considered.

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#### 4.3.1 Personnel Water Use Minimization Practices

One key factor contributing to the success of water use minimization programme includes the creation of awareness among employees about the importance of water conservation and water use efficiency and the commitment by employees to saving water. A number of published works on waste minimization in industries emphasize the importance of personnel participation in waste minimization programmes (Puplampu and Siebel, 2003). They reason that unless companies establish a work environment where employees are actively participating by submitting and helping implement ideas that improve business, the company has not fully established a foundation for launching a continuous improvement programme.

Because employees are the most knowledgeable about the various processes, they should be encourage to take part in proposing new ways of minimizing water use in the plant. Capacity building can be achieved through training programmes organized periodically by the utility sections of the plant. This can be done through the use of announcements, interviews, group discussion, one-to-one chat, water seminars, putting up of notices and reminders at vantage points in the plant.

### 4.3.2 Condition of Process Equipments

Apart from the fact that personnel water use minimization practices can cause a significant decrease in the volume of water consumed, the conditions of process equipment cannot be left out. If process equipments, such as water vessels, bottle washer equipment, etc are kept in good condition and are not left to develop leakages, water conservation mechanism can be a cost effective strategy. Minor and major leakages as well as faulty equipments should be reported immediately and repaired. Routine maintenance schedule of process equipments must be carried out as often as possible. It is only if process equipments are maintained properly that water conservation through leakage prevention can be achieved.

### 4.3.3 Conditions of Pipelines and Valves

The importance of the conditions of pipelines and valves cannot be overemphasized. It is important that all pipelines and valves used in the plant are not buried but are made visible so that leaks can be detected and rectified more easily. Routine maintenance of pipelines and valves should be carried out so as to repair leakages and broken pipes. Also loose valves should be corrected for at all times. Wherever possible, dry clean up practices such as wiping or sweeping are to be used either in place of or prior to wet clean up.

### 4.3.4 Retrofitting

Retrofitting is very necessary in order to conserve water in the plant. It was noticed that the bath house of the plant is fitted with high volume low pressure shower heads. This situation has resulted in a high volume of water gushing out when the showers are opened which intend wastes a lot of water. Again in the workshop a tap was found leaking for close to a week until it was changed. It is therefore imperative that faulty equipment, pipeline and valves are attended to as soon as possible in order to conserve water.

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## 4.4 CHARACTERISTICS OF WASTEWATER

The plant uses biological processes to treat the wastewater before discharge into the environment. A summary of the wastewater laboratory results of the study are given in appendix C, Table C.3 and C.4. The mean value of each parameter considered for the various sampling times have been computed and tabulated as well as the standard deviation and standard errors of 95% confidence interval. Plots of the mean water quality data for the influent and effluent wastewater as well as EPA Ghana guideline for the various parameters considered were also made.

Table 4.1 shows the characteristics of the average influent (INF 1, INF 2, INF 3, INF 4, INF 5, INF 6, INF 7, INF 8, and INF 9) and the average effluent (EFF 1, EFF 2, EFF 3, EFF 4, EFF 5 and EFF 6) wastewater and the EPA Ghana guidelines for Beverage Industries discharging into water bodies.

**Table 4. 1: Wastewater Characteristics**

| Parameter | Average Influent | Standard Error ± | Average Effluent | Standard Error ± | EPA Ghana |
|---|---|---|---|---|---|
| Temp °C | 48.2 | 0.7 | 28.3 | 0.6 | 30 |
| TDS mg/l | 862.2 | 56.1 | 839.8 | 59.3 | <1000 |
| Conductivity µS/cm | 1750.1 | 100.6 | 842.8 | 58.8 | 750 |
| Colour mg/l | 77.8 | 36.0 | 100 | 41.3 | 100 |
| TSS mg/l | 87.7 | 27.8 | 176.7 | 114.3 | <50 |
| Turbidity mg/l | 46.8 | 3.8 | 94.8 | 67.8 | 75 |
| DO mg/l | 3.6 | 0.6 | 5.7 | 0.6 | <1 |
| pH | 11.3 | 0.2 | 8.5 | 0.3 | 6-9 |
| BOD mg/l | 1116.8 | 192.7 | 49.8 | 32.9 | <50 |
| COD mg/l | 3114.2 | 252.7 | 569.2 | 115.9 | <250 |
| $NH_3$-N mg/l | 11.5 | 1.1 | 2.1 | 0.3 | 1.0 |
| $NO_3$-N mg/l | 1.9 | 0.8 | 2.1 | 1.0 | 50 |
| $NO_2$-N mg/l | 0.0 | 0.0 | 0.0 | 0.0 | N/A |
| $PO_4$-P mg/l | 5.2 | 0.6 | 5.6 | 0.5 | N/A |
| Sulphates mg/l | 60.6 | 24.2 | 117.7 | 17.7 | 250 |
| Cadmium mg/l | 0.2 | 0.1 | 0.2 | 0.1 | <0.02 |
| Copper mg/l | 0.4 | 0.1 | 0.4 | 0.1 | 1 |
| Lead mg/l | 1.6 | 0.6 | 1.4 | 1.2 | <1 |
| Coliforms N/100ml | 5466.7 | 1952.6 | 15850 | 6377.1 | 400 |
| F Coliforms N/100ml | 216.7 | 105.1 | 600 | 364.9 | 10 |

Even though most effluent parameters including temperature, pH, conductivity, colour, total dissolved solid, biochemical oxygen demand, dissolved oxygen, copper and sulphates met the EPA Ghana guidelines others such as total suspended solids, chemical oxygen demand, turbidity, cadmium, lead, coliforms and faecal coliforms were above the EPA Ghana guidelines.

### 4.4.1 Temperature

The temperature of the influent wastewater to the treatment plant ranged from 47°C to 50°C and the mean temperature was 48.2°C. Effluent temperature ranged from 28°C to 30°C. This drop in temperature could be due to heat loss by convection to the atmosphere and conduction to the walls of the receiving tanks. Mostly optimum temperatures for bacterial activities are in the range from about 25°C to 35°C (Tchobanoglous, Burton and Stensel, 2003). This suggests that a drop in temperature



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aids bacterial activities in the treatment tanks. The mean effluent temperature of 28.8 was within the EPA Ghana guideline of <3°C above ambient temperature which ranges between 29°C and 30°C.

### 4.4.2 pH

All the influent wastewater analyzed was alkaline. The mean pH value was 11.3 and was in the range of 11.6 to 10.8. The mean pH values of the effluent wastewater ranged from 7.9 to 8.9 and were all within EPA Ghana guideline range of 6 to 9. The decrease in pH of the wastewater after treatment indicates that some form of treatment had been achieved. Figure 4.6 is a plot of the average influent and effluent pH results and EPA Ghana guideline.

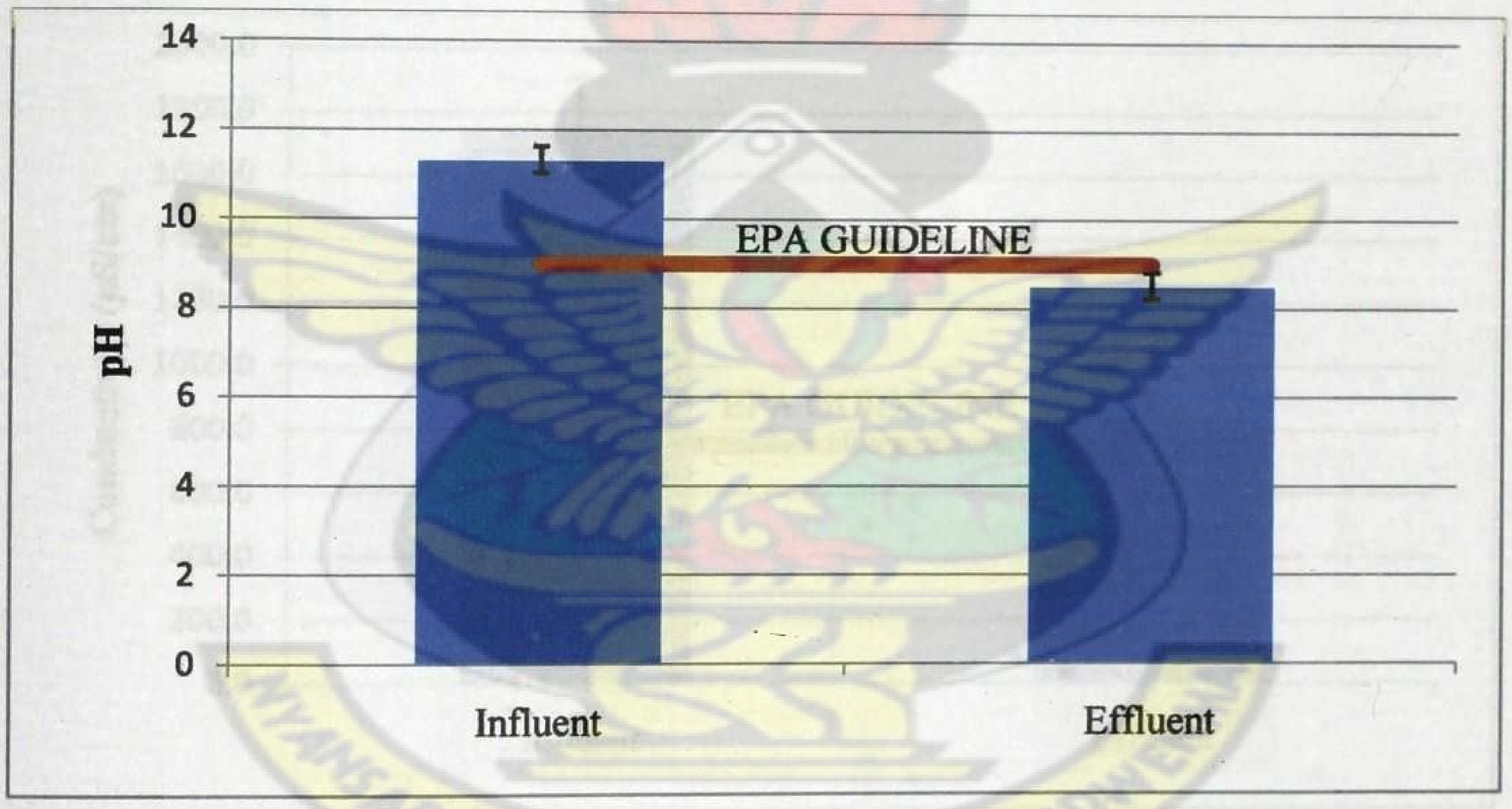


**Figure 4. 6: Influent and Effluent pH and EPA guideline**

### 4.4.3 Conductivity

Generally conductivity of water is determined to obtain the ability of the waters to conduct electrical current. The mean influent conductivity values ranged between 1999 µS/cm to 1750 µS/cm and was 1750 µS/cm.

This may be attributed to the high concentration of dissolved ions present in the wastewater since different chemicals are used during the bottles preparation stage and during the preliminary treatment of the wastewater. Gosselink and Mitsch (2000) established that anions such as chloride, nitrate, phosphate and sulphate as well as cations such as sodium, calcium, magnesium and iron contribute to the overall conductivity. Mean effluent conductivity was 842.8 μS/cm in a range with values from 923 μS/cm to 756 μS/cm. Even though the drop in conductivity shows some amount of ion removal, the conductivity levels for both the influents and effluents wastewater were unsatisfactory compared to EPA Ghana guideline value of 750 μS/cm. Figure 4.7 is a plot of the average influent and effluent conductivity results and the EPA Ghana guideline.

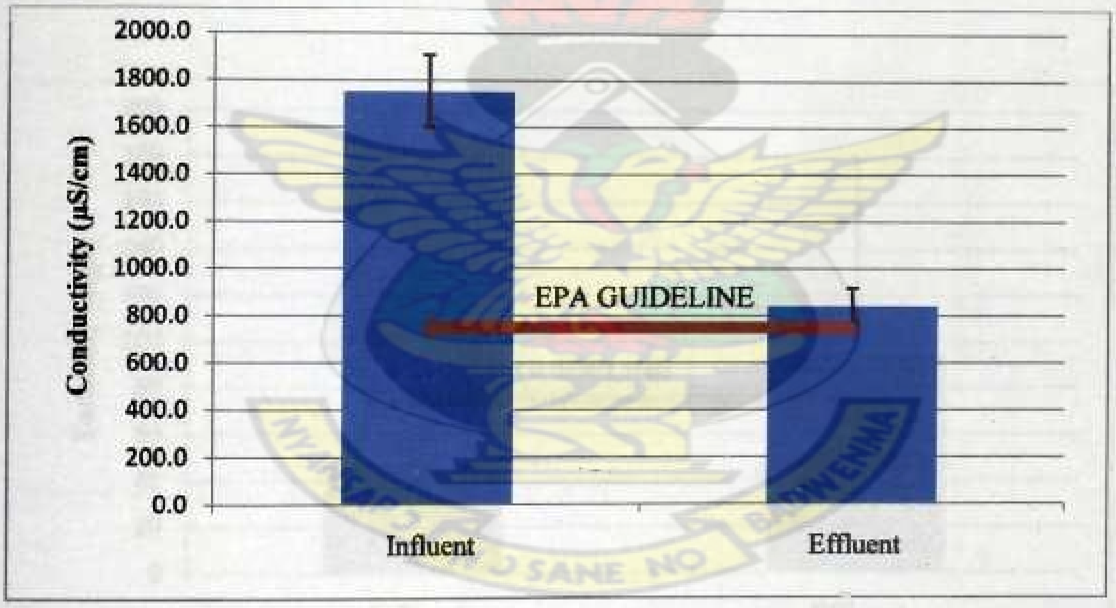


**Figure 4. 7: Influent and Effluent conductivities and EPA guideline**

### 4.4.5 Turbidity

Turbidity, a measure of the light transmitting properties of water, is another test used to indicate the quality of wastewater discharges with respect to colloidal and residual suspended matter. High levels of turbidity in industrial effluents contribute large amounts of suspended solids to receiving water bodies.

The mean influent turbidity value was in the range of 39 NTU and 57 NTU and was 46.8 NTU. The final effluent turbidity was in the range of 225 NTU and 32 NTU. The influents and most effluents values were below the EPA Ghana guideline value of 75 NTU, with the exception of turbidity values for the first and second effluent sampling. The high values of turbidity during the first and second effluent sampling period could be due to some technical problems with the wastewater treatment units during the sampling times. Figure 4.8 is a plot of the average influent and effluent turbidity results and the EPA Ghana guideline.

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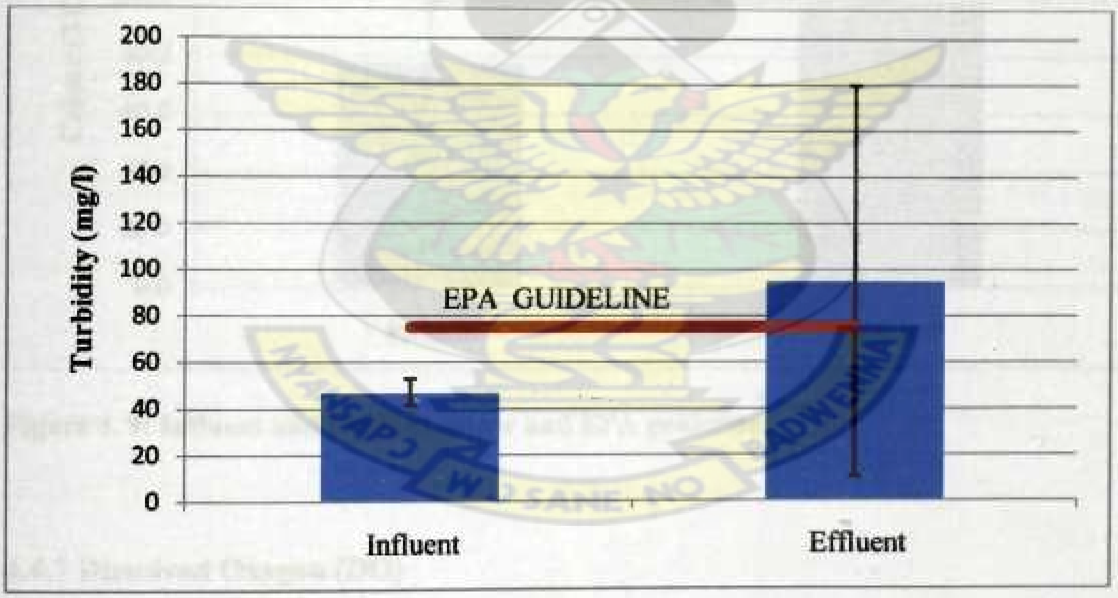


**Figure 4. 8: Influent and Effluent turbidity and EPA guideline**

### 4.4.6 Colour

Various industrial processing activities such as cleaning and bottle washing impact considerable amount of colour to water. Mean colour values for the influent wastewater ranged from 150 TCU to 25 TCU respectively with the mean of 77.8 TCU. The mean final effluent colour was 100 TCU and ranged between 60 TCU to 180 TCU [Figure 4.9]. Higher values of colour were recorded during the first and second sampling periods for the final effluent and this may be due to some technical problems with the wastewater treatment plant during the sampling times. However, it became evidently clear that during the normal functioning of the plant, effluent colour values were within the range of EPA Ghana guideline for discharges into receiving water bodies.

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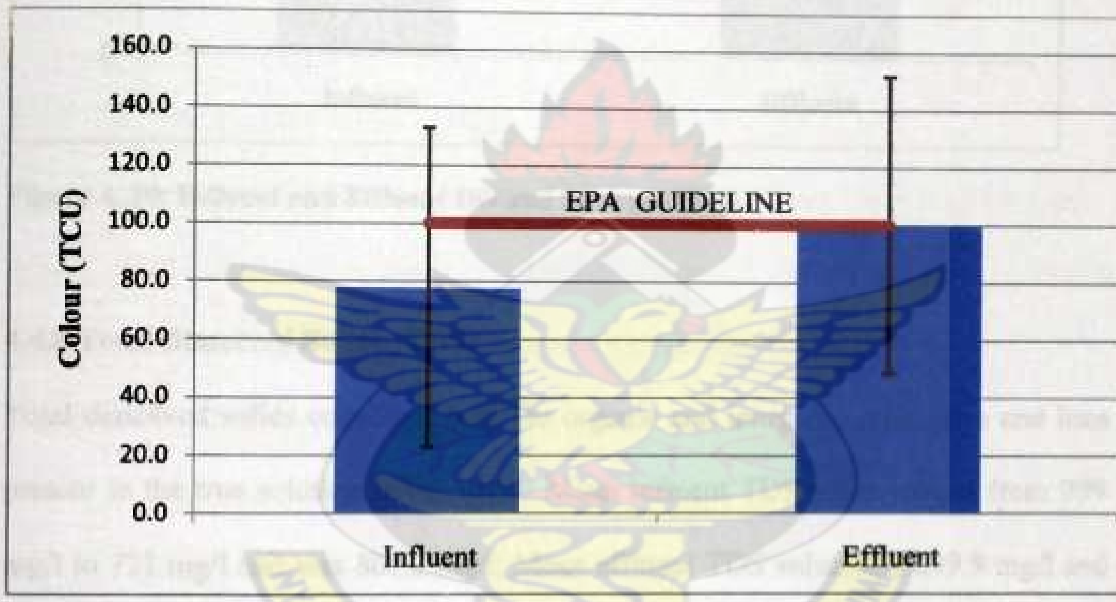


**Figure 4. 9: Influent and Effluent colour and EPA guideline**

### 4.4.7 Dissolved Oxygen (DO)

Dissolved oxygen is required for the respiration of aerobic microorganism as well as all other aerobic life forms. Mean influent DO ranged from 4.8 mg/l to 1.8 mg/l and was 3.6 mg/l. Mean effluent DO was 5.7 mg/l and ranged from 6.4 mg/l to 4.8 mg/l. The increase in the effluent DO may be attributed to the infusion of air by blowers during the wastewater treatment period. Both the influent and effluent DO values were above the EPA Ghana guideline value of >1 mg/l. Figure 4.10 is a plot of the average influent and effluent DO results and the EPA Ghana guideline.

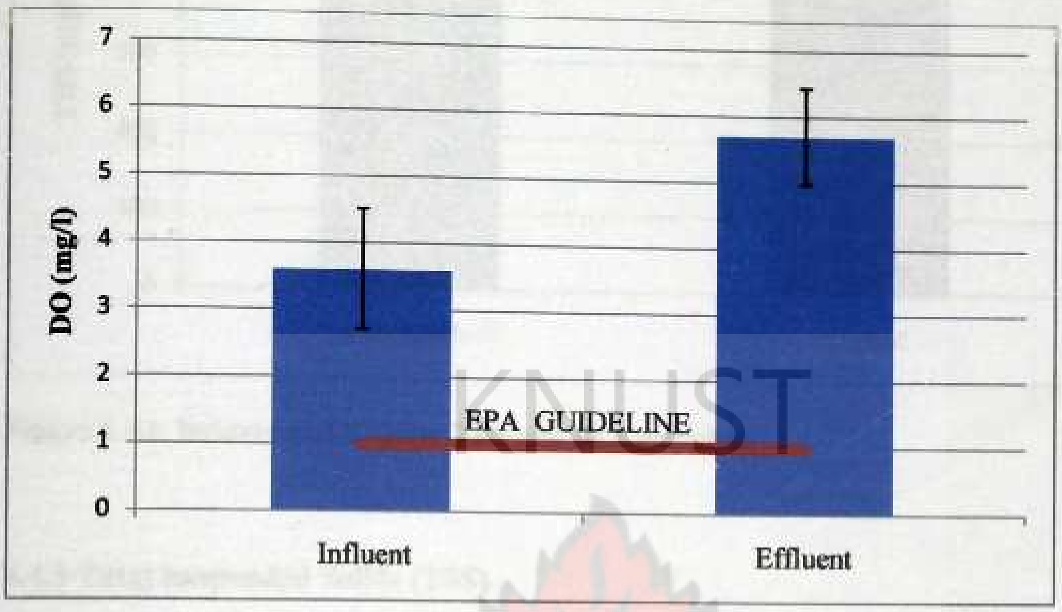


**Figure 4. 10: Influent and Effluent DO and EPA guideline**

### 4.4.8 Total Dissolved Solids (TDS)

Total dissolved solids consist of both the organic and inorganic molecules and ions present in the true solution in the water. Mean influent TDS value ranged from 999 mg/l to 771 mg/l and was 862.2 mg/l. Mean effluent TDS value was 839.9 mg/l and ranged from 923 mg/l to 729 mg/l. Figure 4.11 is a plot of the average influent and effluent TDS results and the EPA Ghana guideline.

It was noted that both average influent and effluent TDS results were within the EPA Ghana guideline for beverage industries discharging into water bodies.

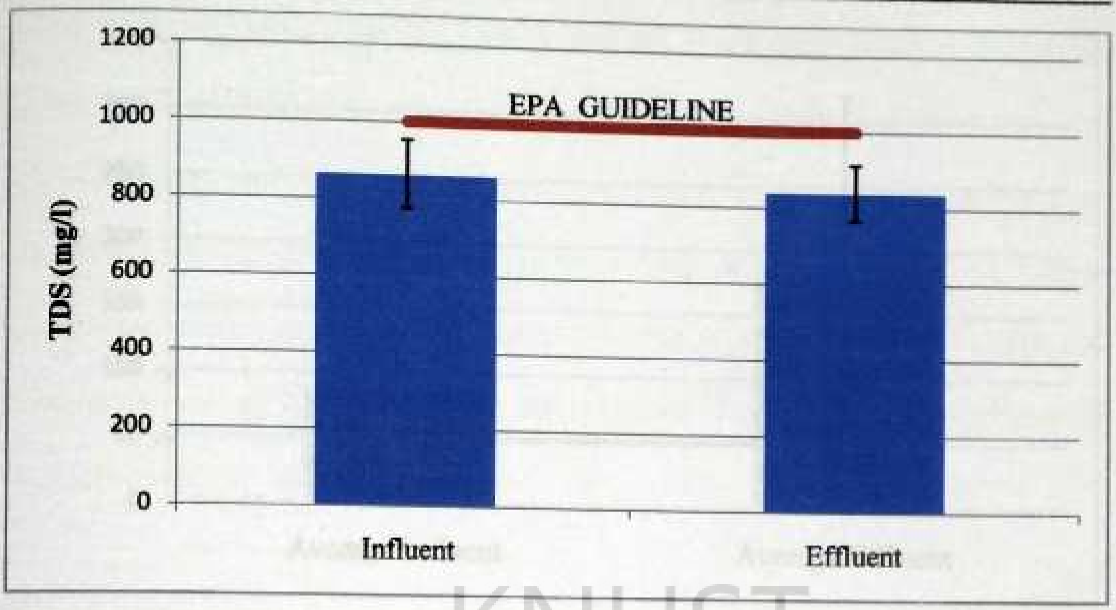


**Figure 4. 11: Influent and Effluent TDS and EPA guideline**

### 4.4.9 Total Suspended Solids (TSS)

The mean influent TSS value ranged from 144 mg/l to 44 mg/l and was 87.7 mg/l. Also the final effluent TSS values ranged from 71 mg/l to 380 mg/l and registered an average of 176.7 mg/l. Even though it was expected that the effluent TSS values be low after treatment, the reverse was observed.

The increase in the effluent TSS concentration could be attributed to the reason that since the installation of the treatment plant 7 years ago, the treatment tanks have never been de-sludged and again, may partly be due to some technical problems with the treatment plant which might have caused the shooting up of the TSS values during the first and second effluent sampling periods. Below is a plot of the average influent and effluent TSS results and the EPA Ghana guideline. It was well noted that all the average effluent results did not conform to the EPA Ghana Permissible guideline of <50 mg/l in Figure 4.12.

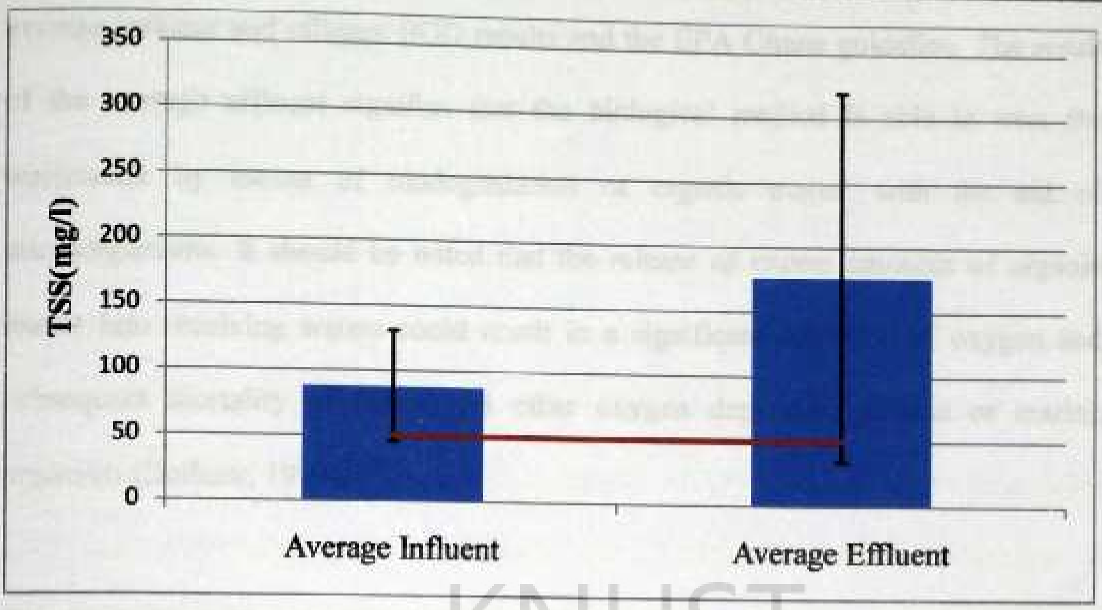


**Figure 4. 12: Influent and Effluent TSS and EPA guideline**

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### 4.4.10 Organic Matter

An indication of organic content of the effluent and the receiving water can be accessed from the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels (Tchobanoglous, Burton and Stensel, 2003)..

#### 4.4.10.1 Biochemical Oxygen Demand ($BOD_5$)

The influent BOD concentration to the treatment plant ranged from 1504 mg/l to 700 mg/l, with a mean of 1116.8 mg/l. The high values of BOD may be attributed to the high concentration of the organic matter content in the wastewater. The mean effluent BOD concentration was 49.8 mg/l and in the range of 120 mg/l to 19 mg/l. The high effluent concentration of BOD registered during the first and second sampling could be due to some technical problems with the plant during both sampling times.

With the exception of the first and second effluent sampling values all other sampled values met the EPA Ghana guideline of 50 mg/l. Figure 4.13 below is a plot of the average influent and effluent BOD results and the EPA Ghana guideline. The result of the average effluent signifies that the biological method is able to treat the wastewater by means of biodegradation of organic matter with the aid of microorganisms. It should be noted that the release of excess amounts of organic matter into receiving waters could result in a significant depletion of oxygen and subsequent mortality of fishes and other oxygen dependent aquatic or marine organism (DeBusk, 1999).

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Tchobanoglous, Burton and Stensel (2003) established that BOD/COD ratio of untreated wastewater range from 0.3 to 0.8. If ratio is 0.5 and greater it means wastewater can be solely treated by biological means. If the ratio is below 0.3 then waste have some toxic components. In this case study the BOD/COD ratio was 0.4 signifying that the wastewater may need further chemical treatment and not biological. Pre-treatment of the wastewater to remove toxic substances may be required. The percentage removal achieved was 93%.

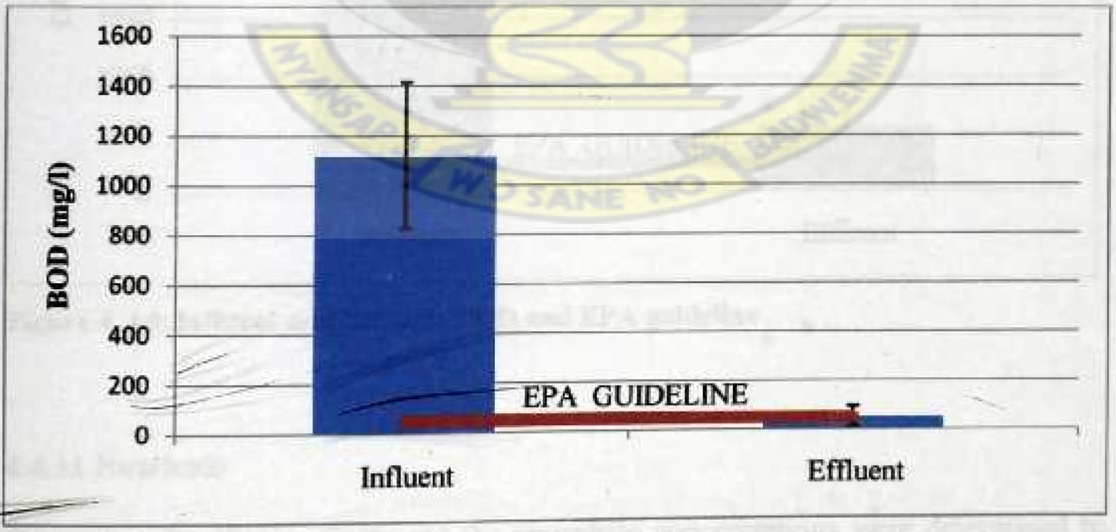


**Figure 4. 13: Influent and Effluent BOD and EPA guideline**

### 4.4.10.2 Chemical Oxygen Demand (COD)

The mean influent COD value ranged between 3760 mg/l to 2466 mg/l and was 3114.2 mg/l. The common interferences of COD which causes it to be higher than the BOD includes sulphides, sulphites, thiosulphate and chlorides (Russell, 2006). The mean effluent COD was between 856 mg/l and 450 mg/l respectively with a value of 569.2 mg/l [Fig 4.14]. COD can be divided into four major fractions: readily biodegradable (20%), particulate slowly biodegradable (60%), non-biodegradable (7%) and particulate non-biodegradable (13%) (Marai, 1984; in Veenstra & Polpraseert, 1997). Even though all the effluent COD values were low as compared to the influent values none met the EPA Ghana guideline value of 250 mg/l. The removal efficiency was 82%.

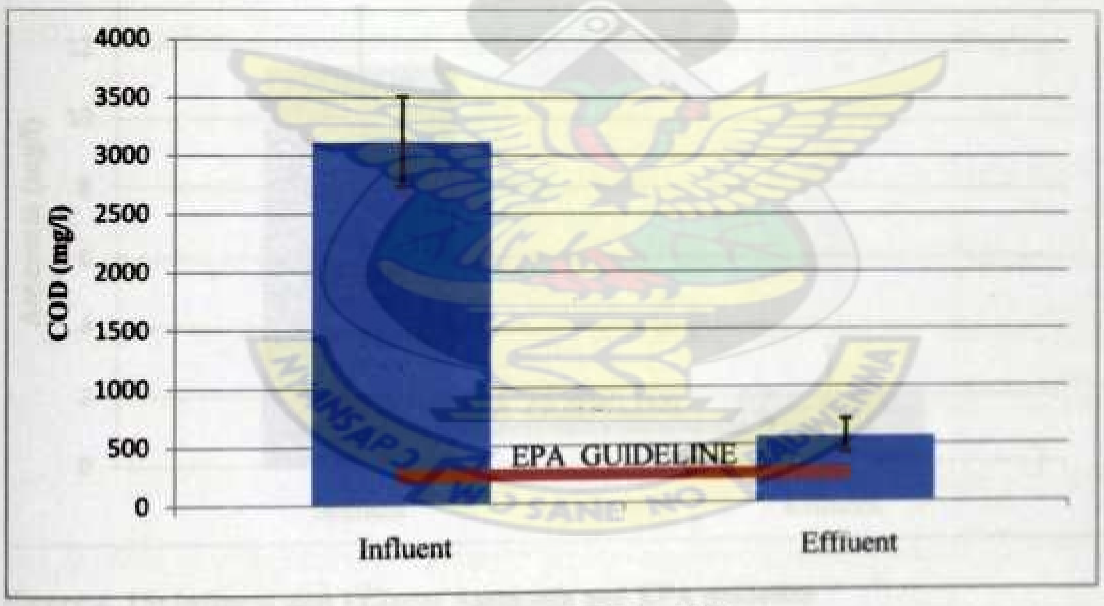


**Figure 4. 14: Influent and Effluent COD and EPA guideline**

### 4.4.11 Nutrients

The ammonia, nitrate, nitrite and the phosphate concentrations were determined to obtain an indication of nutrient content of the influent and effluent wastewater.

**4.4.11.1 Ammonia-Nitrogen ($NH_3$-N)**

Free ammonia is formed as an initial product due to the decomposition of nitrogenous organic matter. The presence of ammonia indicates that decomposition has started recently. The mean influent ammonia value ranged from 15 mg/l to 9.1 mg/l and was 11.5 mg/l. The mean effluent value was 2.1 mg/l and ranged from 2.8 mg/l to 1.7 mg/l. The initial rise in ammonia of the influent quality could be due to the reason that ammonia is a by-product of anaerobic digestion while the fall in the effluent values could be due to the stripping of ammonia with time (volatilization). The average effluent results were above EPA Ghana set guideline as shown in Figure 4.15 below. The percentage removal achieved was 82%.

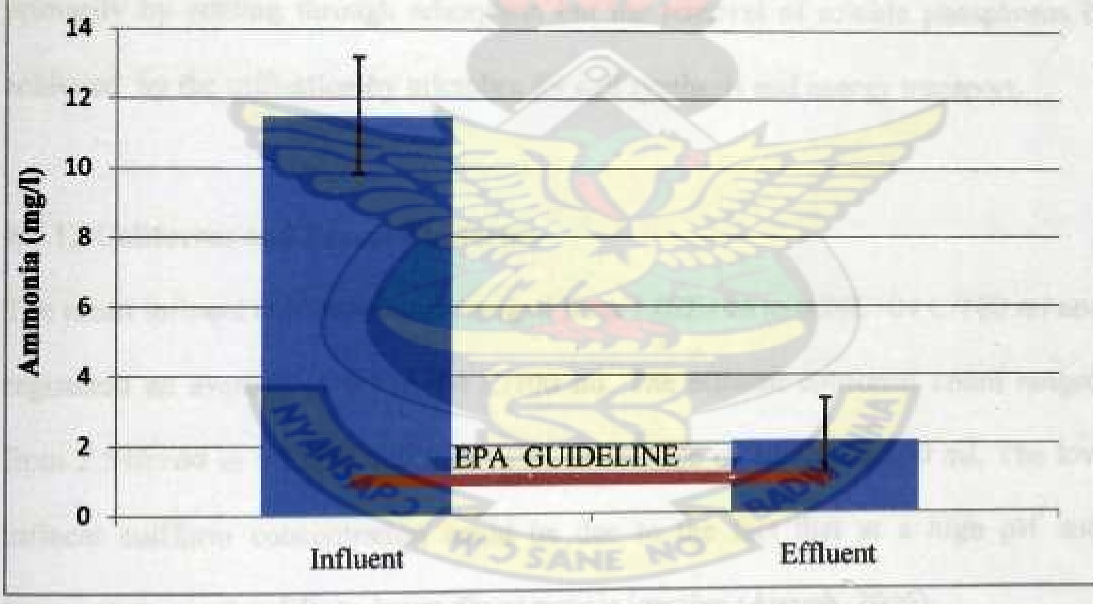


**Figure 4. 15: Influent and Effluent Ammonia and EPA guideline**

**4.4.11.2 Nitrate-Nitrogen ($NO_3$-N)**

Nitrates in water are the end product of decomposition of organic matter. This gives an indication that the organic matter is fully oxidised and is no more harmful. The mean influent nitrate concentration was 1.9 mg/l and in the range of 4.2 mg/l to 0.6

mg/l. Mean effluent nitrate concentration was in the range of 4.4 mg/l to 1.1 mg/l and was 2.1 mg/l. The concentration of both influent and effluent nitrate did not change much and were all within the EPA Ghana guideline value of 50 mg/l. This low influent and effluent nitrate concentration could be due to the denitrification by bacteria, where nitrate is converted into gaseous nitrous oxide and molecular nitrogen into the atmosphere under anaerobic conditions.

#### 4.4.11.3 Phosphate-Phosphorus ($PO_4$-P)

The mean influent phosphate concentration ranged from 6.3 mg/l to 3.98 mg/l and was 5.2 mg/l. The effluent phosphate concentration 5.6 mg/l and in the range of 6.5 mg/l to 5 mg/l. Removal of insoluble portion of phosphorus in wastewater is primarily by settling through adsorption but the removal of soluble phosphorus is achieved by the utilisation by microbes for cell synthesis and energy transport.

### 4.4.12 Coliforms and Faecal Coliforms

The mean influent coliforms count ranged from 1.02E+04 to 0.26E+04 C/100 ml and registered an average of 0.55E+04 C/100 ml. The effluent coliforms count ranged from 2.54E+04 to 0.55E+04/100 ml with an average of 1.66E+04/100 ml. The low influent coliform concentration could be due to the fact that at a high pH and temperature, most coliform group die or remain inactive (Awuah, 2006).

Although it was expected that the total number of effluent coliforms be reduced after treatment the reverse was observed. This could be due to the high organic matter content (>20 mg/l BOD) in the treatment tank which served as food for the bacteria to grow, proliferating rapidly in numbers. Again this trend may be attributed to the small number of predators in the treatment tanks to devour the bacteria or the reason that the treatment tanks have not been desludge since it working life. Figure 4.16 is a plot of the average influent and effluent coliform results and the EPA Ghana guideline.

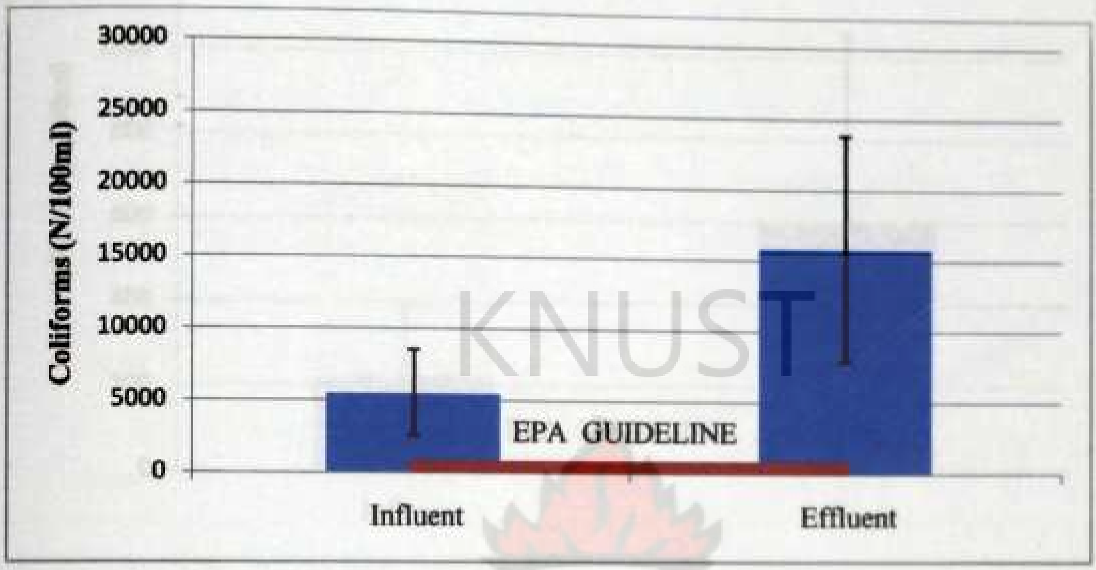


**Figure 4. 16: Influent and Effluent Coliforms and EPA guideline**

In the test to ascertain the presence of faecal coliforms, the mean influent faecal coliforms count ranged from 0.026E+04 to 0.01E+04 FC/100ml and was 0.021E+04 FC/100ml. The mean effluent faecal coliforms count ranged from 0.10E+04 to 0.01E+04 FC/100ml and was 0.06E+04 FC/100ml. Similarly for the faecal coliform count, effluent concentration recorded was higher than the influent concentration.

Again this trend could be attributed to the small number of predators in the treatment tanks to devour the bacteria and the reason that the treatments tanks have not been desludge from the time it was installed and operated. The average results for both coliforms and faecal coliforms concentrations are unacceptable and do not meet the EPA Ghana guideline of 400/100 ml and 10/100 ml respectively. Figure 4.17 is a plot of the average influent and effluent faecal coliform results and the EPA Ghana guideline.

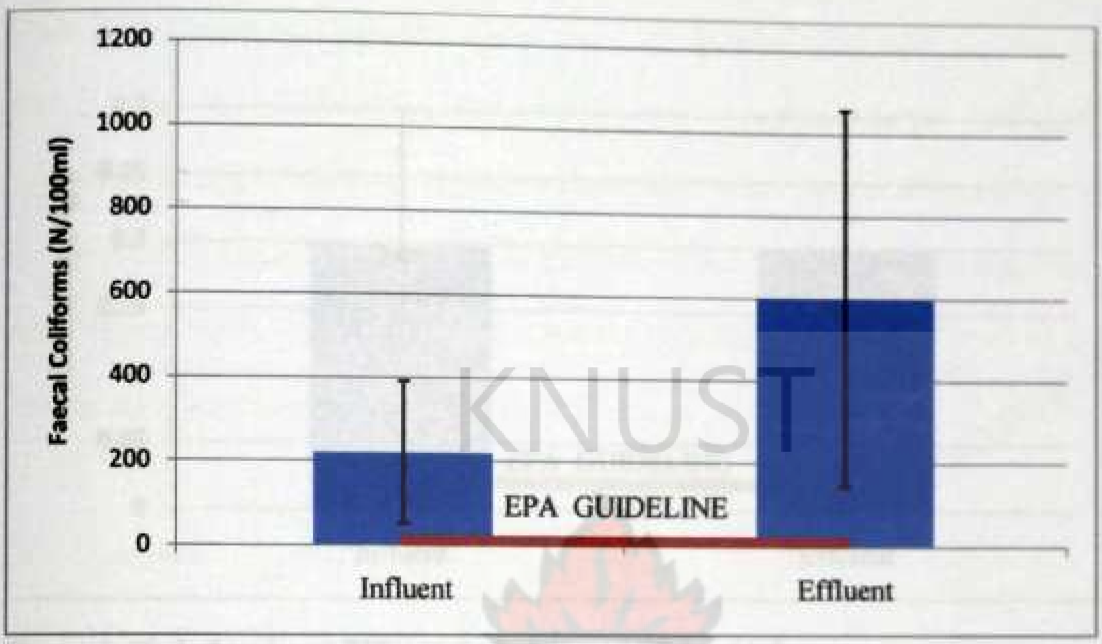


**Figure 4. 17: Influent and Effluent Faecal Coliforms and EPA guideline**

### 4.4.13 TRACE METALS

The concentrations of cadmium, lead and copper were determined to obtain the content of trace metal of both influent and the effluent wastewater and to ascertain whether they are of acceptable values.

#### 4.4.13.1 Cadmium

The mean influent cadmium concentration was 0.2 mg/l and was in the range of 0.345 mg/l to 0.123 mg/l. The effluent cadmium concentration ranged from 0.416 mg/l to 0.11 mg/l and was 0.2 mg/l [Figure 4.18]. The effluent quality is unacceptable according to EPA Ghana guideline of <0.02 mg/l. The high influent and effluent cadmium concentration could be attributed to the wearing of some components of the washer equipment which is employed to wash bottles during the bottle preparation stage of beverage production.

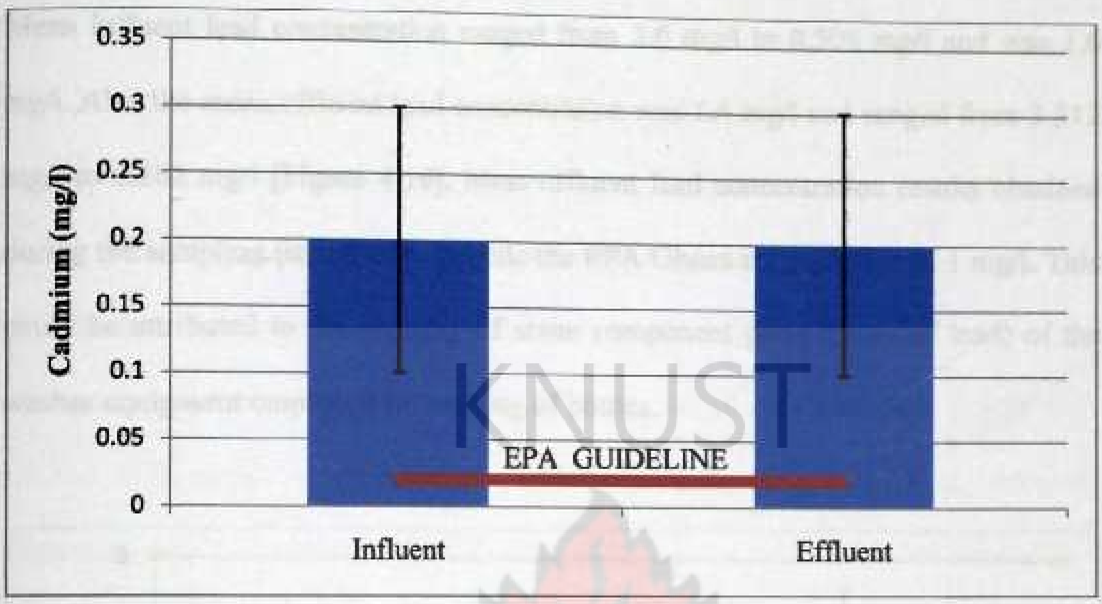


**Figure 4. 18: Influent and Effluent Cadmium and EPA guideline**

The presence of excessive amounts of cadmium will interfere with many beneficial uses of the water because of its toxicity. Therefore it is frequently desirable to measure and control the concentration of these substances (Tchobanoglous, Burton and Stensel, 2003).

### 4.4.13.2 Copper

Mean influent copper concentration ranged from 0.662 mg/l to 0.283 mg/l and was 0.4 mg/l. Similarly mean effluent copper concentration was 0.4 mg/l and ranged from 0.669 mg/l to 0.296 mg/l. Both influent and effluent copper concentration were within the EPA Ghana guideline of <1 mg/l and was satisfactory. Adsorption and chemical precipitation are mechanisms of heavy metal removal (Tchobanoglous, Burton and Stensel, 2003); hence the low copper concentration in the wastewater might be due to this form of treatment.

**4.4.13.3 Lead**

Mean influent lead concentration ranged from 2.6 mg/l to 0.508 mg/l and was 1.6 mg/l. Also the mean effluent lead concentration was 1.4 mg/l and ranged from 3.312 mg/l to 0.262 mg/l [Figure 4.19]. Most effluent lead concentration results obtained during the sampling period were outside the EPA Ghana set guideline of 1 mg/l. This could be attributed to the wearing of some component parts (made of lead) of the washer equipment employed in washing of bottles.

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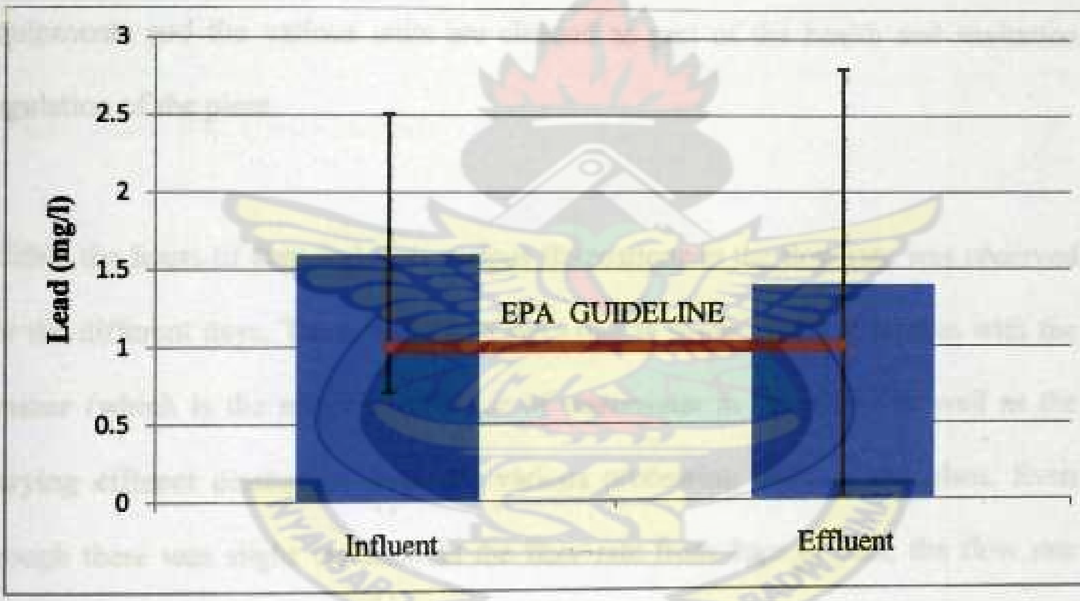


**Figure 4. 19: Influent and Effluent Lead and EPA guideline**

**4.4.14 Sulphates**

Mean influent sulphate concentration ranged from 150 mg/l to 30 mg/l and was 60.6 mg/l. Also the mean effluent sulphate concentration was 117.7 mg/l and ranged from 130 mg/l to 80 mg/l. Both influent and effluent sulphate concentration results obtained during the sampling period were in the range of EPA Ghana set guideline of

250 mg/l. The increase in the sulphate concentration of the effluent wastewater could be attributed to the dosing of sulphuric acid during the wastewater pre-treatment stage in order to bring the pH down for biological activities to be effected.

### 4.4.15 WASTEWATER FLOW RATE MEASUREMENT

The results show continuous fluctuations in the flow; this is shown in Fig 4.18 below. During the exercise period no rainfall effect was observed. The fluctuation in the wastewater flow rate during the exercise could be attributed to several factors. It was observed that the highest flow rate occurred at time 6am during each day of the exercise. This could be attributed to the reason that during that time, process equipments and the various units are cleaned as part of the health and sanitation regulation of the plant.

Within the hours of 8am and 8pm various fluctuations in the flow rate was observed for the different days. These variations were due to some technical hitches with the washer (which is the major contributor of wastewater in the plant) as well as the varying effluent discharges from the various processing units of the plant. Even though there was slight variation in the flow rate from 8pm to 5am, the flow rate remained fairly constant. The maximum, minimum and average flow rate registered during the period was 7.8 l/s, 1.8 l/s and 5.0 l/s respectively.

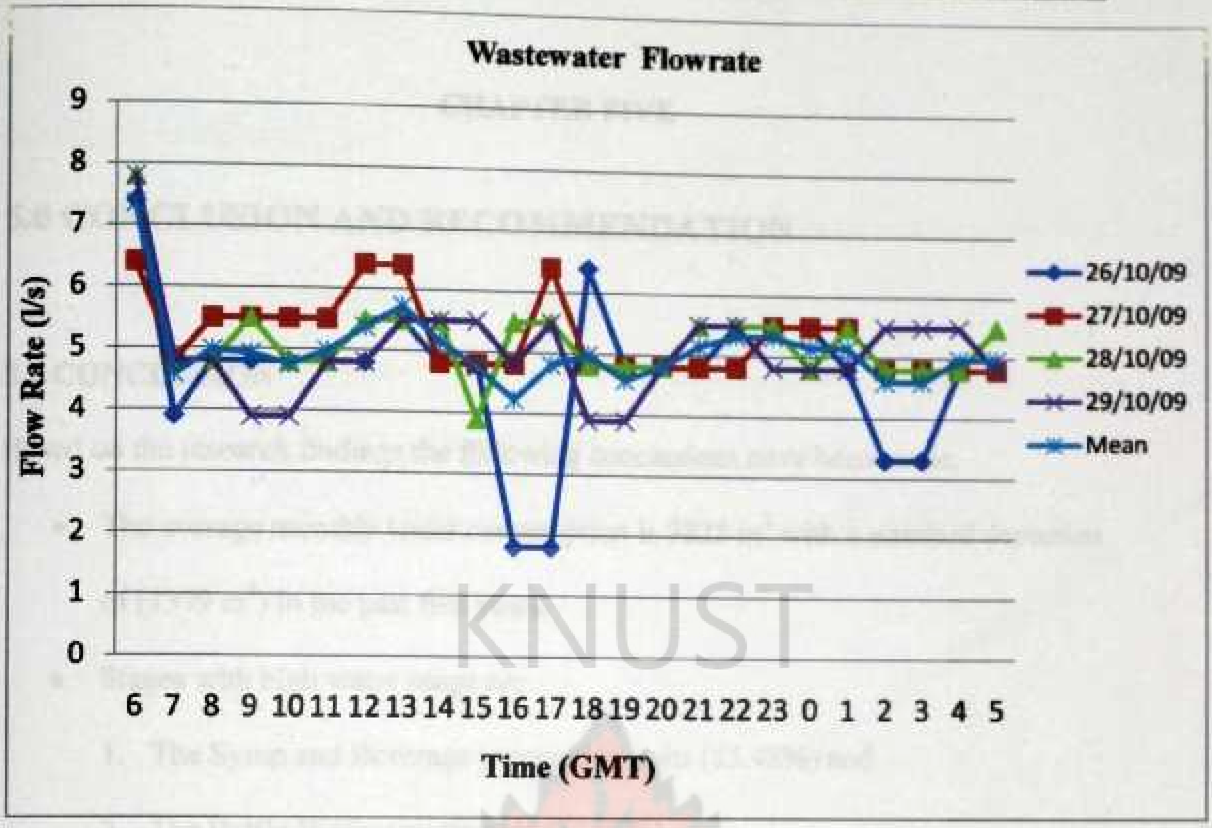


**Figure 4. 20: Wastewater flowrate**

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**CHAPTER FIVE**

# 5.0 CONCLUSION AND RECOMMENDATION

## 5.1 CONCLUSION

Based on the research findings the following conclusions have been made.

- The average monthly water consumption is 9825 $m^3$ with a standard deviation of (1399 $m^3$) in the past five years.
- Stages with high water usage are
    1. The Syrup and Beverage preparation units (55.48%) and
    2. The Bottle Washer equipment (33.95%)
- The specific water consumption of the plant is better and therefore encouraging.
- The wastewater treatment plant is efficient, however parameters such as coliforms, TSS, lead and turbidity were unsatisfactory.

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## 5.2 RECOMMENDATION

- Tanks within the treatment units may be desludge in order to improve on the effluent wastewater quality.
- A slow sand filter may be introduced after the sequential batch reactor two to improve the effluent wastewater quality.
- Disinfection of the effluent wastewater may be carried out before final discharge into the environment.

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# APPENDICES

## APPENDIX A

## ANALYTICAL METHODS

### A.1 Biochemical Oxygen Demand (BOD)

*Dilution method*

**PRINCIPLE**

BOD determination is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewaters, polluted waters and effluents. The method consists of DO determination before and after incubation for five days at 20°C. The BOD is then computed from the initial and final DO.

**PROCEDURE**

A desired quantity of sample, say 25 ml is made up to 1 litre with dilution water. This is mixed well with a mixing rod. The mixed dilution is siphoned into two BOD bottles excluding air bubbles. Initial DO of one of the bottled samples is determined and the other bottle stoppered and incubated in the dark for five days at 20°C. Incubation in the dark prevents photosynthesis action by any algae contained in the sample that might give oxygen to interfere with the BOD determination.

Calculation:

$BOD_5$ mg/l= $(D_0-D_1)/S$ where:

D0 = initial DO

D1 = final DO

S = volume of sample used

**A.2 Chemical Oxygen Demand (COD)**

***Closed tube method***

**PRINCIPLE**

Most organic matter is oxidized by boiling a mixture of chromic and silver catalyst in strong sulphuric acid. The sample is refluxed in strongly acid solution with a known excess potassium dichromate. After digestion, the remaining unreduced potassium dichromate is titrated with ferrous ammonium sulphate (FAS), using ferrion as indicator. Chloride interferences are suppressed by addition of mercuric sulphate to the reaction mixture.

**PROCEDURE**

The digestion tubes and caps are washed with 4M sulphuric acid first to prevent contamination. 10 ml of standard or sample is transferred into the digestion tube and 6 ml digestion solution added. 14 sulphuric acid is carefully run down inside the tube to form an acid layer under the sample-digestion solution layer. The tubes are tightly capped and inverted several times to mix completely. The samples are then refluxed for two hours and then cooled to room temperature. The samples are transferred to a larger container for titration. 1-2 ml ferroin indicator is added and titrated with 0.1M FAS until the colour changes from blue-green to reddish brown. Again, the procedure is repeated for the blank sample.

Calculation:

COD mg/l = (B-C)*M*8000/Vs: where

B = volume of FAS used for blank

C = volume of FAS used for sample

M = molarity of FAS

Vs = volume of sample used

**A.3 Total Suspended Solids (TSS)**

**PRINCIPLE**

Well mixed sample is filtered through a weighted standard glass-fibre filter and the residue retained on the filter is dried to a constant weight a 103 to 105°C. The increase in weight of the filter represents the total suspended solids.

Calculation

TDS mg/l = (A-B)*1000/Sample volume, ml: where

A = weight of filter + residue

B = weight of filter

**A.4 Nitrate-Nitrogen ($NO_3$-N)**

*(Cadmium Reduction Method using Powder Pillow)*

Cadmium metal reduces nitrate present in the water to nitrite. The nitrite ion reacts in an acidic medium with sulphanilic acid to form an intermediate diazonium salt. This salt couples to gentisic acid to form amber coloured product.

**Apparatus**

HACH DR/220 Portable Data Logging Spectrophotometer

**PROCEDURE**

The spectrophotometer is switched on, the programme number of 355 is entered using the Enter button. The wavelength dial is rotated until the display shows 550nm and then mg/l $NO_3$-N HR. The sample to be analyzed is well shaken and 1ml portion of it taken and diluted with to 250ml. 25 ml of the diluted sample is poured into a 25ml sample cell. The contents of one Nitra Ver 5 nitrate reagent powder pillow is added to the prepared sample in the cell and covered. The shift timer is pressed and the cell is vigorously shaken until the timer beeps after one minute. The shaking is stopped and the shift timer key pressed again for a five minute reaction period to begin. A second 25ml sample cell is filled with a portion of the diluted sample and it serves as the blank. When the five minute period is over, the timer beeps and the display show mg/l "$NO_3$-N HR". The zero button is pressed and the display shows "0.00mg/l $NO_3$-N HR". The blank is removed and the prepared sample then placed in the cell holder and the light shield closed. The "Read" button is pressed and the display shows "Reading" then $NO_3$-N results in mg/l is displayed. The actual concentration is calculated by multiplying the read value by the dilution factor.

**A.5 Phosphate- Phosphorus**

*Phos Ver (Ascorbic Acid) Method using Powder pillows*

Orthophosphate reacts with molybdate in an acidic medium to produce a phosphatemolybdate complex. Ascorbic acid then reduces the complex giving an intense blue colour.

**Apparatus**

HACH DR/2010 Portable Data Logging Spectrophotometer

**PROCEDURE**

The spectrophotometer is switched on and the programme number 490 is entered. The wave length is rotated until the display shows 890nm and then mg/l $PO_4^{3-}$ -PV. A 10 ml Cell Riser is inserted into the cell compartment. The sample to be analyzed is well shaken and 1ml portion of it is taken and diluted with distilled water to 200 or 250ml. 10ml of the sample is poured into a 10ml sample cell. The contents on one Phos Ver 3 phosphate powder pillow is added to the sample in the cell and immediately well shaken to mix. A blue colour forms if phosphate is present. The Shift Timer button is pressed and a two minute reaction period begins. A second 10ml sample cell is filled with apportion of the diluted sample which serves as a blank. When the two minute reaction is over the timer beeps and the display shows mg/l $PO_4^{3-}$ -PV. The blank is placed into the cell holder and the light shield closed. The Zero buttons is pressed to set the machine to zero for that particular sample. The blank is removed and the prepared sample put into the cell holder and the light shield closed. The Read button is pressed and the display shows the concentration of the $PO_4^{3-}$ in mg/l. Other concentrations of phosphorus, P and polyphosphate ($P_2O_5$) can also be obtained by pressing arrow buttons in turn. The actual concentration is calculated by multiplying the read value by the dilution factor which in this case is 200 or 250.

**A.6 pH**

**Apparatus**

Water proof pHScan 3+



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The apparatus measures both pH and temperature.

**PROCEDURE**

pH

The cap is removed and the ON/OFF button is pressed to switch on the tester. The electrode is then dipped to about 2 to 3cm into the test sample, stirred once and the reading allowed to stabilize.

**A.7 Conductivity**

At constant temperature, the electrical conductivity of a given wastewater is a function of its concentration of ions. The probe is sensitive to the ionic charges in the solution. A factor that controls the current carrying of the wastewater sample helps the meter provide a direct reading of the conductivity of the test sample.

**Apparatus**

Digital Tetra Con 325, cond 330i conductivity meter.

**PROCEDURE**

The conductivity of each sample is measured with Tetra Con 325 cond 330i conductivity meter. The kit has a probe connected to it which is inserted into well shaken sample and the conductivity value read on the display after the value has stabilized.

## APPENDIX B

### B.1 Calculation of Flow from weir measurement

Height of weir (P) = 20cm

Length of weir (b) = 72.5cm

Height of water above weir (H) = 2.3cm

$$Q = C_d b \sqrt{2g}\, H^{1.5}$$

Where H = height of water above the weir

Q = flow rate

Using Basen formula $C_d = 0.405 + (0.003/H)$, 2/3 in front of formula absorbed

Substituting the respective values $C_d = 0.53$

$Q = 0.53 \times 0.725 \times 4.472 \times 3.718 \times 10^{-3}$

$= 6.05 \times 10^{-3} m^3/s$

$= 6.4$ l/s

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**Table B. 1: Flow rate measurements**

| Hour | 26/10/2009 | 27/10/2009 | 28/10/2009 | 29/10/2009 | Mean |
|---|---|---|---|---|---|
| 6 | 7.4 | 6.4 | 7.8 | 7.8 | 7.4 |
| 7 | 3.9 | 4.8 | 4.8 | 4.8 | 4.6 |
| 8 | 4.8 | 5.5 | 4.8 | 4.8 | 5.0 |
| 9 | 4.8 | 5.5 | 5.5 | 3.9 | 4.9 |
| 10 | 4.8 | 5.5 | 4.8 | 3.9 | 4.8 |
| 11 | 4.8 | 5.5 | 4.8 | 4.8 | 5.0 |
| 12 | 4.8 | 6.4 | 5.5 | 4.8 | 5.4 |
| 13 | 5.5 | 6.4 | 5.5 | 5.5 | 5.7 |
| 14 | 4.8 | 4.8 | 5.5 | 5.5 | 5.2 |
| 15 | 4.8 | 4.8 | 3.9 | 5.5 | 4.8 |
| 16 | 1.8 | 4.8 | 5.5 | 4.8 | 4.2 |
| 17 | 1.8 | 6.4 | 5.5 | 5.5 | 4.8 |
| 18 | 6.4 | 4.8 | 4.8 | 3.9 | 5.0 |
| 19 | 4.8 | 4.8 | 4.8 | 3.9 | 4.6 |
| 20 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 |
| 21 | 4.8 | 4.8 | 5.5 | 5.5 | 5.2 |
| 22 | 5.5 | 4.8 | 5.5 | 5.5 | 5.3 |
| 23 | 5.5 | 5.5 | 5.5 | 4.8 | 5.3 |
| 0 | 5.5 | 5.5 | 4.8 | 4.8 | 5.2 |
| 1 | 4.8 | 5.5 | 5.5 | 4.8 | 5.2 |
| 2 | 3.3 | 4.8 | 4.8 | 5.5 | 4.6 |
| 3 | 3.3 | 4.8 | 4.8 | 5.5 | 4.6 |
| 4 | 4.8 | 4.8 | 4.8 | 5.5 | 5.0 |
| 5 | 4.8 | 4.8 | 5.5 | 4.8 | 5.0 |

**(Flowrate values in Litres/second)**

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**APPENDIX C**

**Table C. 1: EPA (Ghana) Guidelines**

| Parameter | Units | EPA Ghana Standards for discharge for Beverage Industries |
|---|---|---|
| Temp | °C | 30 |
| pH | pH Units | 6-9 |
| Conductivity | µS/cm | 750 |
| Colour | mg/l | 100 |
| TSS | mg/l | <50 |
| TDS | mg/l | <1000 |
| BOD | mg/l | <50 |
| COD | mg/l | <250 |
| Turbidity | mg/l | 75 |
| DO | mg/l | <1 |
| $NH_3$-N | mg/l | 1.0 |
| $NO_3$-N | mg/l | 50 |
| $NO_2$-N | mg/l | N/A |
| $PO_4$-P | mg/l | N/A |
| Cadmium | mg/l | <0.02 |
| Copper | mg/l | 1 |
| Lead | mg/l | <1 |
| Coliforms | N/100ml | 400 |
| F Coliforms | N/100ml | 10 |
| Sulphates | mg/l | 250 |

Source: E.P.A (GHANA) 2000

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**Table C. 2: Removal Efficiency of Wastewater Treatment Plant**

| PARAMETER | UNIT | MEAN INFLUENT | MEAN EFFLUENT | REMOVAL% |
|---|---|---|---|---|
| TEMP | °C | 48.2 | 28.8 | 40.2 |
| pH | pHUnits | 11.3 | 8.5 | - |
| CONDUCTIVITY | µS/cm | 1750.1 | 842.8 | 52 |
| SALINITY | mg/l | 49.2 | 35.5 | 28 |
| HARDNESS | mg/l | 48.2 | 36.5 | 24.3 |
| COLOUR | TCU | 77.8 | 100.0 | -29 |
| TSS | mg/l | 87.7 | 176.7 | -101.5 |
| TDS | mg/l | 862.2 | 839.8 | 2.6 |
| BOD | mg/l | 1116.8 | 49.8 | 93 |
| COD | mg/l | 3114.2 | 569.2 | 82 |
| OIL | | V.O.F | N.V.O.F | N.V.O.F |
| TURBIDITY | NTU | 46.8 | 94.8 | 51 |
| DO | mg/l | 3.6 | 5.7 | -58.3 |
| AMMONIA-N | mg/l | 11.5 | 2.1 | 82 |
| NITRATE | mg/l | 1.9 | 2.1 | -11 |
| NITRITE | mg/l | 0.0 | 0.0 | 0 |
| PHOSPHATE | mg/l | 5.2 | 5.6 | -8 |
| CADMIUM | mg/l | 0.2 | 0.2 | 0 |
| COPPER | mg/l | 0.4 | 0.4 | 0 |
| LEAD | mg/l | 1.6 | 1.4 | 12.5 |
| MAGNESIUM | mg/l | 3.1 | 1.9 | 39 |
| CALCIUM | mg/l | 14.9 | 11.0 | 4 |
| COLIFORM | N/100ml | 5466.7 | 15850 | -190 |
| F COLIFORM | N/100ml | 216.7 | 600 | -64 |
| SULPHATE | mg/l | 60.6 | 117.7 | -94 |

**Note: Negative value implies an increment in the effluent value over that of the influent.**

**Table C. 3: Results of Influent Wastewater Sampling Analysis**

| Parameter | UNIT | INF 1 | INF 2 | INF 3 | INF 4 | INF 5 | INF 6 | INF 7 | INF 8 | INF 9 | MEAN INF | STD DEVTN | STD ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | °C | 48 | 47.5 | 49 | 50 | 48 | 49 | 48 | 47 | 47 | 48.2 | 1.0 | 0.7 |
| pH | pH Units | 11.35 | 11.6 | 11.64 | 11.12 | 11.36 | 11.54 | 10.77 | 11.2 | 11.49 | 11.3 | 0.3 | 0.2 |
| Conductivity | µS/cm | 1632 | 1999 | 1999 | 1564 | 1716 | 1680 | 1709 | 1662 | 1790 | 1750.1 | 153.9 | 100.6 |
| Colour | TCU | 150 | 150 | 150 | 50 | 50 | 50 | 25 | 25 | 50 | 77.8 | 55.1 | 36.0 |
| TSS | mg/l | 44 | 50 | 44 | 113 | 132 | 144 | 60 | 67 | 135 | 87.7 | 42.5 | 27.8 |
| TDS | mg/l | 817 | 999 | 999 | 771 | 885 | 798 | 810 | 781 | 900 | 862.2 | 88.9 | 58.1 |
| BOD | mg/l | 700 | 1000 | 1500 | 1340 | 950 | 1504 | 896 | 877 | 1284 | 1116.8 | 295.0 | 192.7 |
| COD | mg/l | 3760 | 3480 | 3400 | 3040 | 2466 | 3106 | 2994 | 2780 | 3002 | 3114.2 | 386.8 | 252.7 |
| Turbidity | NTU | 39 | 39 | 47 | 47 | 44 | 52 | 47 | 57 | 49 | 46.8 | 5.8 | 3.8 |
| DO | mg/l | 4.8 | 3.2 | 3.8 | 4.4 | 3.2 | 1.8 | 4.1 | 4.2 | 2.8 | 3.6 | 0.9 | 0.6 |
| Ammonia-N | mg/l | 9.12 | 11.06 | 15 | 11.2 | 9.7 | 12.1 | 11.7 | 10.8 | 12.6 | 11.5 | 1.7 | 1.1 |
| Nitrate-N | mg/l | 2.2 | 4.2 | 3.5 | 0.6 | 1.5 | 1.9 | 0.7 | 0.7 | 1.5 | 1.9 | 1.3 | 0.8 |
| Nitrite-N | mg/l | 0.049 | 0.037 | 0.009 | 0.013 | 0.025 | 0.018 | 0.006 | 0.005 | 0.018 | 0.0 | 0.0 | 0.0 |
| Phosphate | mg/l | 4.72 | 4.68 | 3.98 | 4.9 | 6.72 | 5.91 | 5.37 | 6.3 | 4.42 | 5.2 | 0.9 | 0.6 |
| Cadmium | mg/l | 0.198 | 0.27 | 0.345 | 0.297 | 0.256 | 0.203 | 0.132 | 0.129 | 0.123 | 0.2 | 0.1 | 0.1 |
| Copper | mg/l | 0.592 | 0.662 | 0.558 | 0.289 | 0.415 | 0.439 | 0.301 | 0.283 | 0.281 | 0.4 | 0.1 | 0.1 |
| Lead | mg/l | 2.541 | 2.498 | 2.602 | 1.459 | 2.245 | 1.687 | 0.508 | 0.498 | 0.692 | 1.6 | 0.9 | 0.6 |
| Coliform | N/100ml | $1.02 \times 10^4$ | $8.8 \times 10^3$ | $9.0 \times 10^3$ | $3.7 \times 10^3$ | $3.0 \times 10^3$ | $3.2 \times 10^3$ | $3.9 \times 10^3$ | $4.8 \times 10^3$ | $2.6 \times 10^3$ | $5.5 \times 10^3$ | $3 \times 10^3$ | $2 \times 10^3$ |
| F Coliform | N/100ml | $2.6 \times 10^2$ | $1.4 \times 10^2$ | $1.5 \times 10^2$ | $6 \times 10^2$ | $1 \times 10^2$ | $2 \times 10^2$ | $1 \times 10^2$ | $3 \times 10^2$ | $1 \times 10^2$ | $2.2 \times 10^2$ | $1.69 \times 10^2$ | $1.1 \times 10^2$ |
| Sulphate | mg/l | 150 | 80 | 60 | 63 | 30 | 45 | 38 | 45 | 34 | 60.6 | 37.1 | 24.2 |



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**Table C. 4: Results of Effluent Wastewater Sampling Analysis**

| PARAMETER | UNIT | EFF1 | EFF 2 | EFF 3 | EFF 4 | EFF 5 | EFF 6 | MEAN EFF | STANDARD DEVIATION | STANDARD ERROR |
|---|---|---|---|---|---|---|---|---|---|---|
| TEMPERATURE | °C | 30 | 29 | 29 | 28 | 28 | 29 | 28.8 | 0.8 | 0.6 |
| pH | pH Units | 8.89 | 7.89 | 8.37 | 8.42 | 8.58 | 8.61 | 8.5 | 0.3 | 0.3 |
| CONDUCTIVITY | µS/cm | 918 | 923 | 880 | 780 | 756 | 800 | 842.8 | 73.2 | 58.5 |
| COLOUR | TCU | 150 | 180 | 75 | 75 | 60 | 60 | 100.0 | 51.7 | 41.3 |
| TSS | mg/l | 340 | 380 | 84 | 97 | 88 | 71 | 176.7 | 142.8 | 114.3 |
| TDS | mg/l | 918 | 923 | 729 | 802 | 816 | 851 | 839.8 | 74.1 | 59.3 |
| BOD | mg/l | 120 | 80 | 28 | 19 | 32 | 20 | 49.8 | 41.2 | 32.9 |
| COD | mg/l | 856 | 520 | 450 | 515 | 560 | 514 | 569.2 | 144.9 | 115.9 |
| TURBIDITY | NTU | 180 | 225 | 45 | 39 | 32 | 48 | 94.8 | 84.8 | 67.8 |
| DO | mg/l | 6 | 4.8 | 4.9 | 5.7 | 6.4 | 6.5 | 5.7 | 0.7 | 0.6 |
| AMMONIA-N | mg/l | 2.8 | 2.1 | 1.7 | 1.9 | 2.1 | 1.7 | 2.1 | 1.2 | 1.0 |
| NITRATE-N | mg/l | 1.5 | 1.1 | 4.4 | 2.1 | 1.1 | 2.5 | 2.1 | 1.2 | 1.0 |
| NITRITE-N | mg/l | 0.005 | 0.01 | 0.003 | 0.006 | 0.008 | 0.009 | 0.0 | 0.0 | 0.0 |
| PHOSPHATE | mg/l | 5.52 | 5.46 | 5.94 | 6.51 | 5.08 | 5 | 5.6 | 0.6 | 0.5 |
| CADMIUM | mg/l | 0.416 | 0.35 | 0.16 | 0.246 | 0.062 | 0.11 | 0.2 | 0.1 | 0.1 |
| COPPER | mg/l | 0.669 | 0.599 | 0.296 | 0.34 | 0.297 | 0.339 | 0.4 | 0.2 | 0.1 |
| LEAD | mg/l | 3.184 | 3.312 | 0.662 | 0.72 | 0.262 | 0.302 | 1.4 | 1.4 | 1.2 |
| COLIFORM | N/100ml | $2.08 \times 10^4$ | $1.90 \times 10^4$ | $1.76 \times 10^4$ | $2.54 \times 10^4$ | $0.68 \times 10^4$ | $0.55 \times 10^4$ | 15850.0 | 7971.4 | 6377.1 |
| F COLIFORM | N/100ml | $0.10 \times 10^4$ | $0.05 \times 10^4$ | $0.12 \times 10^4$ | $0.07 \times 10^4$ | $0.01 \times 10^4$ | $0.01 \times 10^4$ | 600.0 | 456.1 | 364.9 |
| SULPHATE | mg/l | 130 | 80 | 130 | 118 | 106 | 142 | 117.7 | 22.1 | 17.7 |

## APPENDIX D

*(All values in tables D.1 – D.9 are in cubic metres)*

**Table D. 1: Results of Water Consumption at the metered stages for the month of August**

| DATE | BOTTLE WASHER | BOILER HOUSE | PRODUCTION FLOOR CLEANING 1 | FLEET MAINTENANCE YARD | SYRUP & BEVERAGE PREPARATION UNITS | BATH HOUSE & WORKSHOP | $CO_2$ PLANT | CANTEEN |
|---|---|---|---|---|---|---|---|---|
| 8/1/2009 | 0 | 0 | 8 | 1 | 0 | 0 | 2 | 2 |
| 8/2/2009 | 25 | 2 | 1 | 0 | 65 | 1 | 1 | 3 |
| 8/3/2009 | 78 | 8 | 6 | 1 | 150 | 3 | 6 | 2 |
| 8/4/2009 | 114 | 10 | 11 | 1 | 181 | 2 | 26 | 2 |
| 8/5/2009 | 114 | 9 | 6 | 0 | 168 | 3 | 2 | 3 |
| 8/6/2009 | 88 | 8 | 13 | 1 | 170 | 2 | 15 | 7 |
| 8/7/2009 | 101 | 9 | 9 | 0 | 148 | 2 | 22 | 0 |
| 8/8/2009 | 15 | 2 | 0 | 3 | 30 | 2 | 8 | 1 |
| 8/9/2009 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 0 |
| 8/10/2009 | 109 | 8 | 0 | 0 | 118 | 0 | 2 | 2 |
| 8/11/2009 | 134 | 12 | 4 | 0 | 175 | 3 | 2 | 3 |
| 8/12/2009 | 144 | 12 | 6 | 0 | 195 | 3 | 3 | 3 |
| 8/13/2009 | 169 | 8 | 6 | 1 | 163 | 2 | 1 | 2 |
| 8/14/2009 | 137 | 10 | 12 | 1 | 174 | 2 | 2 | 4 |
| 8/15/2009 | 7 | 0 | 0 | 0 | 26 | 1 | 2 | 3 |
| 8/16/2009 | 19 | 4 | 0 | 0 | 33 | 2 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8/17/2009 | 141 | 10 | 4 | 1 | 130 | 1 | 3 | 2 |
| 8/18/2009 | 142 | 12 | 4 | 0 | 169 | 2 | 2 | 3 |

**Table D.1: Results of Water Consumption at the metered stages of the plant for the month of August (Continuation)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8/19/2009 | 123 | 14 | 6 | 1 | 170 | 3 | 6 | 1 |
| 8/20/2009 | 144 | 14 | 5 | 1 | 230 | 2 | 15 | 2 |
| 8/21/2009 | 155 | 14 | 8 | 0 | 224 | 2 | 16 | 2 |
| 8/22/2009 | 22 | 11 | 3 | 1 | 119 | 3 | 10 | 2 |
| 8/23/2009 | 102 | 3 | 9 | 0 | 20 | 2 | 2 | 2 |
| 8/24/2009 | 108 | 11 | 3 | 0 | 190 | 2 | 7 | 3 |
| 8/25/2009 | 143 | 13 | 4 | 1 | 241 | 0 | 6 | 1 |
| 8/26/2009 | 161 | 16 | 5 | 1 | 262 | 2 | 15 | 2 |
| 8/27/2009 | 149 | 16 | 6 | 0 | 233 | 2 | 23 | 3 |
| 8/28/2009 | 63 | 7 | 0 | 0 | 83 | 2 | 7 | 3 |
| 8/29/2009 | 7 | 0 | 0 | 0 | 12 | 1 | 0 | 2 |
| 8/30/2009 | 4 | 1 | 6 | 0 | 1 | 0 | 0 | 0 |
| 8/31/2009 | 9 | 3 | 0 | 1 | 60 | 0 | 0 | 0 |
| TOTAL | **2727** | **249** | **145** | **16** | **3940** | **55** | **206** | **65** |

**Table D. 2: Results of Water Consumption at the metered stages for the month of September**

| DATE | BOTTLE WASHER | BOILER HOUSE | PRODUCTION FLOOR CLEANING 1 | FLEET MAINTENANCE YARD | SYRUP & BEVERAGE PREPARATION UNITS | BATH HOUSE & WORSHOP | $CO_2$ PLANT | CANTEEN |
|---|---|---|---|---|---|---|---|---|
| 9/1/2009 | 99 | 6 | 0 | 1 | 72 | 1 | 1 | 1 |
| 9/2/2009 | 135 | 12 | 2 | 1 | 229 | 2 | 31 | 1 |
| 9/3/2009 | 114 | 13 | 4 | 0 | 247 | 3 | 0 | 4 |
| 9/4/2009 | 137 | 15 | 16 | 2 | 327 | 4 | 21 | 4 |
| 9/5/2009 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 |
| 9/6/2009 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9/7/2009 | 97 | 9 | 2 | 0 | 184 | 2 | 5 | 3 |
| 9/8/2009 | 105 | 10 | 7 | 1 | 198 | 3 | 29 | 1 |
| 9/9/2009 | 79 | 9 | 4 | 0 | 174 | 2 | 4 | 3 |
| 9/10/2009 | 85 | 11 | 4 | 1 | 205 | 3 | 16 | 1 |
| 9/11/2009 | 82 | 9 | 11 | 1 | 164 | 2 | 19 | 3 |
| 9/12/2009 | 0 | 0 | 4 | 1 | 10 | 2 | 4 | 1 |
| 9/13/2009 | 9 | 2 | 0 | 0 | 0 | 1 | 0 | 0 |
| 9/14/2009 | 84 | 10 | 4 | 1 | 211 | 2 | 0 | 2 |
| 9/15/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/16/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/17/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/18/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/19/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

**Table D. 2: Results of Water Consumption at the metered stages for the month of September**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9/20/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/21/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/22/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/23/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/24/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/25/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/26/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/27/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/28/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/29/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/30/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| TOTAL | 1026 | 109 | 58 | 9 | 2021 | 27 | 130 | 25 |

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**Table D. 3: Results of Water Consumption at the metered stages for the month of October**

| DATE | BOTTLE WASHER | BOILER HOUSE | PRODUCTION FLOOR CLEANING 1 | FLEET MAINTENANCE YARD | SYRUP & BEVERAGE PREPARATION UNITS | BATH HOUSE & WORK SHOP | $CO_2$ PLANT | CANTEEN |
|---|---|---|---|---|---|---|---|---|
| 10/1/2009 | 22 | 7 | 2 | 1 | 70 | 1 | 2 | 2 |
| 10/2/2009 | 59 | 10 | 2 | 0 | 137 | 1 | 3 | 3 |
| 10/3/2009 | 62 | 12 | 2 | 1 | 170 | 1 | 2 | 3 |
| 10/4/2009 | 133 | 9 | 2 | 1 | 131 | 2 | 4 | 0 |
| 10/5/2009 | 89 | 15 | 4 | 0 | 213 | 2 | 1 | 4 |
| 10/6/2009 | 126 | 14 | 3 | 1 | 253 | 2 | 0 | 2 |
| 10/7/2009 | 132 | 15 | 4 | 1 | 263 | 2 | 10 | 3 |
| 10/8/2009 | 131 | 14 | 4 | 1 | 223 | 3 | 0 | 6 |
| 10/9/2009 | 58 | 9 | 13 | 1 | 132 | 3 | 0 | 6 |
| 10/10/2009 | 69 | 10 | 0 | 0 | 134 | 1 | 0 | 3 |
| 10/11/2009 | 0 | 4 | 8 | 0 | 52 | 1 | 4 | 0 |
| 10/12/2009 | 33 | 13 | 4 | 0 | 211 | 2 | 15 | 3 |
| 10/13/2009 | 123 | 14 | 3 | 1 | 262 | 2 | 1 | 1 |
| 10/14/2009 | 96 | 14 | 6 | 1 | 210 | 3 | 41 | 2 |
| 10/15/2009 | 119 | 14 | 2 | 1 | 252 | 3 | 33 | 3 |
| 10/16/2009 | 87 | 10 | 6 | 1 | 140 | 3 | 47 | 3 |

**Table D.3: Results of Water Consumption at the metered stages for the month of October (Continuation)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10/17/2009 | 93 | 11 | 3 | 0 | 215 | 3 | 21 | 4 |
| 10/18/2009 | 9 | 2 | 0 | 0 | 16 | 1 | 0 | 0 |
| 10/19/2009 | 108 | 13 | 8 | 1 | 258 | 4 | 4 | 3 |
| 10/20/2009 | 33 | 4 | 4 | 0 | 57 | 2 | 1 | 3 |
| 10/21/2009 | 0 | 2 | 0 | 0 | 2 | 0 | 6 | 4 |
| 10/22/2009 | 9 | 3 | 1 | 1 | 12 | 4 | 17 | 2 |
| 10/23/2009 | 101 | 13 | 3 | 1 | 195 | 3 | 13 | 9 |
| 10/24/2009 | 89 | 15 | 3 | 1 | 251 | 3 | 20 | 0 |
| 10/25/2009 | 110 | 14 | 4 | 0 | 228 | 1 | 13 | 0 |
| 10/26/2009 | 128 | 14 | 5 | 1 | 245 | 3 | 20 | 0 |
| 10/27/2009 | 128 | 14 | 4 | 1 | 253 | 3 | 19 | 2 |
| 10/28/2009 | 89 | 14 | 3 | 1 | 225 | 3 | 18 | 3 |
| 10/29/2009 | 94 | 10 | 6 | 0 | 134 | 2 | 24 | 3 |
| 10/30/2009 | 92 | 16 | 14 | 1 | 226 | 5 | 0 | 7 |
| 10/31/2009 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | **2422** | **329** | **123** | **19** | **5170** | **69** | **339** | **84** |

**Table D. 4: Results of Water Consumption at the metered stages for the month of November**

| DATE | BOTTLE WASHER | BOILER HOUSE | PRODUCTION FLOOR CLEANING 1 | FLEET MAINTENANCE YARD | SYRUP & BEVERAGE PREPARATION UNITS | BATH HOUSE & WORKSHOP | $CO_2$ PLANT | CANTEEN |
|---|---|---|---|---|---|---|---|---|
| 11/1/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/2/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/3/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/4/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/5/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/6/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/7/2009 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/8/2009 | 111 | 10 | 2 | 0 | 107 | 2 | 0 | 0 |
| 11/9/2009 | 141 | 11 | 4 | 1 | 179 | 3 | 21 | 3 |
| 11/10/2009 | 164 | 13 | 4 | 0 | 224 | 3 | 5 | 3 |
| 11/11/2009 | 140 | 14 | 5 | 2 | 244 | 3 | 20 | 2 |
| 11/12/2009 | 127 | 14 | 4 | 1 | 245 | 3 | 25 | 3 |
| 11/13/2009 | 168 | 14 | 5 | 0 | 218 | 3 | 21 | 4 |
| 11/14/2009 | 171 | 14 | 6 | 1 | 233 | 3 | 15 | 3 |
| 11/15/2009 | 63 | 7 | 11 | 0 | 85 | 2 | 4 | 0 |
| 11/16/2009 | 162 | 14 | 6 | 0 | 192 | 3 | 28 | 4 |
| 11/17/2009 | 156 | 13 | 3 | 1 | 175 | 0 | 24 | 2 |
| 11/18/2009 | 182 | 14 | 5 | 1 | 283 | 2 | 20 | 3 |
| 11/19/2009 | 189 | 16 | 3 | 0 | 236 | 4 | 26 | 4 |

**Table D. 4: Results of Water Consumption at the metered stages for the month of November (Continuation)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 11/20/2009 | 184 | 13 | 4 | 1 | 263 | 3 | 32 | 2 |
| 11/21/2009 | 159 | 12 | 7 | 1 | 201 | 0 | 12 | 2 |
| 11/22/2009 | 79 | 9 | 9 | 0 | 159 | 8 | 0 | 0 |
| 11/23/2009 | 136 | 12 | 4 | 1 | 245 | 2 | 6 | 2 |
| 11/24/2009 | 202 | 10 | 7 | 1 | 160 | 5 | 4 | 3 |
| 11/25/2009 | 227 | 13 | 7 | 0 | 203 | 4 | 36 | 5 |
| 11/26/2009 | 186 | 14 | 5 | 1 | 238 | 4 | 30 | 3 |
| 11/27/2009 | 180 | 13 | 2 | 1 | 244 | 4 | 22 | 2 |
| 11/28/2009 | 171 | 15 | 9 | 1 | 250 | 3 | 23 | 3 |
| 11/29/2009 | 105 | 10 | 14 | 1 | 156 | 4 | 14 | 0 |
| 11/30/2009 | 154 | 13 | 2 | 0 | 226 | 2 | 20 | 4 |
| TOTAL | **3557** | **288** | **128** | **15** | **4766** | **70** | **408** | **57** |

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**Table D. 5: Input Water and Beverage Produced for the month of August**

| DATE | RESERVOIR 1 (M5) | RESERVOIR 2, 3a, 3b (M4) | $CO_2$ PLANT(M7) | CANTEEN (M6) | TOTAL WATER INPUT | BEVERAGE PRODUCED |
|---|---|---|---|---|---|---|
| 8/1/2009 | 27 | 29 | 2 | 3 | 61 | 0 |
| 8/2/2009 | 18 | 42 | 1 | 3 | 64 | 0 |
| 8/3/2009 | 89 | 104 | 6 | 3 | 202 | 56.68 |
| 8/4/2009 | 86 | 149 | 26 | 3 | 264 | 76.69 |
| 8/5/2009 | 92 | 145 | 2 | 3 | 242 | 72.68 |
| 8/6/2009 | 91 | 130 | 15 | 8 | 244 | 79.55 |
| 8/7/2009 | 64 | 130 | 22 | 0 | 216 | 77.52 |
| 8/8/2009 | 34 | 39 | 8 | 2 | 83 | 0 |
| 8/9/2009 | 0 | 0 | 0 | 1 | 1 | 0 |
| 8/10/2009 | 24 | 141 | 2 | 3 | 170 | 46.52 |
| 8/11/2009 | 97 | 164 | 2 | 3 | 266 | 78.73 |
| 8/12/2009 | 90 | 175 | 3 | 3 | 271 | 89.63 |
| 8/13/2009 | 87 | 203 | 1 | 3 | 294 | 75.53 |
| 8/14/2009 | 97 | 166 | 2 | 5 | 270 | 77.98 |
| 8/15/2009 | 38 | 46 | 2 | 3 | 89 | 0 |
| 8/16/2009 | 0 | 2 | 0 | 0 | 2 | 0 |
| 8/17/2009 | 70 | 155 | 3 | 3 | 231 | 76.5 |
| 8/18/2009 | 56 | 186 | 2 | 3 | 247 | 76.23 |
| 8/19/2009 | 121 | 166 | 6 | 2 | 295 | 73.71 |
| 8/20/2009 | 94 | 175 | 15 | 3 | 287 | 105.53 |

**Table D.5: Input Water and Beverage Produced for the month of August (Continuation)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 8/21/2009 | 119 | 200 | 16 | 2 | 337 | 103.88 |
| 8/22/2009 | 60 | 130 | 10 | 3 | 203 | 16.49 |
| 8/23/2009 | 41 | 31 | 2 | 2 | 76 | 0 |
| 8/24/2009 | 85 | 138 | 7 | 3 | 233 | 78.83 |
| 8/25/2009 | 114 | 217 | 6 | 2 | 339 | 112.98 |
| 8/26/2009 | 28 | 301 | 15 | 3 | 347 | 118.97 |
| 8/27/2009 | 0 | 254 | 23 | 3 | 280 | 102.97 |
| 8/28/2009 | 29 | 194 | 7 | 3 | 233 | 32.61 |
| 8/29/2009 | 0 | 8 | 0 | 2 | 10 | 0 |
| 8/30/2009 | 0 | 7 | 0 | 0 | 7 | 0 |
| 8/31/2009 | 37 | 48 | 0 | 0 | 87 | 24.05 |

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**Table D. 6: Input Water and Beverage Produced for the month of September**

| DATE | RESERVOIR 1 (M5) | RESERVOIR 2, 3a, 3b (M4) | $CO_2$ PLANT(M7) | CANTEEN (M6) | TOTAL WATER INPUT | BEVERAGE PRODUCED |
|---|---|---|---|---|---|---|
| 9/1/2009 | 36 | 121 | 1 | 2 | 160 | 0 |
| 9/2/2009 | 134 | 182 | 31 | 2 | 349 | 128.02 |
| 9/3/2009 | 0 | 366 | 0 | 4 | 370 | 114.7 |
| 9/4/2009 | 128 | 207 | 21 | 6 | 362 | 127.1 |
| 9/5/2009 | 0 | 0 | 0 | 1 | 1 | 0 |
| 9/6/2009 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9/7/2009 | 95 | 143 | 5 | 3 | 246 | 70.66 |
| 9/8/2009 | 111 | 148 | 29 | 2 | 290 | 76 |
| 9/9/2009 | 85 | 126 | 4 | 3 | 218 | 78.15 |
| 9/10/2009 | 91 | 120 | 16 | 2 | 229 | 71.41 |
| 9/11/2009 | 58 | 153 | 19 | 4 | 234 | 59.24 |
| 9/12/2009 | 0 | 13 | 4 | 2 | 19 | 0 |
| 9/13/2009 | 0 | 17 | 0 | 0 | 17 | 0 |
| 9/14/2009 | 95 | 130 | 0 | 3 | 228 | 106.01 |
| 9/15/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/16/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/17/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/18/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/19/2009 | N/A | N/A | N/A | N/A | N/A | N/A |

**Table D. 6: Input Water and Beverage Produced for the month of September (Continuation)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 9/20/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/21/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/22/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/23/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/24/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/25/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/26/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/27/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/28/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/29/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 9/30/2009 | N/A | N/A | N/A | N/A | N/A | N/A |

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**Table D. 7: Input Water and Beverage Produced for the month of October**

| DATE | RESERVOIR 1 (M5) | RESERVOIR 2, 3a, 3b (M4) | $CO_2$ PLANT(M7) | CANTEEN (M6) | TOTAL | BEVERAGE PRODUCED |
|---|---|---|---|---|---|---|
| 10/1/2009 | 22 | 158 | 2 | 3 | 185 | 39.22 |
| 10/2/2009 | 59 | 186 | 3 | 3 | 251 | 59.23 |
| 10/3/2009 | 62 | 221 | 2 | 4 | 289 | 66.46 |
| 10/4/2009 | 133 | 151 | 4 | 0 | 288 | 89.5 |
| 10/5/2009 | 89 | 274 | 1 | 4 | 368 | 118.02 |
| 10/6/2009 | 126 | 307 | 0 | 3 | 436 | 115.5 |
| 10/7/2009 | 132 | 306 | 10 | 4 | 452 | 127.01 |
| 10/8/2009 | 131 | 342 | 0 | 7 | 480 | 101.73 |
| 10/9/2009 | 58 | 173 | 0 | 7 | 238 | 54.19 |
| 10/10/2009 | 69 | 153 | 0 | 3 | 225 | 94 |
| 10/11/2009 | 0 | 69 | 4 | 0 | 73 | 0 |
| 10/12/2009 | 33 | 388 | 15 | 3 | 439 | 125.13 |
| 10/13/2009 | 123 | 374 | 1 | 2 | 500 | 117.37 |
| 10/14/2009 | 96 | 300 | 41 | 3 | 440 | 125.31 |
| 10/15/2009 | 119 | 258 | 33 | 4 | 414 | 134.11 |
| 10/16/2009 | 87 | 124 | 47 | 4 | 262 | 92.88 |
| 10/17/2009 | 93 | 141 | 21 | 4 | 259 | 94.17 |
| 10/18/2009 | 9 | 28 | 0 | 0 | 37 | 0 |
| 10/19/2009 | 108 | 176 | 4 | 4 | 292 | 114.99 |
| 10/20/2009 | 33 | 66 | 1 | 3 | 103 | 24.05 |
| 10/21/2009 | 0 | 7 | 6 | 4 | 17 | 0 |

**Table D. 7 Input Water and Beverage Produced for the month of October (Continuation)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 10/22/2009 | 9 | 33 | 17 | 3 | 62 | 0 |
| 10/23/2009 | 101 | 221 | 13 | 10 | 345 | 117.51 |
| 10/24/2009 | 89 | 276 | 20 | 0 | 385 | 123.48 |
| 10/25/2009 | 110 | 186 | 13 | 0 | 309 | 93.96 |
| 10/26/2009 | 128 | 243 | 20 | 1 | 392 | 102.6 |
| 10/27/2009 | 128 | 248 | 19 | 3 | 398 | 117.63 |
| 10/28/2009 | 89 | 193 | 18 | 4 | 304 | 104.48 |
| 10/29/2009 | 94 | 127 | 24 | 3 | 248 | 58.8 |
| 10/30/2009 | 92 | 195 | 0 | 8 | 295 | 100.34 |
| 10/31/2009 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Table D. 8: Input Water and Beverage Produced for the month of November**

| DATE | RESERVOIR 1 (M5) | RESERVOIR 2, 3a, 3b (M4) | $CO_2$ PLANT(M7) | CANTEEN (M6) | TOTAL | BEVERAGE PRODUCED |
|---|---|---|---|---|---|---|
| 11/1/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/2/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/3/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/4/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/5/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/6/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/7/2009 | N/A | N/A | N/A | N/A | N/A | N/A |
| 11/8/2009 | 58 | 136 | 0 | 0 | 194 | 77.32 |
| 11/9/2009 | 96 | 163 | 21 | 4 | 284 | 54.61 |
| 11/10/2009 | 122 | 247 | 5 | 3 | 377 | 88.8 |
| 11/11/2009 | 114 | 175 | 20 | 4 | 313 | 59.2 |
| 11/12/2009 | 92 | 186 | 25 | 4 | 307 | 119 |
| 11/13/2009 | 124 | 184 | 21 | 4 | 333 | 106.51 |
| 11/14/2009 | 90 | 216 | 15 | 4 | 325 | 95.64 |
| 11/15/2009 | 51 | 92 | 4 | 0 | 147 | 30.2 |
| 11/16/2009 | 84 | 205 | 28 | 4 | 321 | 88.91 |
| 11/17/2009 | 93 | 179 | 24 | 3 | 299 | 78.8 |
| 11/18/2009 | 118 | 222 | 20 | 4 | 364 | 105.17 |
| 11/19/2009 | 119 | 235 | 26 | 4 | 384 | 121.1 |
| 11/20/2009 | 125 | 217 | 32 | 3 | 377 | 119.02 |
| 11/21/2009 | 112 | 184 | 12 | 3 | 311 | 101.67 |

**Table D.8: Input Water and Beverage Produced for the month of November (Continuation)**

| | | | | | | |
|---|---|---|---|---|---|---|
| 11/22/2009 | 87 | 114 | 0 | 0 | 201 | 63 |
| 11/23/2009 | 116 | 170 | 6 | 3 | 295 | 110.85 |
| 11/24/2009 | 0 | 277 | 4 | 4 | 285 | 66.87 |
| 11/25/2009 | 88 | 359 | 36 | 5 | 488 | 87.02 |
| 11/26/2009 | 95 | 257 | 30 | 4 | 386 | 110.73 |
| 11/27/2009 | 108 | 226 | 22 | 3 | 359 | 113.4 |
| 11/28/2009 | 82 | 216 | 23 | 4 | 325 | 115.78 |
| 11/29/2009 | 79 | 169 | 14 | 1 | 263 | 51.12 |
| 11/30/2009 | 111 | 187 | 20 | 4 | 322 | 95.56 |

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**Table D. 9: Monthly Water Consumption data for the period 2005-2009**

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | NOV | DEC | AVERAGE | STANDARD DEVIATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | 11070 | 9879 | 9058 | 10279 | 11213 | 10260 | 6102 | 8596 | 6800 | 7532 | 13567 | 13052 | 9784 | 2309 |
| **2006** | 10847 | 11197 | 11019 | 14532 | 14839 | 14511 | 8349 | 14416 | 10234 | 14485 | 13235 | 11705 | 12447 | 2161 |
| **2007** | 12880 | 10387 | 10722 | 11827 | 11256 | 9978 | 7268 | 8222 | 8194 | 8359 | 8236 | 11924 | 9938 | 1840 |
| **2008** | 10897 | 11018 | 9753 | 10296 | 12501 | 11473 | 8289 | 11133 | 7483 | 8477 | 9107 | 8778 | 9934 | 1523 |
| **2009** | 9621 | 8637 | 6583 | 7335 | 9195 | 7691 | 6246 | 6685 | 6644 | 4801 | 7140 | 6945 | 7294 | 1340 |
| **AVERAGE** | **11063** | **10226** | **9427** | **10854** | **11801** | **10783** | **7251** | **9810** | **7871** | **8731** | **10257** | **10481** | **9825** | **1399** |

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**Table D. 10: Weekly Specific Water Consumption values**

| WEEK NO. | SPECIFIC WATER CONSUMPTION(m3)/(m3) |
|---|---|
| 1 | 3.8 |
| 2 | 3.7 |
| 3 | 3.5 |
| 4 | 3.4 |
| 5 | 3.4 |
| 6 | 3.5 |
| 7 | 3.6 |
| 8 | 3.5 |
| 9 | 3.4 |
| 10 | 3.4 |
| 11 | 3.5 |
| 12 | 3.4 |
| Plant Standard | 4 |

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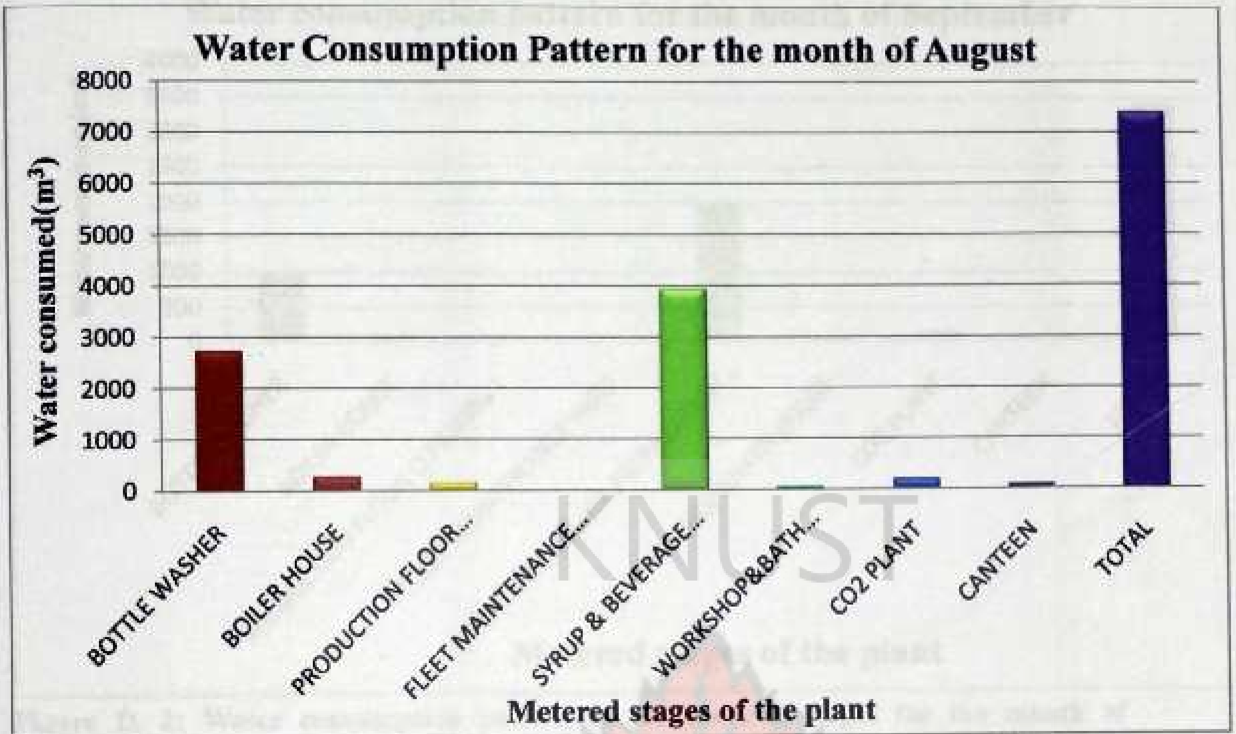


**Figure D. 1: Water consumption pattern at the metered stages for the month of August**

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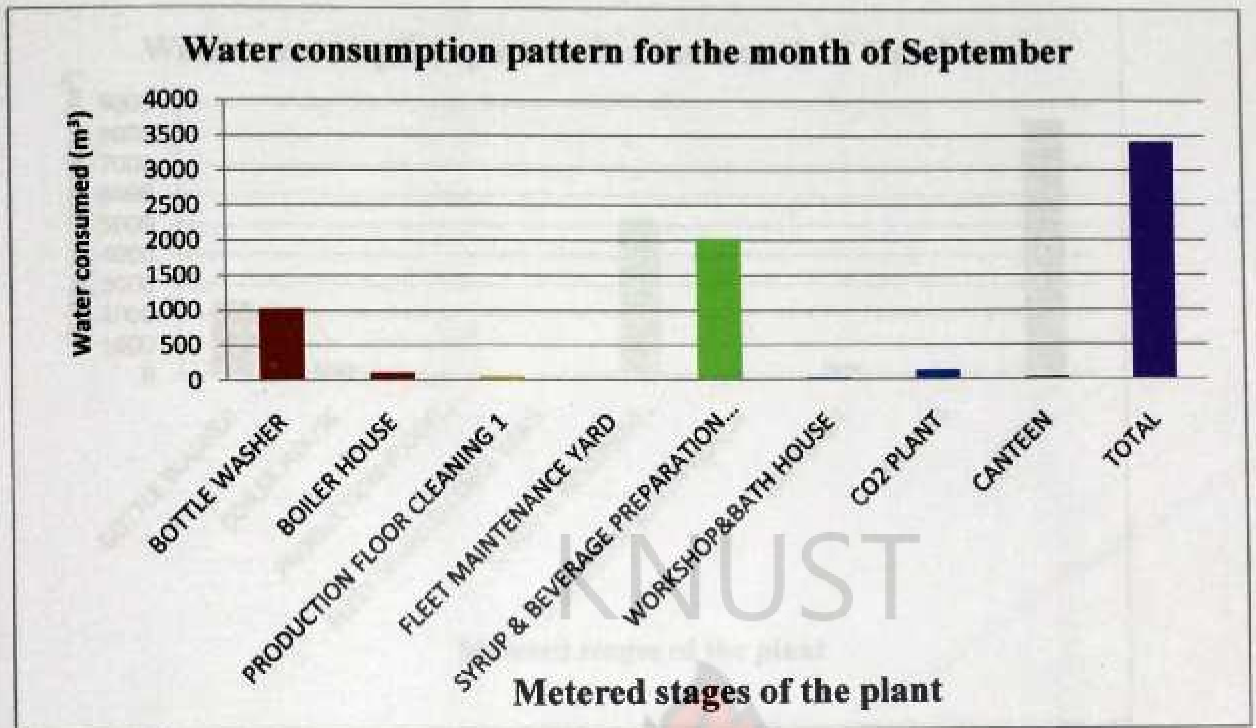


**Figure D. 2: Water consumption pattern at the metered stages for the month of September**

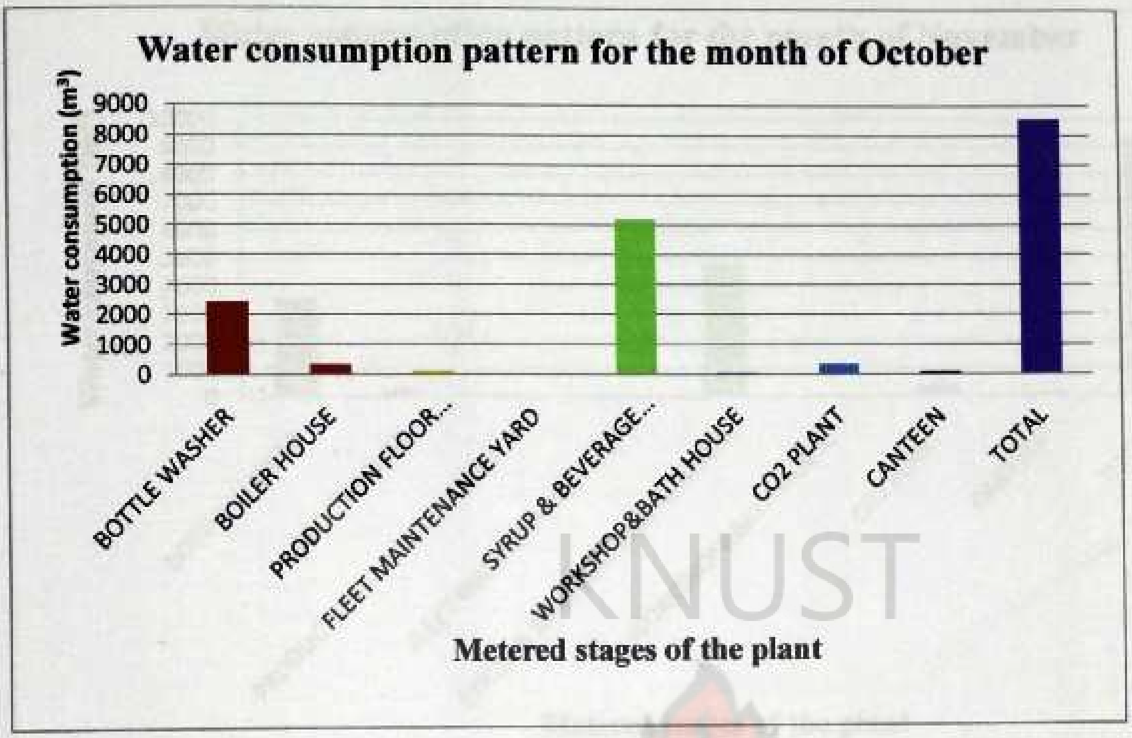


**Figure D. 3: Water consumption pattern at the metered stages for the month of October**

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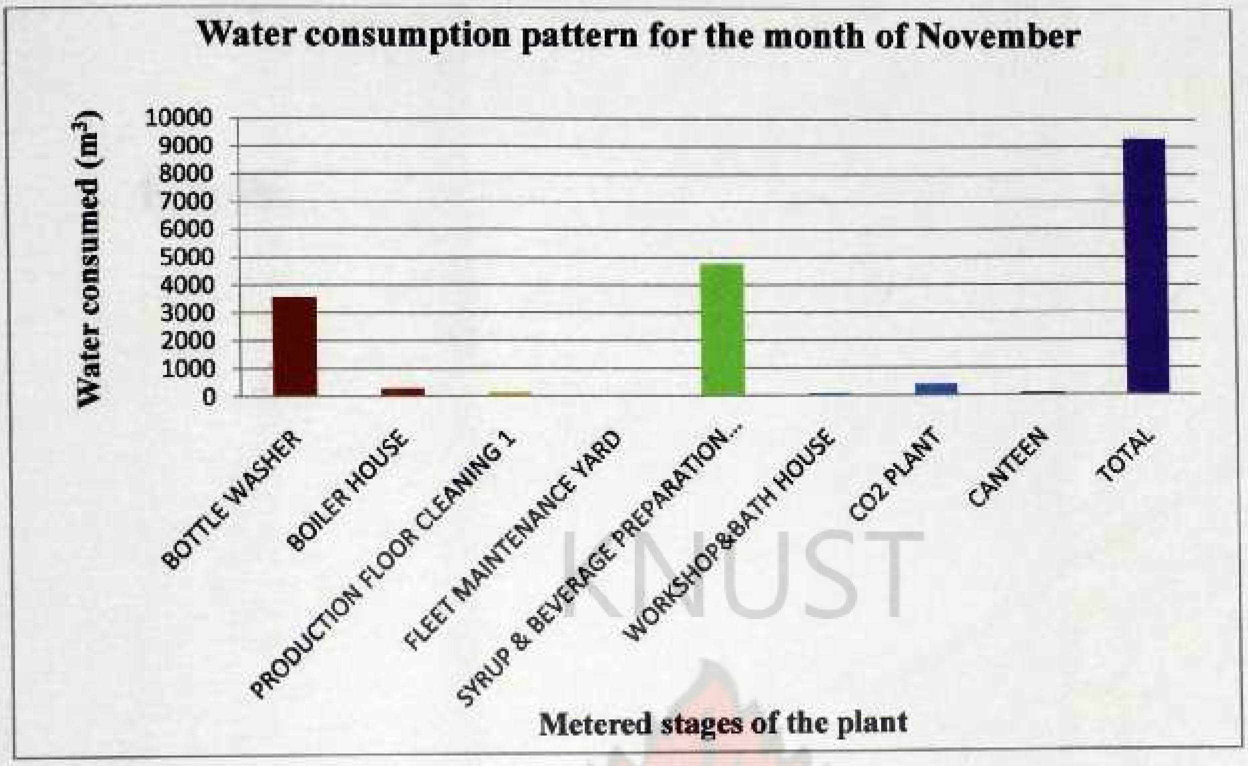


**Figure D. 4: Water consumption pattern at the metered stages for the month of November**

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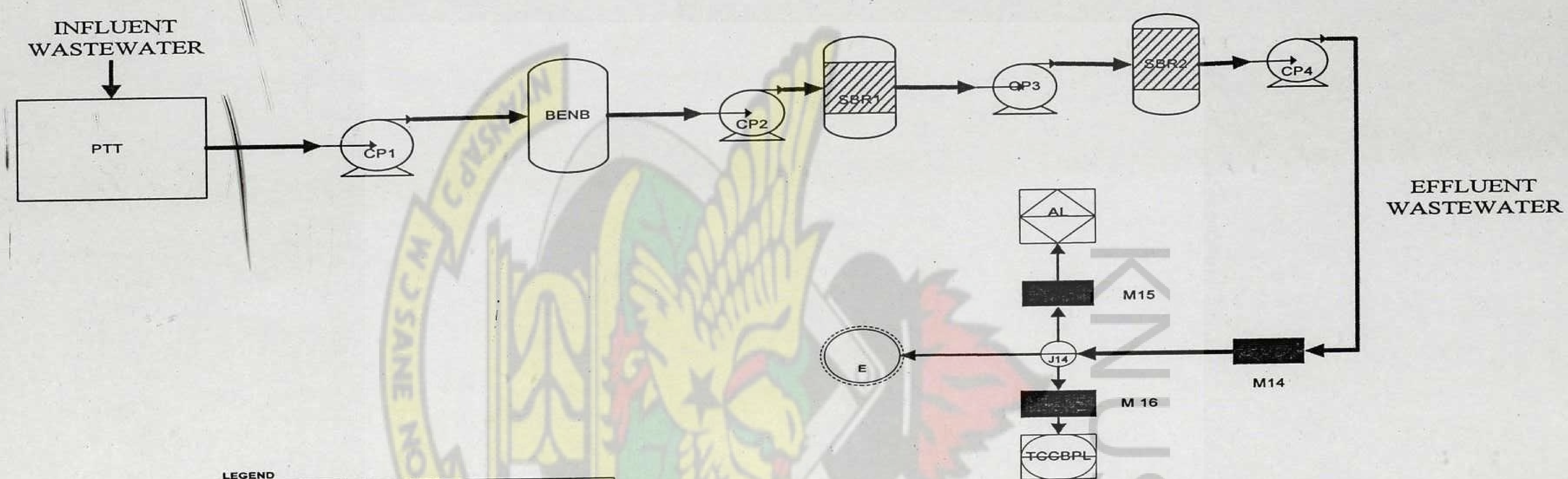
**E.2:** Process flowsheet for the treatment of wastewater in the plant.




LEGEND

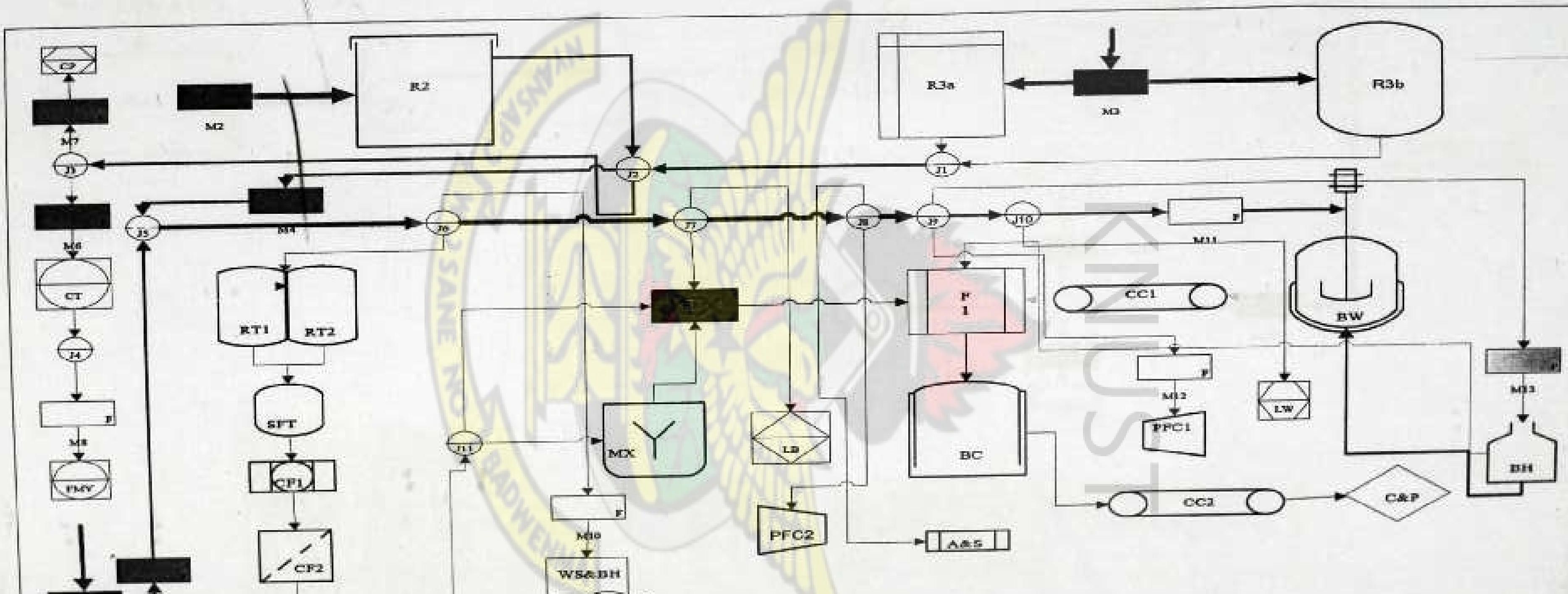
| NO | LETTER | DESCRIPTION |
|---|---|---|
| 1 | PTT | Pre- Treatment Tank |
| 2 | CP1 | Centrifugal Pump 1 |
| 3 | CP2 | Centrifugal Pump 2 |
| 4 | CP3 | Centrifugal Pump 3 |
| 5 | CP4 | Centrifugal Pump 4 |
| 6 | BENB | Balancing, Equalizing, Neutralization, Basin |
| 7 | SBR1 | Sequential Batch Reactor One |
| 8 | SBR2 | Sequential Batch Reactor Two |
| 9 | AL | Ahinsan Lavatory |
| 10 | E | Environment |
| 11 | TCCBPL | The Coca- Cola Bottling Plant Lavatory |
| 12 | M14 | Meter Fourteen |
| 13 | M15 | Meter Fifteen |
| 14 | M16 | Meter Sixteen |
| 15 | J 14 | Junction 14 |

| | |
|---|---|
| KNUST<br>COLLEGE OF ENGINEERING<br>DEPARTMENT OF CIVIL ENGINEERING | TITLE: PROCESS FLOW SHEET OF THE WASTEWATER TREATMENT PLANT |
| | DRAWN BY: OKOH AGYEMANG EMMANUEL |
| | SUPERVISED BY: PROF MRS. ESI AWUAH AND DR. LAWRENCE DARKWAH |
| | DATE: IST NOVEMBER 2009 |
| | SCALE: NOT DRAWN TO SCALE |

**SHEET TWO**

## APPENDIX E

**E.1:** Process flowsheet for the production of beverage at the plant.




LEGEND

| NO | LETTER | DESCRIPTION | QUANTITY |
|---|---|---|---|
| 1 | R | Reservoir | 4 |
| 2 | RT | Reaction tank | 2 |
| 3 | SFT | Sand Filter Tank | 1 |
| 4 | PF | Polished Filter | 1 |
| 5 | CP | $CO_2$ Unit | 1 |
| 6 | FM | Famb/ Blender | 1 |
| 7 | MX | Mixer | 1 |
| 8 | F1 | Filler | 1 |
| 9 | BC | Bottle Crowner | 1 |
| 10 | CC1 | Chain Conveyor | 2 |
| 11 | C&P | Coding & Packing | 1 |
| 12 | CF | Carbon Filter | 2 |

| NO | LETTER | DESCRIPTION | QUANTITY |
|---|---|---|---|
| 13 | BW | Bottle Washer | 1 |
| 14 | TWP | Treated Water Produced | 1 |
| 15 | CT | Canteen | 1 |
| 16 | FMY | Fleet Maintenance Yard | 1 |
| 17 | WS&B | Workshop and Bath House | 1 |
| 18 | LB | Laboratory | 1 |
| 19 | A & SO | Administration and sales office | 1 |
| 20 | PFCT | Production Floor Cleaning Tap | 2 |
| 21 | BH | Boiler House | 1 |
| 22 | LW | Lubricating Water | 1 |
| 23 | M | Meter | 13 |
| 24 | J | Junction | 13 |

| KNUST COLLEGE OF ENGINEERING DEPARTMENT OF CIVIL ENGINEERING | |
|---|---|
| TITLE: | PROCESS FLOW SHEET FOR THE PRODUCTION OF BEVERAGE AT THE PLANT |
| DRAWN BY: | OKOH AGYEMANG EMMANUEL |
| SUPERVISED BY: | PROF MRS ESI AWUAH<br>DR. LAWRENCE DARKWAH |
| DATE: | IST NOVEMBER 2009 |
| SCALE: | NOT DRAWN TO SCALE |

**SHEET ONE**