EVALUATION OF WASTEWATER MANAGEMENT SYSTEMS IN ABUJA FOR SUSTAINABILITY AND DEVELOPMENT OF APPROPRIATE ENGINEERING STRATEGY

EMMANUEL ABIODUN OLUWADAMISI
MATRIC NO: 131547

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BY

EMMANUEL ABIODUN OLUWADAMISI
MATRIC No. 131547

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DEDICATION

This work is dedicated to my wife, Barrister (Mrs.) Helen Oluwadamisi and my children Joshua, Caleb, Gloria and Tobi Oluwadamisi for their understanding and love throughout the period of this academic pursuit. All Glory belongs to God, the Giver of life and Author of knowledge.

ABSTRACT

Environmental pollution due to improperly managed wastewater has been a major challenge and of public health concern in Nigeria. Not many studies related to wastewater management have been carried out in Nigeria, hence the paucity of data on wastewater management in the country. The Wastewater Treatment Plants (WTP) in Nigeria's capital city, Abuja are presently performing below capacity due to several problems. The aim of this study was to evaluate the wastewater management system for Abuja and develop an engineering strategy to improve it.

Six WTPs at Wuye lagoon, Gudu, Niger, Lungi, Mogadishu barracks and Sheraton were assessed in comparison with the existing wastewater Master Plan of Abuja. The sites were visited along with their sewer lines and manholes to assess their structural and environmental engineering adequacy. Influent and effluent samples were collected weekly from these plants at peak period in the morning hours (6.00 – 7.00am) in triplicates over six months period from October 2007 to March 2008. These samples were analyzed for quality parameters such as 5-Day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), nitrate, nitrite, sulphate, chloride, phosphate, and microbial content. Data were further analysed using ANOVA at p= 0.05. Based on the evaluation, a suitable wastewater treatment plant was designed.

These WTPs are mini activated sludge treatment plants with submersible mechanical aerators. Wuye lagoon has a capacity of 50,000 Population Equivalent (PE). Gudu, Lungi and Mogadishu barracks have 6000 PE each while Niger and Sheraton have 3000 PE each. Average reduction of BOD_5 of 6±50.2%, 4±25.8%, 30±0.8%, 10.2±0.2%, 10.8±24.9% and 5±39.6% were observed for Wuye lagoon, Gudu, Mogadishu, Niger, Lungi and Sheraton respectively. For other evaluated parameters, average reduction in COD, nitrate, sulphate, chloride, phosphate and microbial quality were 7.8±12.4%, 13.1±4%, 13.5±65.4%, 21.5±89.8%, 10.1±8.4% and

48±87.9% respectively. Sludge treatments significantly affect the physico-chemical parameters. No regular aeration was carried out in the plants. In the satellite towns of Gwagwalada, Kuje, Kubwa and Nyanya, there were no sewer facilities, hence septic tanks and soak-away pits were constructed to handle the generated wastewater which is contrary to the provisions of Abuja Master Plan. Non-biodegradable substances such as nylon and plastics were observed in manholes. Discharge of evacuated septic sludge into sewer lines was the practice. A wastewater treatment plant combining both natural and electromechanical system was designed (Design flow of 2070 m^3/d, BOD_5 of 517Kg/day and Suspended Solids of 517.5kgSS/day). The treatment plant using water hyacinth yielded nutrient removal of about 70.0% when power is not available and enhanced treatment of up to 99.0% BOD removal when power is available.

The designed wastewater treatment plant using appropriate engineering strategy was adequate and capable of solving the wastewater management problems of Abuja. The design would be useful in other major cities in Nigeria.

Keywords: - Wastewater, Treatment plants, Management, Influent, Effluent, Sewer lines

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I have always loved Civil Engineering and Project Management until I travelled to the Netherlands to study Sanitary and Environmental Engineering at the International Institute for Hydraulic and Environmental Engineering (IHE), Delft in 1995 where I was exposed to global environmental challenges and the need for manpower development in water and waste water management. My contact with Professor D. D. Mara of Department of Civil Engineering, University of Leeds, UK who lectured me in Waste Water Engineering challenged and encouraged my interest in this area. I commend the great sacrifice and interest of Professor Mara in this unique field of Engineering. My other supervisors during my studies at Delft such as Professors Veenstra and Trifunovic are all appreciated. I wish to sincerely appreciate all lecturers of Civil Engineering Department, University of Ibadan for their tremendous contributions to this work especially during myseminar presentations. Particularly, I wish to acknowledge with thanks contributions of Professor. A. O. Agbede, Dr. B. I. O. Dahunsi and Dr. F. A. Olutoge as well as Professor A. Y. Sangodoyin of the Department of Agricultural and Environmental Engineering, University of Ibadan.

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Oluwadamisi, E. A.
University of Ibadan, Nigeria

CERTIFICATION

This is to certify that this study was carried out by Engr. Emmanuel Abiodun Oluwadamisi (Matric No. 131547) in the Department of Civil Engineering, University of Ibadan, Ibadan Nigeria under our supervision.

Supervisors:

--- Date: ....

Prof. A. O. Coker

BSc.(Ibadan), MSc.(OAU, Ife), Ph.D.(Ibadan), MNSE, COREN Reg. Engr.
Professor of Water Resources and Environmental Health Engineering,
Department of Civil Engineering, Faculty of Technology,
University of Ibadan, Ibadan, Nigeria

--- Date: ....

Prof. M.K.C. Sridhar

BSc.(Andhra), MSc (Baroda), PhD (IISC)
Professor of Environmental Health Sciences,
Department of Environmental Health Sciences,
Faculty of Public Health, College of Medicine,
University of Ibadan, Ibadan, Nigeria

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Environmental pollution from waste generated by human activities has been a major problem and challenge to environmental engineers all over the world. Accordingly, METCALF and EDDY (1991) observed that wastewater collected from municipalities and communities must ultimately be returned to receiving water bodies or the land. Thus, to achieve this without polluting the environment, adequate treatment to remove contaminants from the wastewater is necessary. Wastewater, if untreated and allowed to accumulate, undergoes decomposition of its organic materials which lead to production of large quantities of malodorous gases.

Similarly, untreated wastewater usually contains numerous pathogenic or disease-causing micro-organisms that dwell in the human intestinal tract. These pathogenic micro-organisms if not properly eliminated can lead to transmission of diseases sometimes at an epidemic level. It is therefore clear that a relationship exists between uncontrolled wastewater disposal by man and the occurrence of water-borne diseases. To avoid environmental pollution and transmission of diseases, adequate provision was made in the development of Abuja Master Plan by proposing the central sewerage system with sewage treatment plants at the five different drainage basins within the Federal Capital Territory (FCT).

Horan (1990) observed that water courses utilized by man either as a source of potable water or for washings/bathing would present potential risks if not well protected. To ensure that problems are avoided or minimized, attention should be given to the management of aquatic resources and also of the pollutants which enter the receiving waters. A sensible management strategy will inevitably involve the determination of wastewater characteristics, method of collection, subsequent treatment systems, and the quality of effluents discharged to the environment.

Domestic wastewater generated from households seems to be the closest form of waste to man; and this also happens to be the major form of wastewater in Abuja. Although industrial areas exist within the districts of the new Federal Capital Territory, the city is mainly an administrative Capital City of Nigeria.

1.1.1 **Federal Capital Territory – Abuja**

Abuja was created as the New Federal Capital Territory of Nigeria in 1976 after a committee on the location of the Federal Capital of Nigeria carried out an extensive examination of the dual government role of Lagos, its suitability as a National Capital and the possibility of an alternative New Capital City elsewhere in the country accessible to all and spacious.

The option of a new Capital City centrally located was considered and the site selected was an 8000 Km^2 area centrally located within Nigeria and easily accessible by all the states of the Federation. Since Abuja was not an existing city, development started immediately after its status was clearly defined by the 1976 FCT Federal Government Decree.

The master plan for Abuja, the Federal Capital Territory (FCT) was then developed by International Planning Associates (IPA), a consortium of three American firms: Planning Research Corporation; Wallace, McHarg, Roberts and Todd; and Archi-systems, a division of the Hughes Organization. The master plan defined the general structure and major design elements of the city that are visible in the city's current form. More detailed design of the central areas of the capital, particularly its monumental core, was accomplished by Kenzo Tange, a renowned Japanese architect, with his team of city planners at Kenzo Tange and Urtec Company. Most countries then commence relocation of their embassies to Abuja, and many maintain their former embassies as consulates in Lagos. Abuja is currently the headquarters of the Economic Community of West African States (ECOWAS).

The geography of Nigeria is characterized by three large plateau areas divided from one another by the troughs of the Niger and Benue Rivers. Along the seacoast stretches into an alluvial plain raging about 100 miles (160 km) in width. This alluvial plain bulges out into the Atlantic ocean where the Niger Delta with its intricate pattern of watercourses penetrates it. The characteristic vegetation of the coastal plain is a dense tropical rain forest. This is replaced by various types of Savanna vegetation as the plateau uplands rise from the coastal plain. Moving north, the climate becomes drier until at the northern boundary of the country where it becomes nearly a desert.

The site selected is surrounded by the then Niger, Kaduna, Plateau and Kwara States of the Federation (Figure 1).

Figure 1: Map of Nigeria with the 36 States and Abuja at the Centre
Source: (http://www.business-travel-nigeria.com/images/map_of_nigeria.gif**)**

The Federal Capital Territory is central to all parts of Nigeria lying just above the hot and humid low lands of the Niger and Benue trough but below the drier parts of the country which is lying to the North. It lies just north of the wide alluvial plains formed by the confluence of the Niger and Benue rivers. It has an undulating topography and consists of flitted plain rising from an elevation of (92m) in the southwest corner to above (610m) at the northeast corner rising out of this flitted plain are numerous rocky knobs and isenbergs and several ranges of low mountains. This kind of landscape also characterizes the large areas of the region surrounding the Territory (International Planning Associates Joint Ventures Management Board, 1979).

Abuja was not an existing City as it is today, but a relatively virgin land. Thus a Master Plan was developed to guide in the developmental processes. Development started immediately after its status was clearly defined by the 1976 FCT Federal Government decree and by 1991, most of the needed infrastructure including buildings, roads, water and sewage system has progressed considerably to facilitate the actual movement of the Capital from the densely populated city of Lagos to the New Federal Capital – Abuja. Figure 2 is the map of the Federal Capital territory, with Abuja as the Federal Capital City.

The new Federal Capital City (FCC) was planned to be developed in phases I, II, III etc according to availability of resources and requirement. The phases are further subdivided into districts. Figures 3 and 4 show the different phases and districts of the FCC respectively. The districts have low, medium and high density areas to accommodate different types of houses and income groups. Some of the districts considered as low density include Maitama and Asokoro districts, while medium density areas include: Wuse I and Wuse II, Garki I and Garki II. The-high density areas are supposedly the satellite towns which include Gwagwalada, Kubwa, Karu and Nyanya etc.

Presently, many infrastructures exist in phases I and II and parts of phase III of the Federal Capital City (FCC). Although these facilities were not completely ready and adequate, but what was on ground motivated the government to move in 1991 since Lagos was getting more and more highly populated and difficult to manage environmentally.

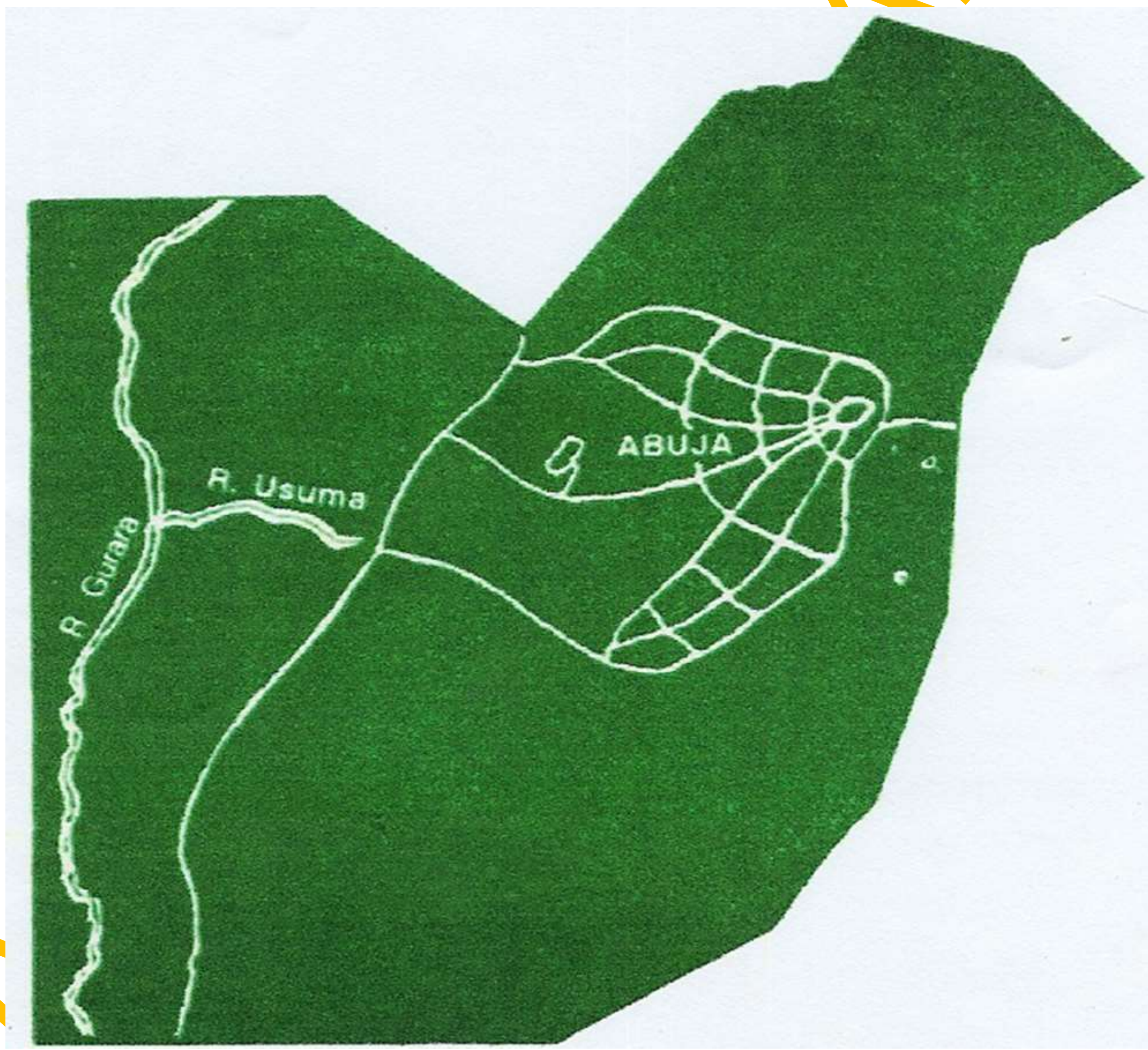

Figure 2: Map of Federal Capital Territory showing Abuja (Abuja Master Plan)

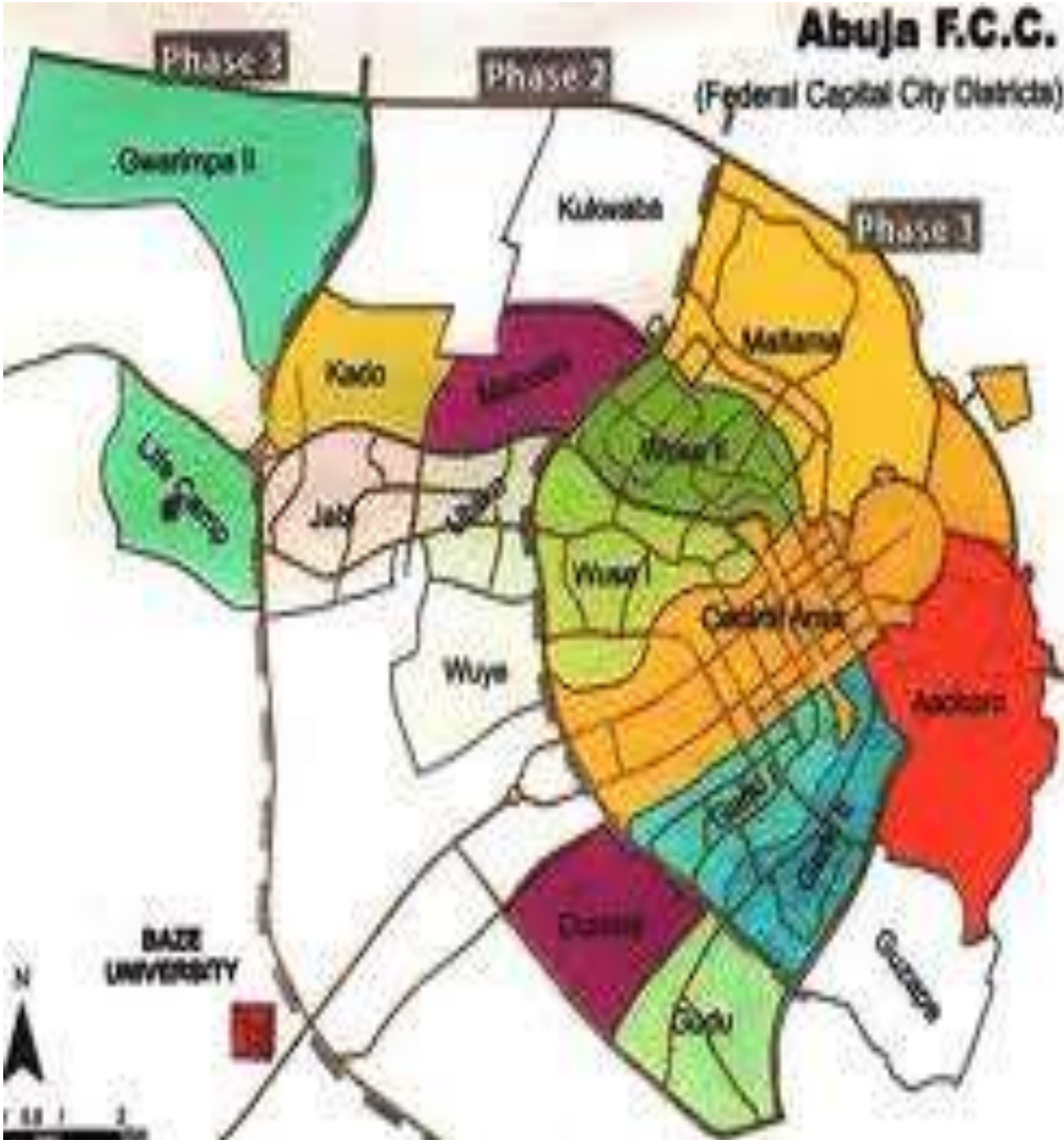

Figure 3: Map of FCC showing the different Phases
Source:**(**http://t3.gstatic.com/images?q=tbn:ANd9GcR5z2UJUJdEGlLHszLQiWqe56UIoj7GeBbofWRAG6_VKRs9Zfvk)

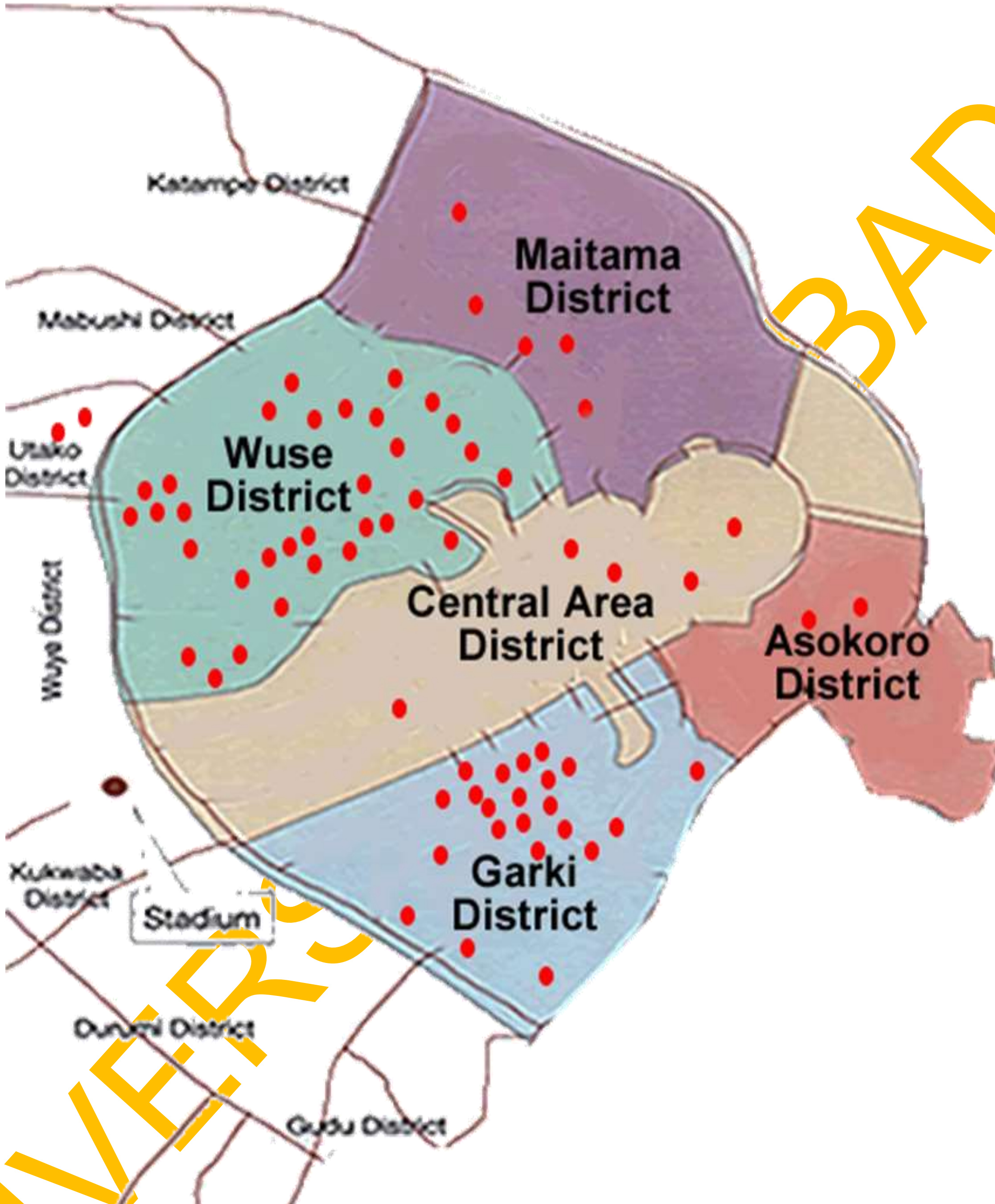

Figure 4: Map of FCC-Phase I showing Districts and other prominent areas
Source: (http://hotelownersforumabuja.com/img/abuja-map.gif)

1.1.2 Concept Plan for Wastewater Management in Abuja

The development of wastewater management plans for Abuja considered two types of issues in deciding the concept to be adopted. These are that:

1. The treatment and disposal of sanitary waste must be conducted in a manner to control disease vectors and contribute to the objectives of maintaining public health. Major diseases of concern in planning activity in the FCT include schistosomiasis, onchocerciasis, cholera, typhoid, malaria and other vector diseases transmitted by anopheles and other mosquitoes as reported in IPA J.V.M.B. (1979). However it generally intends to provide control of pathogenic organisms found in wastewaters of human origin.

2. Wastewater effluent, if given adequate treatment may represent a valuable resource for agricultural irrigation in the city.

Thus the primary focus or objective is on management of wastewater in a manner which utilizes the wastewater as a resource, protects public health and utilizes wastewater treatment systems which can be operated and maintained at reasonable cost and with semi-skilled or unskilled staff. In consideration of the health-related issues for the FCT, the collection and treatment of wastewater emanating from the capital city and its outlying urban areas is essential in meeting the required stated objectives.

1.1.2.1 Wastewater Generation and Re-use

The primary wastewater generation sources in the FCT include domestic wastewater from the capital city inhabitants; employment derived wastewater from the government building and commercial and industrial enterprises that develop in the FCT, process-related wastewater emanating from the industrial estates and from maintenance operations. Rivers and their tributaries in FCT are shown in Figure 5 wherein effluents from the wastewater treatment plant are expected to be discharged. The quality of the effluent discharged into these rivers and tributaries must be such that does not pollute them and hence make them unsafe for aquatic life and other users.

The following assumptions were made in the concept plan of the wastewater management system. (IPA J.V.M.B., 1979)

1. The per capita water consumption in FCT was estimated to be about 265 litres per capital per day, based on estimated supply of 425,000 m^3/day for the interim population of 1.6 million people. It is estimated that the wastewater stream will tend to contain in excess of 250mg/l BOD_5 and of suspended solids.

2. It was assumed that from 20 to 25% of the delivered water supply will be used consumptively (i.e. will not be discharged to sewer system after use). Typical consumptive use is landscape irrigation.

3. It was additionally assumed that the “loss” of water from the sewer system due to consumptive use will be almost equivalent in magnitude to the “gain” in flows due to infiltration of inflow to the sewerage system (particularly during the rainy season), such that the ultimate average wet-weather flow rate to the treatment plant will be approximately equal to the rate of water delivered i.e. 425,000m^3/day.

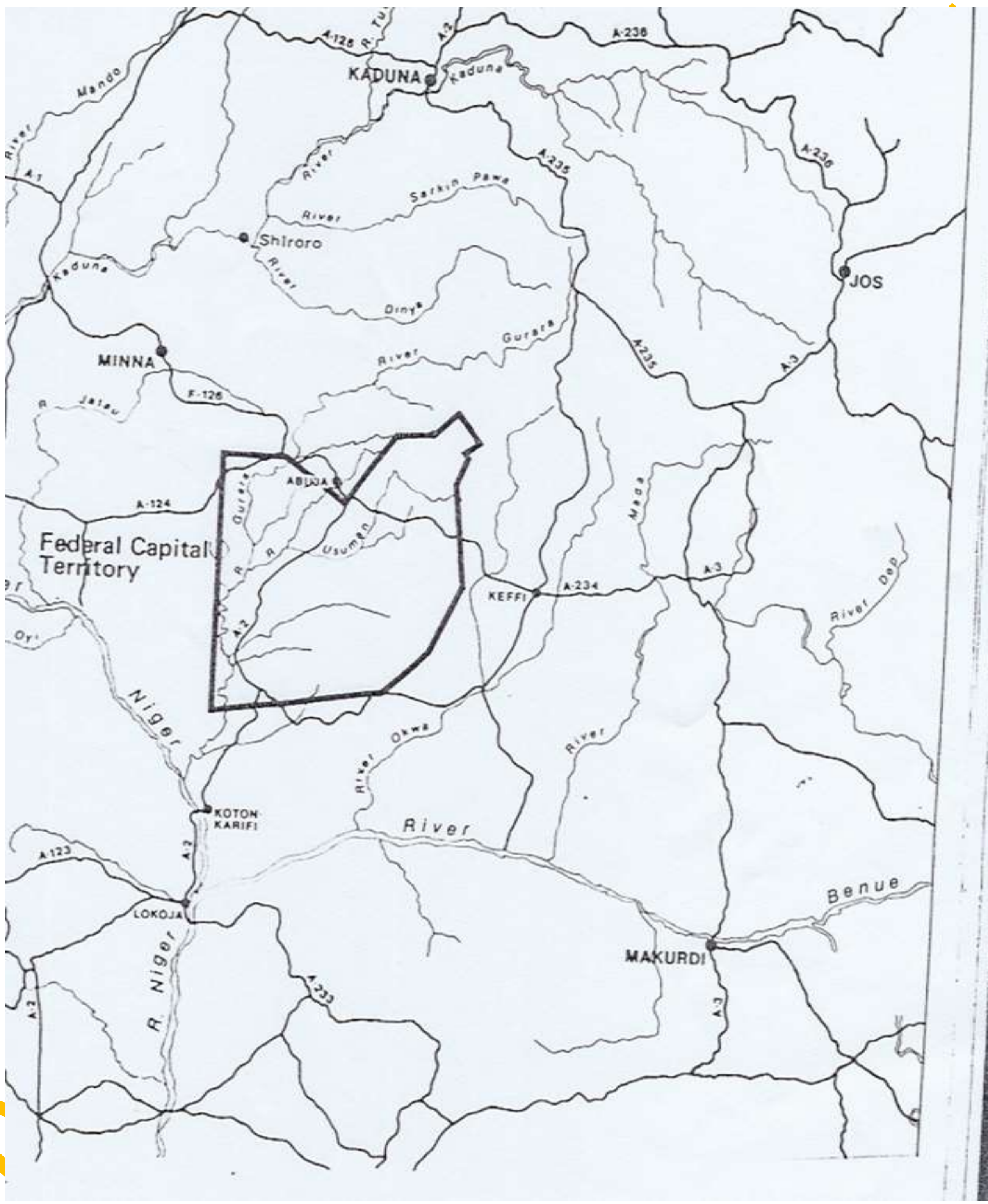

Figure 5: Map of FCT showing Rivers and their tributaries

Source: (Abuja Master Plan)

1.1.2.2 Wastewater Collection System

The design of the sanitary sewerage system for the city was based on a number of major objectives and assumptions as documented in IPA J.V.M.B. (1979)

1. The collection system should be by gravity flow, with no lift stations, force mains, or other powered devices. This type of system presents a number of advantages:

- It is low in construction cost.
- The long time required for the purchase and installation of large pumps is eliminated, together with their high cost.
- The operational and maintenance costs are much lower than for pumped systems.
- The possibility of a "catastrophic" type of system failure is extremely low.
- Staging of construction is simplified.
- Energy requirement is nearly zero.

2. In order to reduce the loads on the wastewater treatment plant, the system adopted was a separate system. That is the storm run-off should not be allowed to enter the sanitary sewerage system.

1.1.2.3 Wastewater Treatment

Performance standards to guide the selection of alternative wastewater treatment systems were developed for three treated effluent discharge conditions:

1. Stream dilution
2. Irrigated agriculture re-use; and
3. Other re-uses.

Regardless of the discharge conditions, it is essential that any treatment system selected be capable of inactivating schistosome eggs, and that impoundments be managed so as to minimize the suitability of the impoundment for the breeding of mosquitoes.

Three wastewater treatment alternatives were selected in consideration of the treatment requirements set for Abuja and characterized in terms of land required, relative site development, total capital and operating costs, relative sludge generation, and supporting energy requirements. Land area and energy requirements were estimated for a treatment system collectively capable of treating a daily flow of 425,000m^3 (IPA J.V.M.B., 1979). The selected treatment systems vary in complexity of technology from a combination of:

1. An anaerobic-oxidation pond system;
2. An anaerobic-aerated pond system; and
3. A standard activated sludge secondary treatment system.

From the evaluation of the alternatives, the wastewater treatment philosophy selected for the capital city by the master plan was the combined anaerobic pond-aerated pond system. IPA J.V.M.B, (1979) reported that anaerobic ponds are required to eliminate schistosome eggs. The combination has relatively low capital and operating costs and low sludge handling requirements. This system which is suited to the climatologically setting of the FCT is capable of meeting treatment requirements with a minimal commitment to mechanical equipment. Additionally, this processing philosophy is considerably less land-consumptive than the oxidation pond system and cheaper than standard secondary or advanced systems.

The treatment plant design flow rate is 560,000 m^3/day. These design capacities allow for 25% peaking factor in relation to the average water consumption of 450,000 m^3/day used for water supply.

The anaerobic ponds and aerated ponds are designed as modular units, with each anaerobic pond-aerobic pond module capable of treating 9,500m^3/day. Sixty such modules are required to provide wastewater treatment service to the entire 1.6 million people (IPA J.V.M.B., 1979).

As a result of the modularity of the components of the wastewater treatment plant, the expansion of this facility can be scheduled in close coordination with the expansion of sewer service in the city. The individual anaerobic ponds are designed with a depth of 3m to provide a minimum 0.6m sludge storage depth (sufficient for at least five years of accumulation of decomposing sludge at the pond bottom). A design hydraulic detention time (the time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank) of 1.36 days was selected as adequate for schistosome egg kill in the anaerobic environment.

The aerated ponds were designed at a depth of 4.5m to provide a minimum hydraulic detention time of seven days. Provision was also made in the preliminary design for effluent solids clarification, as well as plant piping and pumping. The wastewater treatment system described in this section would provide secondary treatment with residual biochemical oxygen demand and suspended solid residual of 30 to 50mg/l respectively. Figure 6 shows the location of sewage treatment aerator and trunk sewer lines in the Federal Capital City (FCC).

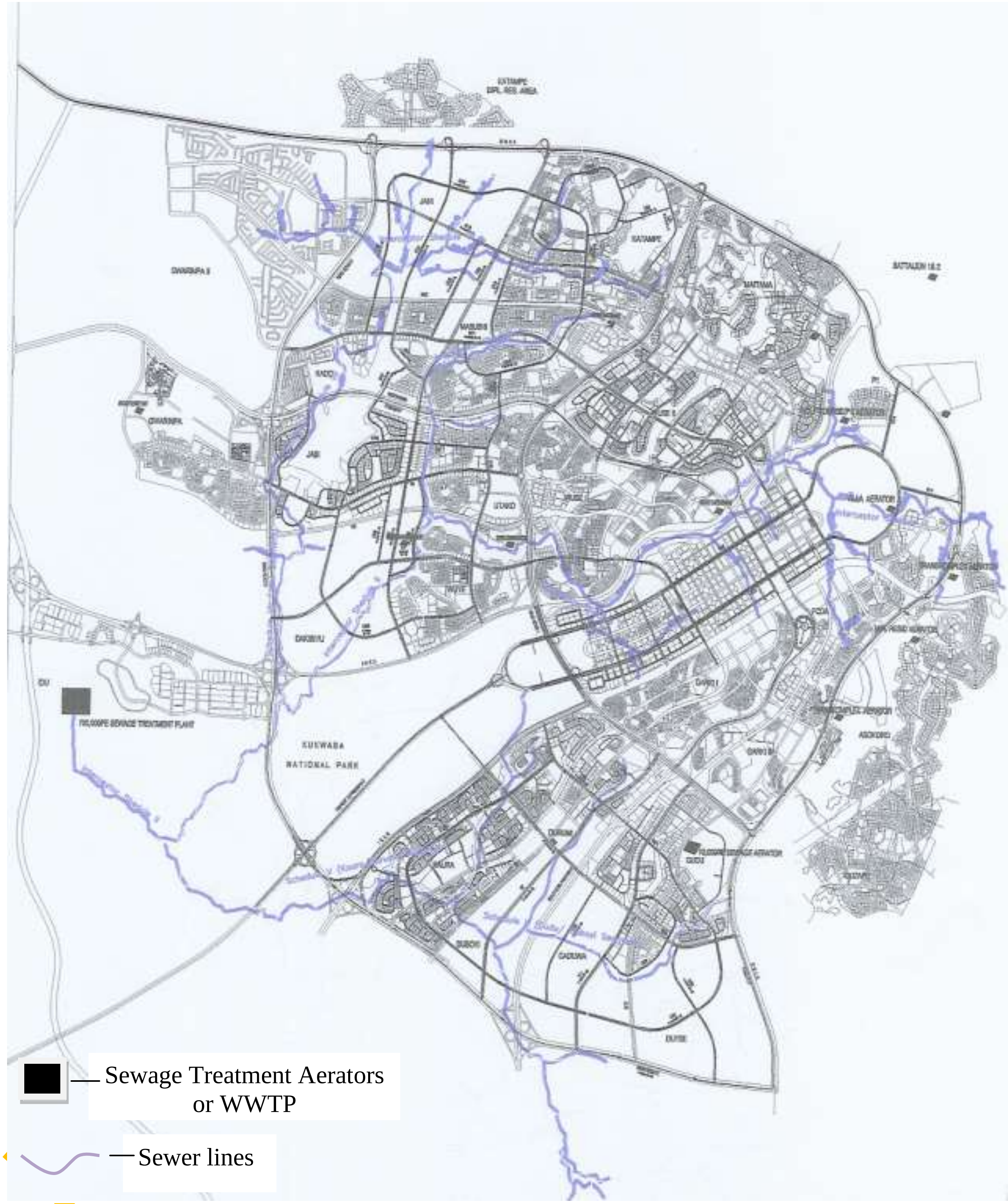

Figure 6: Diagram Showing the Location of Wastewater Treatment Aerator and Trunk Sewer Lines in Federal Capital City
Source: (Abuja Master Plan)

1.2 Problem Identification.

The problem currently is that the development of the Abuja in terms of the provision of sewerage infrastructure was delayed and could not match the influx of Nigerians who want to move to their new capital, thus inhabitants no longer comply with the provisions of the master plan. They build on sewer lines; throw non-biodegradable substances into sewer lines, construct septic tanks where there are no sewer lines, and sometimes discharge generated sewage into storm water line.

The provided sewage treatment plants could not function effectively due to excessive sand infiltration into the system, discharge of non-biodegradable substances into the system, poor and fluctuating electricity supply and non-availability of adequate funds to operate and maintain the plants. These and several other problems have rendered the sewerage system non effective and in a dilapidated state. Wastewater is discharged into waterways untreated due to blockage of manholes as shown in Plate 1 and others been overfilled as shown in Plate 2. The lack of provision of the central sewerage system in the satellite towns of Gwagwalada, Kuje, Kubwa, Nyanya etc have left inhabitants of such areas with no other alternative than to construct septic tanks and soak-away pits in order to manage their sewage which is not acceptable for a modern city like Abuja and was also not allowed in the Abuja Master plan.

Plate 1: Blocked Manhole due to polythene bags at Gwarinpa District - Abuja

Plate 2: Overfilled Manhole at Wuse - Abuja

1.3 Aim and Objectives of Research.

The aim of this research was to examine and evaluate the existing wastewater management systems in Abuja and to design appropriate strategies for effective wastewater management for the city.

More specifically, the objectives of the research were to:

1. Carry out an inventory of wastewater generation, collection, treatment and reuse in Abuja.
2. Identify the problems militating against the wastewater treatment system in Abuja and propose engineering solutions to the problem.
3. Design appropriate strategies for wastewater management in Abuja in order to prevent transmission of diseases, and to have an environmentally-friendly modern sewerage system for the capital city for Nigeria.

1.4 **Research Justification**

In a developing country such as Nigeria with old cities and communities, wastewater generated are commonly discharged openly and into drainages (open or closed), and in towns and communities, they are discharged into septic tanks/soak-away pits and cesspools. These systems are problematic as soils become saturated with decomposed solids, and effluents of very high suspended solids causing environmental pollution and even underground water pollution in some cases.

In order to avoid these and other problems, the sewage management for Abuja adopted the modern central system with sewage treatment plants as end of the pipeline solution to environmental pollution. Unfortunately, central sewerage system usage and management in Nigeria have not been fully appreciated. This is because they are not generally available except in Abuja and a few institutions or estates. It requires highly trained professionals to operate them; regular supply of electricity of specified voltage without fluctuations, and funding for operation and maintenance. Lack of these supporting conditions has led to poor performance of the system and thus the need for a well-thought out approach (both in terms of engineering and management) in order to proffer solution to these problems.

This research work evaluated the wastewater management system and the efficiency of the available treatment plants in existence in Abuja. In handling generated wastewater, evolution has taken place from the use of pit latrines to septic tanks and now to central sewerage system. Most modern cities of the world have followed these same patterns. Abuja in Nigeria cannot be an exception and therefore the need to evolve a way forward both in Engineering and management to sustain and fully adopt the new wastewater management system.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sources of Wastewater and Usage

The major sources of wastewater in a community as documented by METCALF and EDDY (1991) are the residential areas, commercial districts, institutional and recreational sources. Each of these areas, proper estimation of the quantity of wastewater produced is vital for the design of sewer capacity to be provided for present and probable future quantities of expected wastewater during the design period of the sewerage system.

Wastewater flow rates in most residential are commonly determined on the basis of population density and the average per capital contribution of wastewater. Table 2.1 shows typical wastewater flow rates from residential sources as presented by METCALF and EDDY (1991).

Table 2.1: Typical wastewater flow rates from residential sources

Sources	Unit	Typical Flow in l/c.d
1. Apartment:		
High-Rise	Person	190 l/c day
Low- Rise	Person	247 l/c day
2. Hotel	Guest	171 l/c day
3. Individual Residence:		
Typical home	Person	266 l/c day
Better home	Person	304 l/c day
Luxury home	Person	361 l/c day
4. Motel	Unit	380 l/c day

Source: METCALF and EDDY INC. (1991)

Commercial wastewater flow rates are generally expressed in m^3/ha.day and are based on existing future development. The average unit-flow rate allowances for commercial developments normally range from 7.5 to 14m^3/ha.day (METCALF and EDDY 1991). Institutional facilities essentially are domestic in nature; however the flow rates vary with region, climate and type of facility. The table below shows the typical wastewater flow rates from institutional sources.

Table 2.2: Typical wastewater flow rates for institutional sources

Source	**Unit**	**Typical flow in L/unit. d**
Hospital (medical)	Bed	627 L/bed.d
Prison	Employee	38 L/employee.d
	Inmate	437 L/inmate.d
	Employee	38 L/inmate.d
School, day		
With cafeteria, gym and showers	Student	95 L/person.d
With cafeteria only	Student	57 L/person.d
Without cafeteria and gym	Student	41.8 L/person.d
School, boarding	Student	285 L/person.d

Source: METCALF and EDDY INC. (1991)

Wastewater from Industrial sources varies with the type and size of facility, the degree of wastewater reuse of the industry and the on-site wastewater treatment methods. Typical design values for estimating the flows from industrial areas that have little or no wet-process type industries is 9-14 m^3/ha.day for light industrial developments; and 14-28 m^3/ha.day for medium industrial developments.

Wastewater usage can be direct or indirect. The direct use means using treated wastewater for irrigation, aquaculture, industries, recreation, and even as potable water after passing through advance treatment. Indirect usage entails the utilization of wastewater which was disposed as raw material for other uses.

The direct use of wastewater for agricultural purposes as practiced in Nigeria had already been practiced for over 2000 years in Greece and China. (Pillai, 1955). Similarly, as early as 16th century, sewage farming was practiced in Germany; and in United States, the use of wastewater for farming started in the 1870's (Biswas and Arar, 1988).

Presently wastewater usage is practiced mainly in the arid and semi-arid tropical areas of the World. Veenstra (1992) observed that wastewater usage for agricultural purposes is common in Yemen and other Arab Countries, thus reiterated two major constraints with respect to reuse of wastewater as related to the quality of the treated effluent as: long term salinity effects on soil and crops; and public health risks to the workers and consumers. Therefore, the need for consideration of these two major factors before wastewater usage need not be over-emphasized.

Biswas and Arar (1988) also indicated that in the Arabian region, treated wastewater is used for irrigation of municipal areas; and the quality requirements in the Arab Gulf States have been based on 10 mg/L of BOD and 10 mg/L of suspended solids.

The range of wastewater use in the United States is wider than most parts of the world. In Southern California, wastewater is used for recreational purposes; but the treatment applied on the wastewater consists of combined biological wastewater treatment with sand filtration to produce water devoid of bacteria and viruses of human origin. Boating, fishing, and swimming take place at these recreational sites. In other locations in California, injection of wastewater into groundwater occurs so as to prevent sea water intrusion, but the level of treatment is exorbitant.

2.2 Nature of Sewage

According to Sridhar (1986), Sewage is the waste water of a community consisting of faeces, urine, kitchen washing and laundry washing. It is rich in organic matter, nitrogen, phosphorus and other minerals and vitamin. It is a veritable medium for a variety of microorganisms, both non-pathogenic and pathogenic. Fresh sewage is colloidal in nature, yellow, brown or black in colour with odour; depending on its age (fresh or stabilized).

The complex nature of domestic sewage precludes its complex analysis. Since it is comparatively easy to determine the amount of oxygen used by the bacteria as they oxidize the wastes the concentration of organic matter in the waste is expressed in terms of the oxygen required for its oxidation.

$$\text{Waste} + \text{Oxygen} \xrightarrow{\text{bacteria}} \text{Treated waste} + \text{new bacteria}$$

There are basically three ways of expressing the oxygen demand of a waste.

(1) Theoretical Oxygen Demand (ThOD): This corresponds to the stoichiometric amount of oxygen required to oxidize completely a given compound. Usually expressed in milligrams of oxygen required per litre of solution. It is a calculated value and can only be evaluated if a complete chemical analysis of the wastewater is available, which is very rarely the case. Therefore, its utilization is very limited.

(2) Chemical Oxygen Demand (COD): This is the amount of oxygen required to oxidize the organic fraction of a sample which is susceptible to permanganate or dichromate oxidation in an

acid solution. COD does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements take five days. (Brown, 2001). COD can also be determined using Standard Dichromate Oxidation method, Rapid COD tests and Instrumental COD Methods.

(3) Bio-chemical Oxygen Demand (BOD): This is used as a measure of the quantity of oxygen required for oxidation of biodegradable organic matter present in wastewater sample by aerobic biochemical action. It is also a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. Oxygen demand of wastewater is exerted by three classes of materials: (a) carbonaceous organic materials useable as a source of food by aerobic organisms; (b) oxidizable nitrogen derived from nitrite, ammonia, and organic nitrogen compounds which serve as a food for specific bacteria (e.g. *Nitrosomonas* and *Nitrobacter*); (c) chemical reducing compounds, e.g., ferrous ion (Fe^{2+}) and sulfide (S^{2-}), which are oxidized and dissolved. For domestic sewage, nearly all oxygen demand is due to carbonaceous organic materials and can be determined by either BOD dilution test or BOD manometric method. (Ramalho, 1977).

According to Brown (2001), BOD is determined by incubating a sealed sample of water for five days at $20^{o}C$ and measuring the loss of oxygen from the beginning to the end of the test. Samples often must be diluted prior to incubation or the bacteria will deplete all of the oxygen in the bottle before the test is complete.

2.2.1 **Strength of Sewage**

Sridhar and Pillai (1986) similarly observed that the higher the concentration of faeces in sewage, the stronger it is said to be, thus Sewage is most often judged by its Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD).

2.2.2 **Protein in Wastewater and Wastewater sludge**

Similarly, research carried out by Sridhar and Pillai (1973) showed that protein existed in wastewater, septic tank sludge, activated sludge, and that the dominant protozoa and bacteria in the activated sludge adhere to these proteins.

As reported by Pamela and Chul (2007), proteins have been identified on the basis of their solubility in different solvents such as water, salt solution, alkali, acid and ethanol. Knowledge of the nature of proteins in wastewater and wastewater sludge is useful for determining the pollution effects on the environment and the changes in the protein structures during decomposition or treatment and also for determining the possible usage of the resulting materials in agriculture, including animal nutrition.

Proteins constitute one of the largest fractions of organic material in secondary effluent from domestic wastewater treatment plants, and are a significant source of organic released into received waters.

2.2.3 **Protease Activity in Sewage**

Protease, a common enzyme associated with the decomposition of proteinaceous organic matter like human wastes, is present in bacteria and other organisms on the decomposing matter. (Sridhar and Pillai, 1973). Domestic sewage consists mostly of faecal matter, urine, kitchen washings and soil washing. Normal urine is known to contain some protease activity. The result of analysis of faecal suspension, kitchen washing indicate that all these materials which are present in the sewage contribute, to various extents the protease activity (Sridhar and Pillai, 1973).

2.2.4 **Enzymes in Raw Sewage**

Domestic sewage is composed mostly of faecal matter, urine, soil and other washings. The observations on the enzymes in these constituents and in the sewage as a whole are considered thus:

1. Faecal matter: Since 1908, studies of enzymes in a variety of biological matters have been carried out and observations have been made on faecal and urinal matters. Sridhar and Pillai (1966) showed in their study that lipase, diastase, and catalase are present in faeces.

2. Urine: The enzymes in urine have also attracted attention. It has been shown that the total daily excretion of diastase is fairly constant in normal individuals; an average of from 10 to 20 units was reported by Sridhar and Pillai (1966). Pepsin and lipase have also been shown to be present in Urine, but the amounts of these increase during certain pathological conditions. The amount of catalase in urine is an index of the number of cells therein and the urine of patients suffering from pyelitis can be differentiated from that of normal individuals by its catalase content.

Diastase, trypsin, pepsin, lipase as well as disaccharide' enzymes are nearly always present in domestic sewage partly derived from animal and vegetable waste products and are continuously formed by the microorganisms (American Public Health Association, 1971).

2.2.5 **Present State of Knowledge**

Digestion or stabilization of sewage is brought about by microorganisms; the possible involvement of enzymes in the process was not envisaged until after 1908 (Sridhar and Pillai, 1966). With the more rapid development of the general concept of enzymes in the early years, the knowledge of the enzymes in biological materials, such as faeces and urine, was naturally applied to the study of enzymes in sewage, the material in sewage filters and in the anaerobic systems of sludge digestion and gas production. The advent of the activated sludge process as a more rapid and efficient method of sewage treatment has afforded an interesting biological material for the study of enzymes as well.

2.2.6 Electrophoretic separation of protein in sewage and Sludge:

Electrophoresis is the phenomenon or the pattern of movement of the ions or charged particles in aqueous solution when subjected to direct electric current towards one or other of the electrode. The rate at which the movement occurs depends on a number of factors, particularly on the charge, size and shape of the molecules. This technique of disc electrophoresis is used to separate the proteins in sewage, septic tank sludge, activated sludge, the bacteria and the dominant protozoan- *Epistylis articulata* from the activated sludge and in the bacteria adhering to this protozoan (Sridhar et al, 1974).

2.2.7 An Enzymic Approach to the Study of Sewage and Sludge

The study of the principles of sewage treatment seems to have begun in 1877 with concept of organized ferments and as the knowledge of enzymes in general advanced in the early years of this century, attempts were also made to investigate the clotting enzymes in sewage filters, in certain bacteria and activated sludge (Sridhar and Pillai, 1966).

2.2.8 **Catalase activity in polluted water:**

In 1811, Thenard observed that hydrogen perioxide (H_2O_2) was able to decompose the tissues of plants and animals with the evolution of oxygen. This action was later shown to be due to an enzyme (catalase), which is present in all aerobic living systems and is broken down hydrogen peroxide, a toxic product of oxidative metabolism, into water and oxygen. This enzyme, unlike others, is active over a wide range of pH (3 to 9) and temperature (4^0 to 25^0 C) and does not require any co-factors or catalase (Sridhar and Pillai, 1969).

2.2.9 **Catalase activity in sewage effluents**

A new method of assessing the quality of sewage effluents has thus been developed to measure more accurately and rapidly the biological activity in treated sewage by the application of recent knowledge of the enzyme, catalase. Catalase is generally present in all aerobic living systems. In these systems catalase is essential for spontaneous breakdown of hydrogen peroxide which is formed in the cell as a toxic product of oxidative metabolism, into water and oxygen (Sridhar and Pillai, 1969).

2.2.10 **Magnetic bugs cut sewage sludge**

Adding iron dust to wastewater makes bacteria reusable. Magnetic bacteria could cut sewage sludge. They could shave up to five tonnes of waste off the several hundred tonnes produced every day by a plant serving 100,000 people, say Japanese researchers. Bacteria used to break down some harmful pollutants in waste water add to leftover sludge. Much of this ends up buried in landfills; but microbes will cling to powdered iron sprinkled into the brew and magnets can then drag them out, reducing the sludge volume and enabling a plant to re-use the bugs (Sakai, 2003).

The report of APHA (1976) confirmed that microbes will cling to powdered iron sprinkled into the brew. Magnets can then drag them out, reducing the sludge volume and enabling a plant to re-use the bugs and that magnetic separation is fast and reliable. A year-long test, in which 80 litres of raw sewage were passed through a rotating magnetic drum every day, produced no bacterial sludge.

Bacteria can be strained out or allowed to settle. Both approaches have disadvantages, says microbiologist Tom Curtis, and that "Gravity is cheap but not very effective; membranes are effective but expensive. "Magnetic separation "is ingenious, and it could find favour", he adds, but it's too early to say whether the running costs will make the technique competitive (APHA, 1976).

2.3 Health Significance of Wastewater

Pathogenic organisms like viruses, bacteria, and helminthes are commonly present in wastewater in high numbers. These organisms can survive in the wastewaters for a long period of time due to the conducive environment the wastewater creates for their survival. Since it is difficult to analyze the presence of each individual type of microorganism in the sewage, the faecal coliform are used as indicator group to indicate to what extent the wastewater is contaminated with human excreta and to what degree treatment will be able to reduce the level of contamination (Veenstra, 1992).

The quality of wastewater discharged into rivers, or pool of water should be such that it will not tamper with the health of inhabitants who may in one way or the other use the water for different purposes. Thus it is important to check the presence and collection of micro pollutants which may tamper with the health of inhabitants.

Similarly, persistent organic chemicals sometimes exist in municipal wastewater at low concentrations and ingestion over prolonged periods would produce detrimental effects on human health. This is not likely to occur with agricultural/aquaculture use of wastewater, unless cross-connections with potable supplies occur. The principal health hazards associated with the chemical constituents of wastewater thus arise from the contamination of crops or groundwater.

Odour is one of the most serious environmental concerns to the public, new techniques for odour measurement are now being used to quantify the development and movement of odours that may emanate from wastewater facilities. Special efforts are being made to design facilities that minimize the development of odours (METCALF and EDDY, INC. 1991). However, no strong evidence has been adduced to suggest that population groups residing near wastewater treatment plants or wastewater irrigation sites are at greater risk from pathogens in aerosolized wastewater resulting from aeration processes or sprinkler irrigation.

Shuval et al (1986) suggested that the high levels of immunity against most viruses endemic in the community are essentially from environmental transmission by wastewater irrigation.

2.4 Guidelines for Wastewater Usage

Wastewater usage cuts across so many areas of human endeavour like agriculture, recreation, irrigation and sometimes for human consumption as potable water. Environmental specialists and WHO Scientific Group on Health Aspects of usage of treated wastewater have set guidelines for the safe use of wastewater for different purposes. These guidelines as shown in Table 2.3 for agricultural purposes were established on the consensus view that the actual risk associated with irrigation using treated wastewater is much lower than previously thought; and that earlier standards and guidelines for effluent quality, such as the WHO (1973) recommended standards, were unjustifiably restrictive particularly with respect to bacterial pathogens

Table 2.3: Safe Guidelines for Wastewater Usage in Agriculture

Category[a]	Use	Exposed	Intestinal	Fecal	Wastewater Treatment expected to achieve required microbial quantity
A	Unrestricted[d]	Workers Consumers & public	≤ 1	≤ 1000[e]	WSPs designed to achieve the microbiological quality indicated or equiv. treatment
B	Restricted[f]	Workers	≤ 1	No Recom. Standard	Retention time in WSP for 8-10.d or equiv helminth & faecal coliform removal.
C	Localized [g]	None	Not Applicable	Not Applicable	Pretreatment as required by irrigation techn. But not less than prim. sediment

Source: World Health Organization, WHO (1989)

a) In specific cases, local epidemiological, socio-culture and environmental factors should be taken into account, and the guidelines modified accordingly.

b) *Ascaris* and *Trichuris* species and hookworms (arithmetic mean number of eggs per litre).

c) During the irrigation period (geometric mean number per 100 ml).

d) Irrigation of crops likely to be eaten uncooked, sports fields, and public parks.

During the last decade wastewater reclamation, recycling and reuse especially in agriculture has received much attention around the world especially in arid and semi-arid regions.

In Yemen where there is scarcity of water, domestic wastewater may present a valuable additional source of water for use after adequate treatment. Wastewater reuse in agriculture may serve different purposes such as: providing an extra reliable water source, providing valuable fertilizers for stimulation of agricultural crop production and minimizing environmental pollution (Veenstra, 1992b). Not every wastewater is suitable for reuse in irrigation and other purposes, thus the need for a guideline for safe use of wastewater effluent.

2.5 Wastewater Collection Systems

Wastewater produced in a community should generally be collected and treated or disposed of in such a way that it does not disturb the healthy living of the inhabitants in the area. Generally, there are two wastewater collection methods.

2.5.1. On-Site Collection

This involves the collection of wastewater and its disposal within the site or location of the wastewater production. On site-collection and disposal of waste is carried out basically by the use of septic tanks, cesspools, pit latrines etc. for the disposal of human wastes. Traditionally these pits are constructed with depths easily in excess of 10m. The liquid carrying all kinds of organic and inorganic contaminants is expected to infiltrate into the soil.

The overall health hazards from these on-site sanitation systems are dependent on the depth of groundwater table in the area involved. The deeper the groundwater table the better, as long travelling times of wastewater will allow for physical, chemical and biological purification of the infiltrating liquid.

In areas where the groundwater table is close to the surface, there is a lot of concern as the groundwater may be polluted with increased concentration of nitrates and even microorganisms. (Driscoll, 1986).

2.5.2. **Sewerage System**

The sewerage system involves the transportation of wastewater via sewer pipes to a central collector which finally discharge the wastewater to a treatment plant. This modern system of wastewater helps to keep the whole environment of human residence free from the produced waste; thus preventing risk of environmental pollution, odour and various ills associated with wastewater. This system although expensive initially during conception and construction; its durability, spanning over 50 - 100 years makes it cheaper on the long run. (Chartterjee, 2010).

2.6 **Wastewater Treatment Methods**

There are basically three levels in wastewater treatment methods: Primary, Secondary and Tertiary treatment methods.

1. Primary treatment

Primary treatment involves the partial removal of suspended solids and organic matter from the wastewater by means of physical operations such as screening and sedimentation. Pre-aeration or mechanical flocculation with chemical additions can also be used to enhance primary treatment. Primary treatment acts as a precursor for secondary treatment. It is aimed mainly at producing a liquid effluent suitable for downstream biological treatment and separating out solids as a sludge that can be conveniently and economically treated before ultimate disposal. The effluent from primary treatment contains a good deal of organic matter and is characterized by a relatively high BOD.

2. Secondary treatment

The purpose of secondary treatment is the removal of soluble and colloidal organics and suspended solids that have escaped the primary treatment. This is typically done through biological processes, namely treatment by activated sludge, fixed-film reactors, or lagoon systems and sedimentation.

3. Tertiary/Advanced wastewater treatment

Tertiary treatment goes beyond the level of conventional secondary treatment to remove significant amounts of nitrogen, phosphorus, heavy metals, biodegradable organics, bacteria and viruses. In addition to biological nutrient removal processes, unit operations frequently used for this purpose include chemical coagulation, flocculation and sedimentation, followed by filtration and activated carbon. Less frequently used processes include ion exchange and reverse osmosis for specific ion removal or for dissolved solids reduction (Economic and Social Commission for Western Asia, 2003).

Also, wastewater treatment methods can be classified into two types based on the location of treatment works. These are on-site treatment and off-site treatment. On-site treatment involves the collection of wastewater and its treatment near the site of its production via septic tank/soak away or cesspools. While off-site treatment involves the collection of wastewater from all points of production within a district, community or town and its treatment at a designated point outside the city. The treatment of wastewater of large quantities can be done through so many treatment processes depending on the level of treatment expected, availability of funds and the treatment standard specified for such a country.

Similarly, wastewater treatment methods can be grouped into two main categories namely natural (biological treatment) and technological systems.

1. **Natural systems (Biological Treatment)**. In this type of system, sewage is treated by means of Anaerobic, Facultative and Aerobic (maturation) stabilization ponds, land treatment systems (different types of wetland or direct land application).

2. **Technological Systems**. Here, high technology system is adopted in such a way that the natural wastewater treatment is accelerated through artificial input of extra oxygen.

In general, natural treatment systems are advantageous as they do not rely so much on skilled operational labour nor do they need sophisticated (imported) equipment. However, they require land areas of more than 2m^2 per population equivalent while for technological system, it requires less than 1m^2 per population equivalent depending on the type of treatment plant and its capacity (Veenstra, 1992b).

2.6.1 Waste Stabilisation Ponds

Waste stabilization ponds (WSPs) are generally arranged as a series of shallow ponds which receive a continuous flow of wastewater. These shallow ponds could be earthen basins using a completely mixed biological process without solids return. The mixing process may be either natural (wind, heat or fermentation) or induced (mechanical or diffused aeration). The waste stabilization process can be classified by considering the type(s) of biological activity occurring in the pond. Three types of ponds may be distinguished in a waste stabilization pond treatment process, they are: - Anaerobic ponds, Facultative ponds and Maturation ponds.

Anaerobic ponds are deep wastewater treatment ponds that exclude oxygen and encourage the growth of algae, with bacteria to help break down the effluent. The anaerobic pond acts mostly like an uncovered tank that breaks down the organic matter in wastewater with the use of organisms, releasing methane and carbon dioxide.

Facultative ponds are divided into two types: primary, which receives raw wastewater: and secondary, which receives the settled wastewater left over from the anaerobic pond. Facultative ponds are designed for BOD_5 removal using algae, which help to produce oxygen to the pond.

Finally, maturation ponds are ponds that receive the effluent from a facultative pond and its size and number depends on the quality of the bacteria that is released in the effluent. This kind of pond is shallow and shows less vertical stratification than the other types of ponds. Its water volume is well oxygenated throughout the day, due to the population of algae. The purpose of this type of pond is to remove pathogens and fecal coliforms by the oxidation process. Maturation ponds only achieve a small removal of BOD_5, but they remove more nitrogen and phosphorus than the other pond systems (Liu and Lipták, 1999).

The normal sequence is that the raw wastewater first settle in an anaerobic pond; followed by the facultative pond, where organic matter of the wastewater is oxidized to carbon dioxide and water. Finally it flows into the maturation pond where the treatment is mainly concentrated on pathogen removal. Figure 7 shows typical flow diagram of waste stabilization pond.

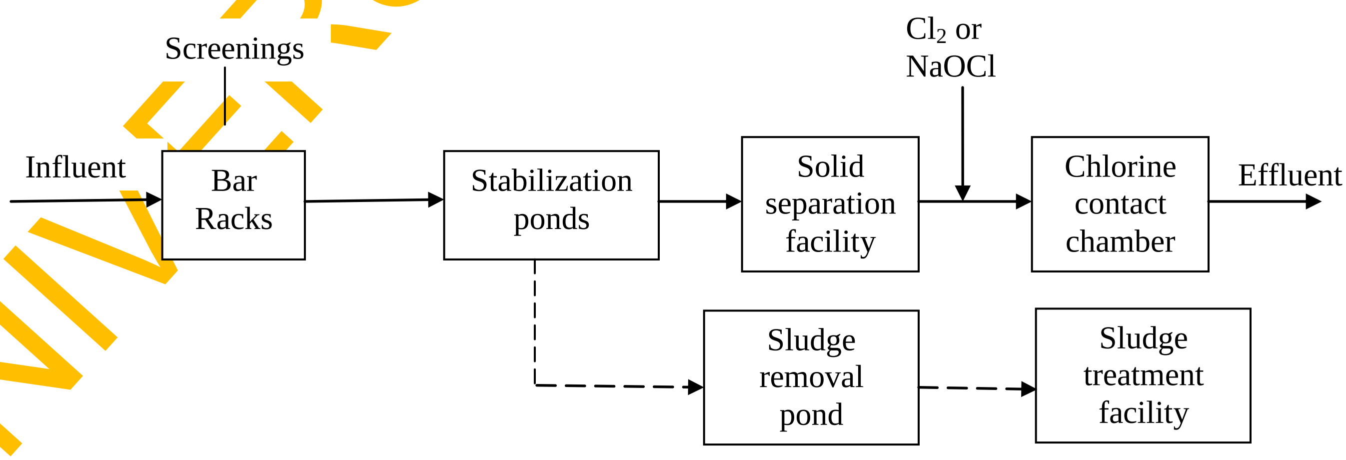

Figure 7: Typical flow diagram for stabilization ponds

WSPs are most often referred to as oxidation pond or lagoon – this is a natural secondary wastewater treatment. The primary treatment takes place in the anaerobic pond, which serves the purpose of removing suspended solids and some of the soluble matter (BOD_5). Waste stabilization pond technology is particularly well suited to countries in tropical and subtropical regions, because the greater amount of sun and the higher temperatures contribute to a more efficient removal of waste. The secondary wastewater treatment is man-made basins and has the ability to stabilize the waste and reduce the pathogens. WSPs have been used all around the world because of the efficiency to reduce the waste with the use of micro-organisms, although its effectiveness is affected by the different climatic conditions in different locations. This treatment is most appropriate for wastewater treatment and is followed by a microbiological and chemical quality guidelines with a low cost, minimal operational, and maintenance requirements.

The overall performance of wastewater stabilization ponds is strongly dependent on the hydraulic and surface loading rates applied and on the prevailing environmental conditions of its location such as temperature, solar radiation level etc. with reference to the design criteria of the WSP which are based on the maximum and minimum BOD volumetric loading. It is suggested that for high temperatures (>20^{o}C) and a hydraulic detention time of 2.5days, BOD removal would be 60%. Doubling the retention time would only achieve a 17% increase, with a removal rate of 70% (Mara, 2003).

Shuval et al (1986) observed that Wastewater Stabilization Ponds is the most appropriate wastewater treatment method for effluent use in agriculture. Wastewater Stabilization Ponds are also a preferred wastewater treatment system to be used in developing countries, where land is often available at reasonable opportunity cost and skilled labour in short supply.

2.6.2 Activated Sludge Treatment

Activated sludge process is one of the biological wastewater treatment processes most often used for large installations. The process was developed in England in 1914 by Arden and Lockett and was so named because it involved the production of an activated mass of microorganisms capable of stabilizing a waste aerobically (METCALF and EDDY, INC. 1991).

The activated sludge process is an aerobic, continuous-flow system containing a mass of activated micro-organisms that are capable of stabilizing or biodegrading organic matter. The process consists of delivering clarified wastewater, after primary settling, into an aeration basin where it is mixed with an active mass of micro-organisms, mainly bacteria and protozoa, which aerobically degrade organic matter into carbon dioxide, water, new cells, and other end products. The bacteria involved in activated sludge systems are primarily Gram-negative species, including carbon oxidizers, nitrogen oxidizers, floc formers and non-floc formers, and aerobes and facultative anaerobes. The protozoa, for their part, include flagellates, amoebas and ciliates.

An aerobic environment is maintained in the basin by means of diffused or mechanical aeration, which also serves to keep the contents of the reactor (or mixed liquor) completely mixed. After a specific retention time, the mixed liquor passes into the secondary clarifier, where the sludge is allowed to settle and a clarified effluent is produced for discharge. The process recycles a portion of the settled sludge back to the aeration basin to maintain the required activated sludge concentration as shown in Figure 8. The process also intentionally wastes a portion of the settled sludge to maintain the required solids retention time (SRT) for effective organic removal (Economic and Social Commission for Western Asia, 2003).

Operationally, biological wastewater treatment using the activated sludge process is accomplished by the introduction of organic waste into a reactor where aerobic bacterial culture is maintained in suspension. The aerobic environment in the reactor is achieved and maintained by the use of diffused or mechanical aeration system.

The activated sludge system of wastewater treatment is commonly used nowadays in view of the high effluent quality; and the system can easily be controlled to achieve different degree of nutrient removal from the wastewater.

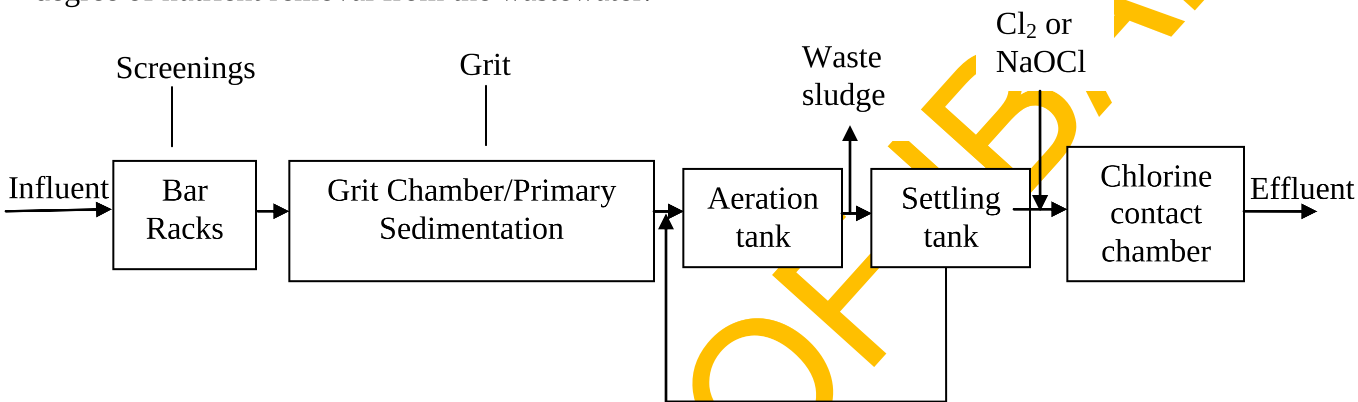

Figure 8: Typical flow diagram for Activated sludge flow process.

The control of the activated-sludge process is important to maintain a high treatment performance level under a wide range of operating conditions. The principal factors in the process control are the following:

(a) Maintenance of dissolved oxygen levels in the aeration tanks;

(b) Regulation of the amount of returning (re-circulated) activated sludge;

(c) Control of the waste activated sludge.

The main operational problem encountered in a system of this kind is sludge bulking, which can be caused by the absence of phosphorus, nitrogen and trace elements and wide fluctuations in pH, temperature and dissolved oxygen (DO). Bulky sludge has poor settleability and compatibility due to the excessive growth of filamentous micro-organisms. This problem can be controlled by chlorination of the return sludge (Liu and Lipták, 1999).

Enzymes in Activated Sludge:

Similarly, Wooldridge (1933), have observed the occurrence and activities of enzymes in the sludge while working with activated sludge. Sludge from sedimentation and humus tanks, demonstrated the presence of dehydrogenises, indophenols oxides and urea's activities. Activated sludge and crude sewage did not show the presence of catalyses and the sludge showed a doubtful peroxides activity. It was further shown that sterile sewage was oxidized readily by non- sterile activated sludge and by bacteria suspensions, less rapidly by protozoa suspensions and that activated sludge contains many oxidation-reduction enzymes.

Sludge Density Index (SDI)

The sludge density index is the reciprocal of the sludge volume index, multiply by 100, and is calculated on the basis of the suspended solid and settled volume of the sludge in 30 minutes.

$$SDI = \frac{\text{Per cent suspended solids}}{\text{Per cent settling by volume}} \times 100$$

Sludge Volume Index (SVI)

The sludge volume index (SVI) is the volume in ml occupied by 1 gram of sludge after setting the mixed liquor for 30minutes in a graduated cylinder (Metcalf and Eddy, 1991). The sludge volume index is calculated on the basis of the suspended solids and the settled volume of the sludge in 30minutes.

$$SVI = \frac{\text{Percent settling volume}}{\text{Percent suspended solids}} \times 100$$

According to Veenstra and Duijl (1995), in the design of Activated sludge treatment, the process is commonly preceded by primary treatment (screening, grit removal and primary setting), and consist of aeration tanks and secondary setting compartments. The major parameters used in the design are the hydraulic and the volumetric loading rates. They are usually designed with hydraulic retention times ranging from two hours to several days. The retention time largely depends on the design objectives. However, the most important design parameter for activated sludge plant is the sludge loading rate or F/M ratio. The F/M ratio is defined as the daily BOD load to the plant (food F) divided by the microbial biomass (micro-organisms M) in the aeration tank.

Thus

$$F/M = \frac{\text{Amount of substrade}}{\text{Amount of Biomass}} = \frac{Q \times [BOD_i]}{[MLSS] \times V} \quad \text{KgBOD/Kg MLSS/d}$$

Where: Q = Daily flow rate to the plant (m^3/day)

BOD_i = settled influent BOD (mg/L)

MLSS = Mixed Liquor Suspended Solids (mg/L)

V = Volume of the Aeration tank (m^3)

2.6.3 Aerated Lagoons

` An aerated lagoon is a basin between one (1) and four (4) metres in depth in which wastewater is treated either on a flow-through basis or with solids recycling. The microbiology involved in this process is similar to that of the activated-sludge process. However, differences arise because the large surface area of a lagoon may cause more temperature effects than are ordinarily encountered in conventional activated-sludge processes. Wastewater is oxygenated by surface, turbine or diffused aeration. The turbulence created by aeration is used to keep the contents of the basin in suspension. Depending on the retention time, aerated lagoon effluent contains approximately one third to one half the incoming BOD value in the form of cellular mass. Most of these solids must be removed in a settling tank before final effluent discharge as shown in figure 9.

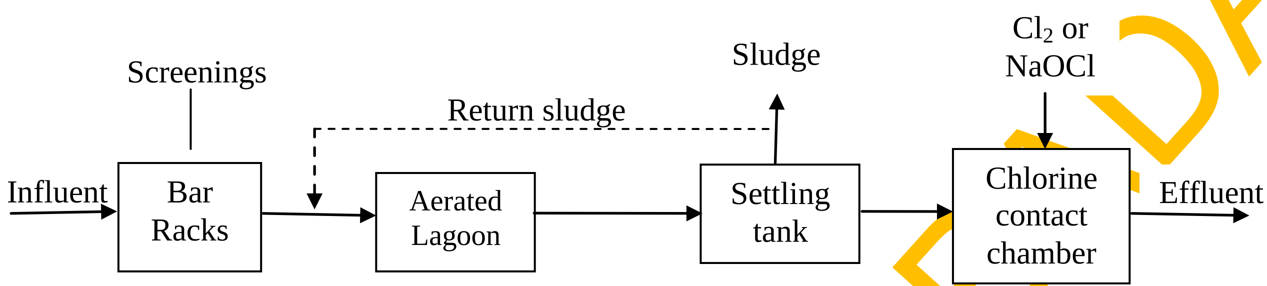

Figure 9: Typical flow diagram for aerated lagoons

All lagoons take advantage of natural processes to treat wastewater. Wind and sunlight on the lagoon surface also plays an important role as do the microbes that live in the wastewater. Natural lagoons are made up of three layers an aerobic (layer with oxygen), an anaerobic (layer with no oxygen) and a facultative (mixed layer). In a constructed aerated lagoon air is pumped into the lagoon to turn the whole pond into an aerobic zone. Adding air to the water speeds up the natural processes that break down organic waste. This means that the lagoon can process more waste in less space. When air is added to the lagoon it changes the environment and the types of microbes that process the wastewater. Different microbes create different chemical reactions as they process waste. The difference in chemical reaction changes or reduces the odours produced by the lagoon (Economic and Social Commission for Western Asia, 2003)

Lagoons have proven to be very adaptable and well suited to tropical (Northern) climates. Examples of an aerated lagoon in the North are Fort Nelson in Alaska, B.C in Canada and Haines Junction in Yukon, Canada. The lagoon in Haines Junction is naturally aerated by the wind, there are no mechanical pumps. When temperatures drop and sunlight disappears in the winter the microbes that do the work of processing waste in the lagoons slow down. This does not mean that that the lagoon stops working. Microbes are still active and solids can settle at the bottom of the pond. When spring returns the microbes in the aerobic level of the pond become very active again. Lagoons are resilient and adaptable to variations in seasonal flows because of the size of the ponds (Qasim, 1999).

2.6.4 On-Site Septic Tank/Soak-away pits System

On-site septic tank/soak-away pit is a treatment method where the wastewater is collected and treated at the site of production. On-site wastewater treatment systems contain three components: a treatment unit which treats water prior to dispersal into the environment; a soil dispersal component which assures that treated water is released into the environment at a rate which can be assimilated; and a management system which assures proper long term operation of the complete system. Disinfection of the treated effluent may be provided prior to dispersal. A typical onsite system consists of a septic tank followed by an effluent distribution system. Alternative treatment systems include aerobic treatment and sand filtration systems.

A septic tank is a tank buried in the ground used to treat sewage without the presence of oxygen (anaerobic). The sewage flows from the plumbing in homes or small businesses establishment into the first of two chambers, where solids settle out. The liquid then flows into the second chamber. Anaerobic bacteria in the sewage break down the organic matter, allowing cleaner water to flow out of the second chamber. The liquid typically discharges through a sub-surface distribution system. Periodically, the solid matter in the bottom of the tank, referred to as septage, must be removed and disposed of properly. Septic tanks are suitable for houses that have both water connection (necessary for flushing toilets) and sufficient land with permeable soil for effluent disposal

The basic treatment mechanisms that occur in the septic tanks include the sedimentation of settleable solids and some pathogenic micro-organisms to the tank bottom; anaerobic stabilization of organic matters contained in the liquid and sludge layers; partial reduction of pathogenic micro-organisms due to anaerobic conditions in the tank. Impermeability of the soil can create problem for the effluent disposal in the use of septic tanks; and in areas where the water table is high, pollution of the groundwater may occur where septic tank is used. Septic tank system is observed to be often used in the satellite areas of the Federal Capital of Nigerian Abuja, although this is not provided for in the Abuja Master Plan.

2.6.5 Trickling Filters

The trickling filter is the most commonly encountered aerobic attached-growth biological treatment process used for the removal of organic matter from wastewater. It consists of a bed of highly permeable medium to which organisms are attached, forming a biological slime layer, and through which wastewater is percolated. The filter medium usually consists of rock or plastic packing material. The organic material present in the wastewater is degraded by adsorption onto the biological slime layer. In the outer portion of that layer, it is degraded by aerobic micro-organisms. As the micro-organisms grow, the thickness of the slime layer increases and the oxygen is depleted before it has penetrated the full depth of the slime layer. An anaerobic environment is thus established near the surface of the filter medium. As the slime layer increases in thickness, the organic matter is degraded before it reaches the micro-organism s near the surface of the medium. Deprived of their external organic source of nourishment, these micro-organisms die and are washed off by the flowing liquid. A new slime layer grows in their place; this phenomenon is referred to as ‘sloughing’ (METCALF and EDDY, INC. 1991).

After passing through the filter, the treated liquid is collected in an under-drain system, together with biological solids that have become detached from the medium. The collected liquid then passes to a settling tank where the solids are separated from the treated waste-water. A portion of the liquid collected in the under-drain system or the settled effluent is recycled to dilute the strength of the incoming wastewater and to maintain the biological slime layer in moist condition as shown in figure 10.

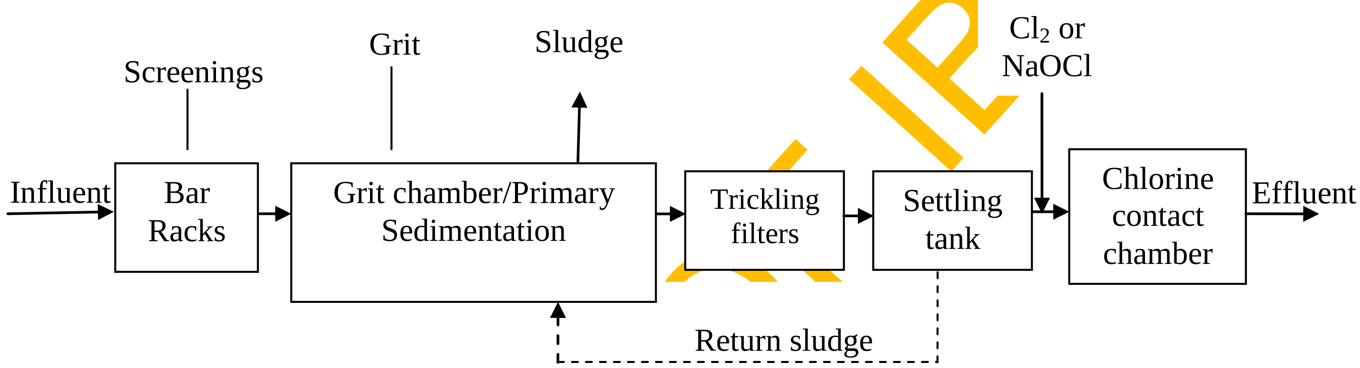

Figure 10: Typical flow diagram for trickling filters

The engineering design of trickling filters is based on three important process parameters: the volumetric organic loading rate (L_V), the organic surface loading rate (OSLR), and the hydraulic surface loading rate (HSLR):

Thus:

i) $$L_V = \frac{\text{Load (KgBOD/d)}}{\text{Volume}_{\text{Filter}}\ (\text{m}^3)} \qquad (\text{KgBOD/m}^3\ \text{filter/d})$$

ii) $$\text{OSLR} = \frac{\text{Load (KgBOD/d)} \times 100}{\text{V. A}_{\text{spec}}} \qquad (\text{gBOD/m}^3\ \text{media surface/day})$$

Where: A_{spec} = Specific filter area per m^3 volume

V = Volume of filter bed (m^3)

iii) $$\text{HLSR} = \frac{\text{Hourly design flow rate Q (m}^3\text{/h)}}{\text{Area}_{\text{filter}}\ A_f\ (\text{m}^2)} \quad (\text{m/h})$$

To compensate for the various filter materials, the volumetric loading rate is frequently replaced by the organic surface loading rate (OSLR) which is defines as: OSLR = 100 × $L_V/A_{specific}$

For a typical natural rock filter, the OSLR equals (13.3 × L_V) assuming a specific surface area of 75m^2/m^3 and L_V expressed in KgBOD/m^3.d (Veenstra and Duijl, 1995).

2.6.6 Rotating Biological Contactors

A rotating biological contractor (RBC) is an attached-growth biological process that consists of one or more basins in which large closely-spaced circular disks mounted on horizontal shafts rotate slowly through wastewater. The disks, which are made of high-density polystyrene or polyvinyl chloride (PVC), are partially submerged in the wastewater, so that a bacterial slime layer forms on their wetted surfaces. As the disks rotate, the bacteria are exposed alternately to wastewater, from which they adsorb organic matter, and to air, from which they absorb oxygen. The rotary movement also allows excess bacteria to be removed from the surfaces of the disks and maintains a suspension of sloughed biological solids. A final clarifier is needed to remove sloughed solids. Organic matter is degraded by means of mechanisms similar to those operating in the trickling filters process. Partially submerged RBCs are used for carbonaceous BOD removal, combined carbon oxidation and nitrification, and nitrification of secondary effluents. Completely submerged RBCs are used for denitrification (METCALF and EDDY, INC. 1991).

Figure 11 shows a typical arrangement of RBCs. In general, RBC systems are divided into series of independent stages or compartments by means of baffles in a single basin or separate basins arranged in stages. Compartmentalization creates a plug-flow pattern, increasing overall removal efficiency. It also promotes a variety of conditions where different organisms can flourish to varying degrees. As the wastewater flows through the compartments, each subsequent stage receives influent with a lower organic content than the previous stage; the system thus enhances organic removal.

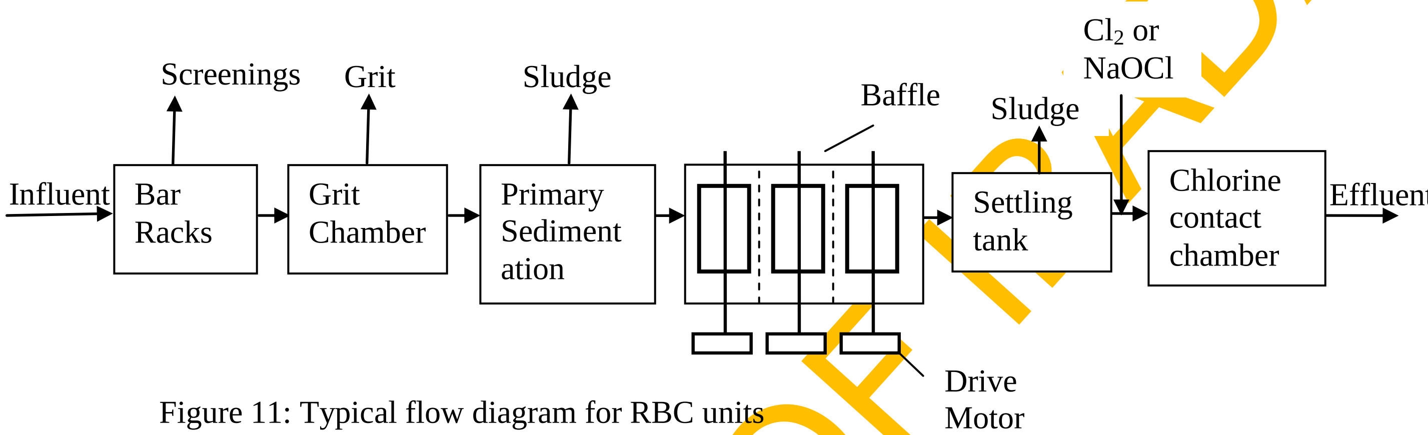

Figure 11: Typical flow diagram for RBC units

2.6.7 Completely Mixed Anaerobic Digestion

Anaerobic digestion involves the biological conversion of organic and inorganic matter in the absence of molecular oxygen to a variety of end-products including methane and carbon dioxide. This involves the transformation of organic matter by a consortium of anaerobic micro-organisms giving the main product as biogas. It is composed of a mixture of methane and carbon dioxide as main components, and di-hydrogen, carbon monoxide and di-hydrogen sulphur as minor components. The metabolic pathway of anaerobic digestion is shown in Figure 12 (Moletta, 2005).

A consortium of anaerobic organisms work together to degrade the organic sludge and wastes in three steps, consisting of hydrolysis of high-molecular-mass compounds, acidogenesis and methanogenesis.

The process takes place in an airtight reactor. Sludge is introduced continuously or intermittently and retained in the reactor for varying periods of time. After withdrawal from the reactor, whether continuous or intermittent, the stabilized sludge is reduced in organic and pathogen content and is non-putrescible. The two most widely used types of anaerobic digesters are standard-rate and high-rate. In the standard-rate digestion process, the contents of the digester are usually unheated and unmixed, and are retained for a period ranging from 30 to 60 days. In the high-rate digestion process, the contents of the digester are heated and mixed completely, and are retained, typically, for a period of 15 days or less. A combination of these two basic processes is known as the two-stage process, and is used to separate the digested solids from the supernatant liquor. However, additional digestion and gas production may occur.

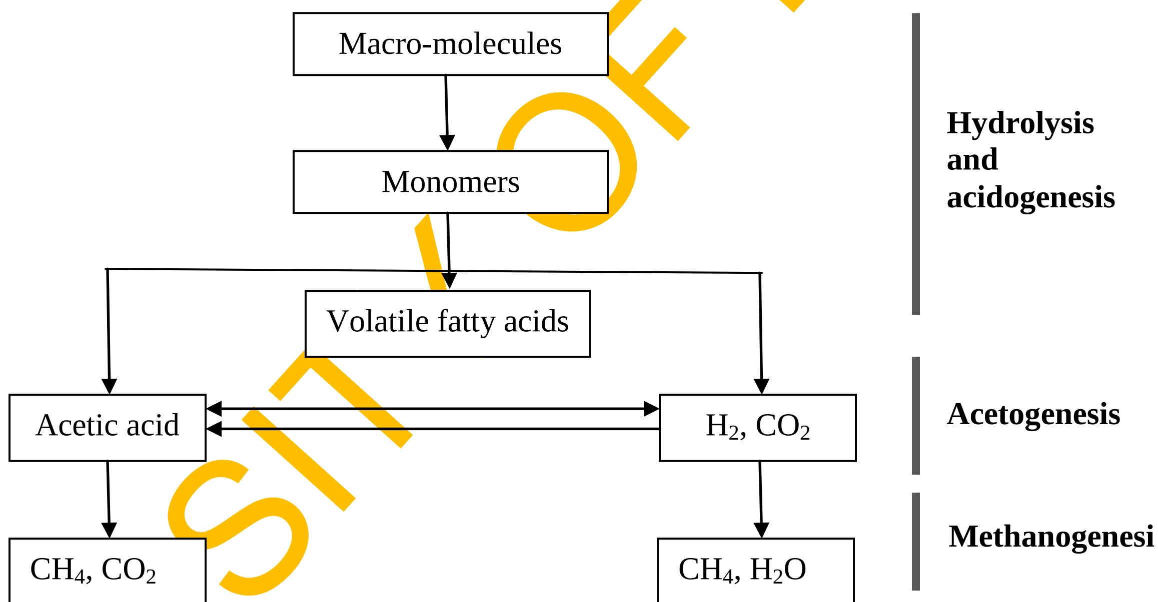

Figure 12: Metabolic pathway of anaerobic digestion

Anaerobic digesters are commonly used for the treatment of sludge and waste-waters with high organic content. The disadvantages and advantages of a system of this kind, as compared to aerobic treatment, stem directly from the slow growth rate of methanogenic bacteria. A slow growth rate requires a relatively long retention time in the digester for adequate waste stabilization to occur; however, that same slow growth means that only a small portion of the degradable organic matter is synthesized into new cells. Another advantage of this type of system is the production of methane gas, which can be used as a fuel source, if produced in sufficient quantities. Furthermore, the system produces a well-stabilized sludge, which can be safely disposed of in a sanitary landfill after drying or dewatering. On the other hand, the fact that high temperatures are required for adequate treatment is a major drawback.

2.6.8 Land Treatment

Land treatment of wastewater is the controlled application of wastewater onto the land surface to achieve a specified degree of treatment through natural, physical, chemical and biological processes within a plant-soil-water matrix. It is the controlled application of wastewater to the soil where physical, chemical, and biological processes takes place as the wastewater passes across or through the soil. The principal types of land treatment are slow rate, overland flow, and rapid infiltration. In the arid western states, pretreated municipal wastewater has been used for many years to irrigate crops. In more recent years, land treatment has spread to all sections of the country. Land treatment of many types of industrial wastewater is also common.

Whatever method is used, land treatment can be a feasible economic alternative, where the land area needed is readily available, particularly when compared to costly advanced treatment plants. Extensive research has to be conducted at land treatment sites to determine treatment performance and study the numerous treatment processes involved, as well as potential impacts on the environment, e.g. groundwater, surface water, and any crop that may be grown.

2.6.8.1 **Slow Rate Infiltration**

In the case of slow rate infiltration, the wastewater is applied to the land and moves through the soil where the natural filtering action of the soil along with microbial activity and plant uptake removes most contaminants. Part of the water evaporates or is used by plants and the remaining is either collected via drains or wells for surface discharge or allowed to percolate into the groundwater. Slow rate infiltration is the most commonly used land treatment technique. The wastewater, which is sometimes disinfected before application, depending on the end use of the crop and the irrigation method, can be applied to the land by spraying, flooding, or ridge and furrow irrigation. The method selected depends on cost considerations, terrain, and the type of crops. Much of the water and most of the nutrients are used by the plants, while other pollutants are transferred to the soil by adsorption, where many are mineralized or broken down over time by microbial action.

2.6.8.2 **Rapid Infiltration**

Rapid infiltration process is most frequently used to polish and recover wastewater effluents for reuse after pretreatment by secondary and advanced treatment processes. It is also effective in cold or wet weather and has been successfully used in Florida, northeastern and arid southwestern states. Large amounts of wastewater are applied to permeable soils in a limited land area and allowed to infiltrate and percolate downward through the soil into the water table below. If the water is to be reused, it can be recovered by wells. The cost-effectiveness of this process depends on the soil's ability to percolate a large volume of water quickly and efficiently, so suitable soil drainage is important.

2.6.8.3 **Overland Flow**

This method has been used successfully by the food processing industries for many years to remove solids, bacteria and nutrients from wastewater. The wastewater is allowed to flow down a gently-sloped surface that is planted with vegetation to control runoff and erosion.

Heavy clay soils are well suited to the overland flow process. As the water flows down the slope, the soil and its microorganisms form a gelatinous slime layer similar in many ways to a trickling filter that effectively removes solids, pathogens, and nutrients. Water that is not absorbed or evaporated is recovered at the bottom of the slope for discharge or reuse (U.S. Environmental Protection Agency (EPA), 2004).

Land treatment has been widely adopted in Australia, New Zealand, Uganda and the United Kingdom for tertiary upgrading of secondary effluent. However, this system is yet to receive adequate attention by the Government in Nigeria.

The use of aquatic plants in wastewater treatment has also been identified as a natural means of wastewater treatment. In particular water hyacinth (*Eichhornia crassipes*) is an aquatic plant that has high rate of nutrient uptake. It therefore present itself along with other members of its family as a useful plant for the treatment of wastewater (Malik, 2007). He also added that this plant is one of the plant species that attracted considerable attention because of its ability to grow in heavily polluted water and with high capacity for uptake of pollutants. It has the ability to absorb inorganic nutrients and store them in its roots, as well as converts nutrients to plant material that can be removed from the water. Water hyacinth along with duckweed and blue algae have found worldwide acceptance in treating wastewater in tropical countries. Plates 3 to Plate 8 capture the scenarios of the wastewater treatment plant at the University of Ibadan which uses water hyacinth for nutrient removal.

Plate 3: Inlet Chamber of the wastewater Treatment Plant at University of Ibadan

Plate 4: Side View of Distribution Chamber at the wastewater Treatment Plant at University of Ibadan

Plate 5: Frontal View of the wastewater Treatment Plant at University of Ibadan

Plate 6: View of One Flow Line of the wastewater Treatment Plant at University of Ibadan

Plate 7: Closer View of a Chamber in the Sewage Works at University of Ibadan

Plate 8: The Drainage System to Avoid Over Flow at the Sewage Treatment Work at University of Ibadan

2.6.8.1 **Factors influencing Land Treatment of Sewage**

The land treatment depends on climate, the type of soil, the type of crops to be grown, the groundwater table and the proper management of the land.

- Climate: The solar radiation, temperature, rainfall, wind and humidity will govern the requirement of sewage for irrigation. These factors influence the evapo-transpiration of water.

- Types of soils: The type of soil, particularly the texture, structure and depth will influence the requirement of water.

- Type of Crops: The water requirements of crops vary with the duration of growth and also with the stage of growth.

2.6.8.2 **Problems Associated with Land Treatment of Sewage**

While it is economical to use sewage for irrigation purposes, it poses several problems to the people handling it. These are sewage sickness of soil, health of farm workers, and quality deterioration of sewage grown crops, ground water pollution and odour problems around.

2.6.8.3 **Sewage Sickness of Soil**

Environmental sustainability depends largely on a sustainable soil ecosystem. When soil is polluted, the physiochemical properties are affected which may decrease its productive potentials (Nwaogu et al, 2012).

Continuous application of sewage on soil leads to destruction of soil porosity and leads to complete loss of crops. It was observed that the fine colloidal particles present in sewage chokes the soil pores and affects the root aeration. On such soil, not even weeds can grow (Pillai, 1955).

2.6.8.4 **Health of Farm Workers:**

Workers on the sewage farm are prone to infections through direct contact with sewage or with sewage irrigated soils. The status of health of sewage farm worker reported from developed countries and from developing countries has been varying. A survey conducted in India in five sewage farms indicated that the percentages of anemia, gastrointestinal diseases, respiratory disease and skin diseases were significantly higher among sewage farm worker as compared to the control group (Central Public Health Engineering Research Institute, 1973).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

Abuja, the study area was created as the New Federal Capital Territory of Nigeria in 1976 after a committee on the location of the Federal Capital of Nigeria carried out an extensive examination of the dual government role of Lagos, its suitability as a National Capital and the possibility of an alternative New Capital City elsewhere in the country accessible to all and spacious. The option of a new Capital City centrally located was considered and the site selected was an 8000 Km^2 area known as Abuja centrally located within Nigeria and easily accessible by all the states of the Federation. Since Abuja was not an existing city, development started immediately after its status was clearly defined by the 1976 FCT Federal Government Decree.

The master plan for Abuja, the Federal Capital Territory (FCT) was then developed to define the general structure and major design elements of the city that are visible in the city's current form. Most of the needed infrastructure including buildings, roads, water; and sewage system has progressed considerably to facilitate the actual movement of the Capital from the densely populated city of Lagos to the New Federal Capital – Abuja. In view of the delay in the completion of the main sewage treatment plant and sewer network for the city; coupled with the fact that several important projects such as houses and public buildings of importance have been completed, simple sewage treatment schemes in the form of Aerators were designed and constructed in designated and isolated areas to enable the usage of these completed facilities. Some of these facilities included the Army Barracks, Staff Quarters, Federal Secretariat, and Legislative Quarters in Gudu etc. Thus, there are thirteen wastewater treatment aerators all around the city handling wastewater generated from between 3000 to 10,000 inhabitants of FCT.

In carrying out this research, an evaluation of the study area was conducted through the following approaches amongst others.

1. Carrying out a study review of the Abuja master plan with particular reference to the wastewater management schemes. This study was subsequently followed by site visits to identify what has been done in terms of practical construction or provision of sewer lines, manholes, treatment plants and other sewerage infrastructure.
2. In order to obtain additional information, oral interviews were conducted amongst personnel currently charged with the responsibility of providing and managing the sewerage infrastructure as well as other stakeholders.
3. Data were also collected at the six sewage treatment plants both at their influent and effluents to determine the qualities of influent sewage and the discharge to the environement from the sewage treatment plants. The collected sample data were analysed using standard analytical and statistical methods as described in standard methods (APHA, 1976). The results were subsequently reviewed and compared with acceptable international and World Health Organization (WHO) standards to check level of acceptance of effluent to the environment.

3.1.1 Collection of Samples within the Project Area

Materials used during samples collection at the various project sites include the following: Masking tape (label), Funnel, Sampling bottles, pH meter, Flow rate meter, CO 150 conductivity meter, Ice pack, Ice bag (box), Water sampler, Safety clones, Nose mask, laboratory coat, Safety boot, etc. The wastewater samples were collected using sterilized sampling bottles, well capped and packed into ice-bag (box). This helped to acclimatized the samples condition for onward transport to the laboratory for testing. Brown glass bottles were filled to the brim so that air is not trapped.

Wastewater samples were collected from various sewage treatment plants/aerators in the project area for a period of six months on weekly basis spanning from October 2007 to March 2008 to give a good representation of generated wastewater during sampling periods and also during the raining and dry seasons. The characteristics of the wastewater were evaluated at influent and at effluent points to ascertain the level of treatment achieved by the various wastewater treatment plants. Plate 9 to Plate 20 in Appendix I are photographs captured during site visit and collection of wastewater sample at Gudu project site and at the laboratory in Abuja where the analysis of were conducted.

3.2 Laboratory Analysis of Collected Wastewater Samples

Samples volume of 2Litres was collected from the different sewage treatment plant locations within the city. These wastewater samples were analyzed at the Abuja Environmental Protection Board laboratory for several constituents using the analytical method. The different wastewater constituents and methods of analysis used are detailed below:

3.2.1 pH

The lovi bond checkit has the ability to test for pH ranging from 3.0-12.0 using pH universal tablets. This method was used to test the samples collected at points. Samples were collected in 250ml sampling bottles and tested for their pH immediately. The samples in the bottles were packed in a plastic cooler containing ice park to maintain the temperature of same before analysis in the laboratory.

The checkit has compartment which were rinsed with the water sample, then refilled to the 10ml mark. A pH universal tablet was added to the sample in the compartment, crushed with a clean stirring rod and replaced by a stopper held firmly in place and repeatedly inverted several times until the tablet was fully dissolved. The colour produced in the sample was compared against the checkit standard colour using daylight and selection of the nearest colour match was read which equal the pH value. The same procedure was adopted for all the collected samples.

3.2.2 **Temperature, Conductivity, Salinity and Total Dissolved Solids (TDS)**

Hach CO150 conductivity meter by HACH Industrial Partners is a potable analytical meter used for the measurement of the above parameters namely temperature, conductivity, salinity, total dissolved solids. It consists of a probe which has the ability to measure these parameters and also temperature. The meter consist of a mode button at which toggling from one parameter to another are made when the meter is put on reading being observed through the movement of the cursor on the liquid crystal display (LCD) unit. End point reading of each parameter was obtained by a ready sign indicator. Probe was rinsed with diluted water and meter put to rest, same procedure was adopted for all the samples.

3.2.3 **Iron**

The HI 3834 Iron test kit (colorimetric method) has the capability to test for iron at the range 0 - 5mg/L Iron, the equipments used are:

- HI 3834 – 0 reagents
- colour comparator tube
- Plastic vessel (20mL)

The cap from the plastic vessel is removed and the plastic vessel rinsed with water sample, then filled to the 10mL mark. One packet of the reagent HI3834-0 was added to the sample and capped and mixed until solids dissolves. Cap was then removed and solutions transferred into the colour comparator cube and allowed to settle for four minutes, colour match from the solution with the comparator standard was read in mg/L of Iron.

3.2.4 **Nitrate**

The HI 3874 Nitrate test kit (colorimetric method) has a test range for nitrate from 0-50mg/L NO_3 – N.

- HI 3874 – 0 reagent
- A colour comparator
- A glass cuvet with cap

One packet of the reagent HI 3874 – 0 was added to 10mL of sample initially introduced into a glass curvet, capped and shaken vigorously for exactly 1 minute. The mixture was then allowed to stand for four minutes to allow full development of colour in the sample. The cap of the curvet was removed and the comparator tube filled with 5ml of the treated sample the colour match between the sample and comparator was read and result obtained as Mg/L nitrate–Nitrogen. To convert the reading to mg/l of Nitrate (NO_3) value obtained was multiplied by a factor of 4.43.

3.2.5 **Total Hardness**

Water hardness is caused by the presence of calcium and magnesium salts. High level of hardness prevents the formation of lather with soap and can cause scaling in water system, particularly boilers and steam generating plants. The hardness test provides a simple method of checking water hardness from a range 0-500mg/L $CaCO_{3:}$

Calcium and magnesium ions are completed by reaction with EDTA. Excess calcium and magnesium ion react with specific indicators to produce a distinctive amount of EDTA with Erichrome black as indicator. The test carried out involved addition of tablets one at a time to a sample of water until the colour changed from the plum red to blue. The result was calculated from the number of tablet used in relation to the volume of water sample taken. i.e. 50ml.

- ✓ One – Hardness tablet was added to sample of water (50mꝉ) shaken until the tablet dissolved.
- ✓ More tablets were added one at a time until the colour of the solution change from plum red to blue.
- ✓ Noting the number of tablets the calculation below is used to compute result (No. of tablets x 40) – 20.

  = mg/L $CaCO_3$ (Hardness).

3.2.6 **Phosphate**

Using vanadomolybdate tablets, phosphate was measured at the range 0-26.5mg/L, the use of colour comparator checkit was employed. The stopper of the comparator kit was removed, compartment rinsed with water sample and then filled to the 10ml mark. One vanadomolybdate tablet was added, crushed with clean stirring rod and capped, held firmly in position and repeatedly inverted several times until the tablet is fully dissolved and allowed to settle for 10 minutes. After this, a final shake was made to the sample and colour produced was compared with that of the test kit standard. Readings were rendered in mg/L of phosphate, same procedure was repeated for all samples

3.2.7 **Aluminium**

The lovi-bond test kit was used to determine the concentrate of aluminum in the sample collected. It has the capacity to sample the aluminum at the range of 0-0.5mg/L.The test was carried out using 10mL sample filled into the compartment having a standard colour match. One aluminum tablet was added to one of compartment crushed with a clean stirring rod and mixed to dissolve. A second aluminum tablet was also added to the same compartment crushed with the stirring rod and capped and compartment inverted several times until both tablets were fully dissolved, preparation was allowed to stand for 10min.

After this period, colour produced was compared against the standard using daylight selecting the nearest colour match; the L/gm of aluminum was read. The same procedure was repeated for all samples.

3.2.8 **Sulphate**

This is a method for sulphates test. The sulphates Turbidity tablet is a name given to the tablet which makes turbid the sample. The whole process gave a description of how the sample becomes turbid when the tablet is added to the sample. Note that this is not a turbidity test.

The sulphate check (Turbidity method) provides a simple method of checking sulphate level in water at the range of 0-400mg/L of SO_4^{2-}

Sulphate test kit:

(1) Sulphate tablets
(2) One double tube assembly
(3) one 5mL syringe

- The double tube assembly was separated and the round outer tube filled to the top with water sample. One sulphate (turbidity) tablet was added and capped and shaken to mix. A cloudy solution indicated the present of sulphate.
- The graduated inner tube was inserted into the round tube and we ensured that cap was in position in the round tube.
- Viewing from above, the inner tube was moved up and down until the black spot was just no longer visible. Then read the graduation mark on the inner tube with the top of the solution in the tube immediately. The value obtained (read) was multiplied by 2, this gave the level (concentration) of sulphate as mg/L of SO_4.

3.2.9 **Chlorine**

The Lovi-bond checkit has the ability to test for free combine and total chorine using DPD no. 1 and DPD no. 3 tablets.

- 10mL of sample was introduced into the test kit compartment and one tablet of DPD was placed and crushed with a clean stirring rod with the stopper in place, the kit was inverted several times until the tablet was fully dissolved.
- The colour produced was compared with the kits standard color using daylight. The nearest colour match was read of the free chlorine. To measure the total and combined chlorine, the stopper was removed and one DPD 3 tablet was added to the same compartment as to that DPD 1, crushed and stirred until the tablet was fully dissolved. Allowed to stand for 2 minutes, the colour was then compared in the same way as for free chlorine. The nearest colour was selected which indicated the total chlorine. The difference between the free chlorine level and the total chlorine level equals the combined chlorine concentration in the samples.

3.2.10 **Chloride**

The HI 3815 chloride test kit is a mercuric nitration method and can give a test range from 0-1000mg/L of chloride. It is a set of kit containing

- Diphenylcarbozone indicator
- A dropper
- Nitric acid solution
- Mercuric Nitrate solution
- Calibrated vessel
- Calibrated syringe with tip.

The cap of the vessel was removed and the vessel rinsed with sample to be analyzed filled to the 5mL mark and capped. Two (2) drops of the indicator was added to the sample and the vessel was swirled in a tight circle. The solution then became reddish – violet. The addition of nitric acid solution dropwise made the solution turn yellow. The titration syringe was used to dispense titration solution drop wise. After each drop, careful observation was made to observe the colour formation from yellow to violet. The milliliters of the titration solution dispensed from the syringe were read and value multiplied by 1000 to obtain mg/L of chloride.

3.2.11 **Biochemical Oxygen Demand (BOD_5)**

Definite precautions were observed in collection of samples to ensure that the samples were good representation of the flow under examination.

Equipment used – Aluminum dipper, glass stopper bottle, pipettes: 0.1ml, 1ml, 5ml, 250ml graduated cylinder 500ml, Erlenmeyer flask, burette stands and clamp dropping bottle, Analytical Balance, 20^{o}C water bath (incubator)

Reagent: (a) Conc. $H_2 SO_4$

(b) 450g $MnSO_4$

(c) Alkaline iodide azide 500g NaOH 135NaI, 1g N_aN_3 in 1.00m^{l} of alkaline iodide solution

(d) N/40 $Na_2 S_2 O_3$ (one volume to 300 volumes in distilled water.

(e) 5g starch (indicator) (5%)

(f) 0.25g $FeCl_3 6H_2O$

(g) 27.5g $CaCl_2$

(h) 22.5g $MgSO_4$. $7H_20$

(i) (8.5g KH_2PO_4, 21.75g K_2Hp O_4, 33.4g Na_2HPO_4. $7H_2O$ and 1.7g NH4CL in about 500mL DH_2O and dilute to 1L) = Ammonia phosphate buffer pH = 7.2

(j) N/40 sodium sulfite (1.575g in 1000ml) distilled water was prepared daily before use.

Procedure:-

(1) Aerate about nineteen litre of distilled water

(2) Add 18.9mL of ferric chloride solution

18.9mL calcium chloride solution

18.9mL magnesium sulfate solution

18.9mL ammonium phosphate solution was used to dilute water sample and mix.

(3) Siphon the dilution water into 300ml glass stopper bottle until the bottle is about one half full.

(4) To the half – full bottle add with a pipette the desired quantity of sample possible quantities

- settled sewage = 2-3%
- Physically treated sample = 3-7%
- Raw sewage = 1-2%
- Biologically treated H_20 = 5-30%
- River water = 25 – 100%

(5) The bottle was filled to the neck with dilution water and stopper so that no air bubbles are entrained (preparation should be in duplicate)

(6) Each preparation in a 20°C was placed in an incubator (water bath) and allowed to stay for 5 days and the one prepared used to determine the initial dissolved oxygen of the sample.

(7) After 5 days, determination of dissolved oxygen was carried out (Ademoroti, 1996).

Calculation: $$\frac{DO_1 - DO_5}{\%\ \text{dilution}}$$

Where: DO_1 = initial dissolved oxygen

DO_5 = final dissolved oxygen

% dilution = Ratio of sample to dilution H_2O

Result = The BOD_5 at 20^oC equals the volumes of thiosulphate used for the titration for the initial and final dissolved oxygen as calculated in the formulae.

3.2.12 **Chemical Oxygen Demand (COD)**

Samples were collected in glass bottles and tested for COD without delay. Samples were heated for 2hrs to boiling point of water in a water bath; this is for oxidation of samples with chromic and strong sulfuric acid. The digestion was done with the help of potassium permanganate. After digestion the remaining unreduced $KMnO_4$ is titrated with sodium thiosulfate to determine the amount of $KMnO_4$ consumed and the oxidised organic matter calculated in terms of oxygen equivalent.

A. Apparatus:-

250mL conical flask
COD water bath pipettes,
Foil paper, magnetic stirrer
Stand and clamp
Burette, measuring cylinder,

B Reagents:-

0.1N $KMnO_4$
4.0N H_2SO_4
10% KI
0.1N $Na_2S_2O_3$
1% starch solution

C Procedure:-

Using 250mL measuring cylinder, 50mL of sample was measured into the conical flask, heated on water bath to boiling points; 5mL of KMnO4 was added to the sample. After the heating preparations were cooled to about 40 – 45^0C, 5mL KI and 10mL $4H_2SO_4$ were added respectively. $Na_2S_2O_3$ was used as the titrant and starch solution as an indicator during titration. During titration, the solution became pale-yellow, 1mL of the indicator was added as titration continued until the blue color disappeared (Note that end point of titration is a colorless solution). Blank sample was also run using distilled water.

$$\text{COD mgO}_2\text{/L} = \frac{(a - b) \times N \times 8 \times 1000}{\text{ML sample}}$$

Where

a = ML $Na_2S_2O_3$ used for blank
b = ML $Na_2S_2O_3$ used for sample
N= Normality of the $Na_2S_20_3$ used for titration.

3.2.13 **Bacteriological Analysis**

13g of dehydrated ingredient of lactose broth was added to distilled water, mixed thoroughly in a 500mL conical flask; 10mL of the mixture was dispensed into vial tubes containing durham tubes in an inverted position. The preparations were sterilized using an autoclave at 121^{o}C for 15minutes and after the sterilization; the preparations in the autoclave were brought out and allowed to cool to about 45^{o}C.

Samples were inoculated into the sterilized medium at the dilutions of 10mL, 1mL, and 0.1mL for each samples preparation respectively. Each of the samples was further subdivided into 15 sterilized medium: 10mL into 5set of tubes, 1mL into 5set of tubes and 0.1mL into 5set of tubes.

After the inoculations, the tubes with their content were all inverted so that the durham tubes in them were filled with the mixture with air trapped in them. Preparations were incubated in the incubator for 24hours. This process is to determine lactose fermenting organisms which with the combine positive (bubble firmed) reaction gives the Most Probable Number of bacterial in each sample.

All these procedures were carried out using aseptic techniques and conducive atmospheric conditions with material:-

Fermentation tubes, Durham vials, Autoclave, incubator, pipettes, (10mL, 1mL, 0.1mL) conical flask, Hot oven, pipette bulb, lamina flow (Hood), sterilized Petri dishes, inoculating loop, burner, thermometers.

3.2.13 **Media Preparation**

Dehydrated ingredient of eosin methylane blue, brilliant green agar and deoxychlolate citrate agar were weighed, dissolved in distilled water as described by Titan Biotec Limited (manufacturer): 9.25g, 13g, and 11.375, respectively in 250mL distilled water in a conical flask. For EMB and BGA, these media were corked with cotton wool and then with foil paper and then autoclaved at 121^{o}C for 15min. DCA on the other hand was heated on a bunsen burner and then brought to boiling for the ingredient to be perfectly dissolved and to be sterilized. All media was brought to a temperature of about 40^{0}C-45^{0}C after sterilization/heating and then poured into sterilized Petri dishes (15-20mL) into each plate and allowed to stand for some times (seconds) for it to solidify then ready for sample to be inoculated i.e. (culturing).

3.2.14 **Vale-port (Flow rate meter)**

The vale port “Bray stoke” current flow-meter is an instrument being designed to withstand long period of operation under water. It is also designed to accurately measure water velocity in open channels with flows varying from 0.03 m/s to 10m/s. The flow meter is available with both wading and suspension setting to allow the equipment to be employed in a wide variety of application.

The basic principle of the meter is to open and close a read switch by rotating magnets around it to open and close a circuit producing a pulse. The pulse count is displayed on one of the liquid crystal display (LCD) in the control circuit. A bias magnet fitted into the meter hub produce a strong magnetic field and allows only one pulse per impeller revolution. The only moving part of the meter is the neutrally buoyant impellers which house the magnet.

The meter was used in a wading mode principle as the water level permits the operator to make measurements of velocity at the required intervals and depths. The centimeter marking on the wading rods permits the meter to be accurately positioned at the required height in the water column and also to establish total depth to enable profile depths to be calculated. The meter was run at a fixed average display at a time 20 second running period after which values in m/s were recorded.

3.3 Statistical Analysis of Data

Having carried out laboratory tests on the collected wastewater samples, the obtained data were analyzed statistically using One-Way ANOVA (Post Hoc Test, LSD or Duncan), for comparison of means, Descriptive Analysis, and Multivariate Regression Analysis.

These statistical analysis were carried out using the following software: Microsoft-Excel, SPSS Statistic 17.0 and STATA 8.

- **One-Way ANOVA (Post Hoc Test, LSD or Duncan)**

A One-Way Analysis of Variance is a way to test the equality of two or more means at one time by using variances.

Assumptions:

- The populations from which the samples were obtained are normally or approximately normally distributed.
- The samples are independent
- The variances of the populations are equal

Hypothesis 1:

H_0 (null hypothesis): all population means are equal

H_1 (alternative hypothesis): at least one of the mean is different

Between Group Variations: the variation due to the interaction between the samples is denoted Sum of Squares (SS (B)) for sum of squares between groups. The variance due to the interaction between the samples is denoted MS (B) for Mean Square Between groups.

Within Group Variations: the variation due to differences within the individual samples denoted Sum of Squares (SS (W)) for sum of squares within groups. Each sample is considered independently, no interaction between samples involved. The variance due to the difference within individual samples is denoted MS (W) for Mean Square Within groups.

Decision Rule: If the between variance is smaller than the within variance, then the means are really close to each other and therefore, accept the claim that they are all equal. Furthermore, the decision will be to reject the null hypothesis if the test statistic from the table is greater than the F critical value.

- **Multivariate Regression Analysis**

Modeling of Effluent Temperature and Sample BOD and Total Nitrogen

In order to obtain the correlation coefficient between effluent temperature and sample BOD and total nitrogen (Nitrate and Ammonia), five major constituents of the wastewater sample were correlated.

The five major constituents are:

1- Temperature

2- Nitrate

3- BOD_5 at 20^oC

4- COD

5- Microbial Content (MPN)

Hypothesis 2:

H_0: $\beta_i = 0$ (The coefficient is not significant)

H_1: $\beta_i \neq 0$ (The coefficient is significant)

Decision Rule

Reject H_0 (null-hypothesis) if **P-value** $\leq \alpha$ (level of significance = 0.05

3.4 Appraisal of Abuja Waste Water Management System

The wastewater management system for Abuja was appraised and categorized into generation, collection and treatment approaches for easy evaluation and identification of where improvements can be recommended. These different categories are discussed and analyzed in this section.

3.4.1 Wastewater Generation System

The Federal Capital Territory, Abuja is basically an administrative centre for Nigeria. Hence, the major sources of wastewater are domestic sources from households and public buildings. However, additional wastewater is generated from hospitals, and some factories located within the industrial layout. It is important to note that wastewater generated from factories, hospitals are expected to be pre-treated at the sources of generation before discharge to public sewers to reduce the load on public sewage treatment plants. The provided sewage treatment plants are thus expected to handle liquid waste of domestic origin.

Analysis of the sources of wastewater generation today in Abuja shows that significant quantity of up to 90% is domestic wastewater. The industrial layout is yet to be developed and as such has insignificant contribution to the generated wastewater within Abuja.

3.4.2 Wastewater Collection System

The wastewater collection system in Abuja is through the centralized system were wastewater is collected from households into district sewers. These district sewers discharge the wastewater into trunk interceptor sewer lines that finally transfer the wastewater to the treatment plants.

Analysis of the wastewater collection system in Abuja shows that not all the districts have the interceptor sewer lines to convey the wastewater to a treatment plant. Most of the districts in phase II of the FCC do not have the interceptor sewer lines, thus their sewage is either conveyed to a nearby cesspool or in some cases, and residents illegally construct septic tanks which are not in the master plan. In some other cases, sewer lines are constructed to a sewage aerator that is designated to handle the sewage generated from that area. Examples of such arrangement are the Army barracks, Legislative quarters etc.

In the satellite towns and area councils, there are no sewer lines or treatment plants to handle generated sewage. The wastewater is collected into septic tanks and cesspools only even though the master plan provided for central sewage system for the entire Federal Capital Territory.

3.4.3 Treatment Plant

The sewage treatment systems currently used in the handling of generated waste water in FCT is the Activated Sludge System and its various modifications into sewage aerator, and extended aeration system. These treatment plants are mainly designed for temporary purposes apart from the main Wupa Basin sewage treatment plant that has all the components including sludge handling facilities.

The evaluation carried out revealed that only some parts of the Federal Capital City (FCC) and some areas and the barracks have the central sewage network with its associated treatment facility. Most areas with high population are not covered by the sewage treatment facilities. Most other areas are forced to construct septic tanks and soak away pits which are obsolete and not acceptable for a modern city like Abuja.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Composition of Wastewater in Abuja

The quality of generated wastewater in Abuja was evaluated by carrying out laboratory analysis of samples at influent and effluent points of six sewage treatment plants in the city. The results of these analyses vary depending on the period of the year. It was observed that during the raining season, there are lots of infiltrations of rainwater into the sewer lines from joints and sometimes through manholes that are not high enough from the ground levels. Such developments increase the quantity of sand and other particulate objects in the treatment plants. Even though, significant quantities of suspended particles are eliminated at the treatment plant screens, fine particles such as sand still find their way into the treatment plant aeration basins. This development significantly affects the biodegradation process in the Aeration basin when the plants are functional.

The average characteristics of wastewater generated in six existing Wastewater Treatment Plants in Abuja was evaluated. Based on the laboratory analysis, the results obtained are shown in the Tables 4.1 to 4.12.

The average results of the analysis was collated and analyzed for each month. It was generally observed that the results are generally not okay in comparison with acceptable international and World Health Organization (WHO) standards. The outcome of this analysis could be attributed basically to the lack of proper functioning of the treatment plants as a result of faults in the electromechanical components of most of the plants.

4.2 Results of Laboratory Analysis Conducted on Samples Collected at Different Locations of the Sewage Treatment Plants in FCT

Key Description of the Units of Parameters

MPN(Per 100mL)	Most Probable No of Bacteria
A=	Influent
B=	Effluent
mg/L	Milligramme per litre
%	Percentage
g	Gram
^{o}	Degree
µS/cm	Micro-siemen
Sp	Specie
rps	Revolution per second

Table 4.1 : Physiochemical and Microbial Component of Wastewater from Niger Barrack Sewage Aerator (STP), Abuja

	PARAMAETER	OCT		NOV		DEC		JAN		FEB			EQUIPMENT	METHOD OF
		A*	B+	A*	B+	A*	B+	A*	B+	A*	B+	STD^a	MODEL	ANALYSIS
1	pH	7.83	7.80	5.68	5.70	6.85	6.49	7.24	7.26	6.5	6.4	6-9	LOVIBOND TEST KIT	COLORITY
2	Temperature (oC)	18.5	19	19.2	19.4	20.8	20.6	22	22.1	20.0	20.2	40	CO150 (HACH)CONDUCTIVITY METER	
3	Salinity (%)	0.2	0.2	0.8	0.6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	"	
4	Dissolve oxygen (mg/L)	3.7	3.1	0.4	0.3	0.8	0.6	2.8	2.61	0.4	0.4	4		
5	Conductivity fus	860	771	1544	469	333	323	123	121	120	117	50-125	CO150 (HACH)CONDUCTIVITY METER	
6	Total dissolve solid (mg/L	762	754	752	223.3	158	153	602	600	501	452	2000	"	
7	Flow Rate (R/sec) m/s	0.39	0.35	1.40	1.36	1.36	1.35	1.33	1.29	1.14	0.76		0012B CURRENT FLOW METER	
8	Hardness (mg/L)	175	125	1.2	100	60	60	80	80	60	60	200	LOVIBOND TEST KIT	COLORITY
9	Nitrate (mg/L)	9.8	9.8	10	8	0.5	0.45	2.1	2	5	8	20	LOVIBOND TEST KIT	COLORITY
10	Iron (mg/L)	1	1	0.5	0.38	0.5	0.5	4	3.81	0.5	0.5	20	"	"
11	Chloride (mg/L)	211	197	280	100	100	50	220	212	30	41	600	"	"
12	Suphate (mg/L)	240	150	180	110	160	80	278	274	200	200	500	"	"
13	Aluminium (mg/L)	0.1	0.1	0	0	0.1	0.1	0	0	0	0	-	"	"
14	Hydrogen peroxide (mg/L)	0	0	0	0	0	0	0	0	0	0	-	"	"
15	Total Chlorine (mg/L)	0.46	0.44	2	0.8	0.20	0.20	0.5	0.5	0.56	0.52	-	"	"
16	Free Chlorine (mg/L)	0	0	0	0	0.09	0.09	0.1	0.1	0	0	1.0	"	"
17	Combine chlorine (mg/L)	0.46	0.44	2	0.8	0.11	0.11	0.4	0.4	0.56	0.52	-	"	
18	BOD (mg/L)	68	60	272	26.1	95	83	38	44	58	56	30	Iodometric method of Azide modification	
19	COD (mg/L)	187	171	204	195	180	179	203	205	199	192	80	OPEN REFLUX METHOD	
20	Fiterable solid (g)					0.08	0.01					-		
21	Suspended solid (mg/L)					-	-					30		
22	Total solid(g)					0.2370	1.08					-		
23	Gramic Matter (g)					0.08	0.01					-		
24	MPN/100Ml	178	115	190	240	240	6x10	310	211	415	184	400mpN/n	FERMENTATION TUBE METHOD	

A* Influent B$^+$ Effluent STD^a Acceptable Standard by Federal Ministry of Environment

Table 4.2 : Flow rates for wastewater to Niger Barrack Sewage Aerator (STP), Abuja

[Flow Rates X 10-3 m3/sec]

TIME OF THE DAY FOR SAMPLING	OCT		NOV		DEC		JAN		FEB	
	A*	B+	A*	B+	A*	B+	A*	B+	A*	B+
MORNING 8.15am	7.1	6.9	6.5	6.3	6.5	6.4	6.5	6.4	4.1	4
AFTERNOON 12.15pm	6.3	6.2	6.1	6.3	5.5	5.4	5.3	5.2	5.9	1.4
EVENING 4.15pm	6.8	6.6	6.3	6.8	6.3	6.3	6.1	5.8	5.4	5.4
AVERAGE FLOW RATE PER DAY	6.7	6.6	6.3	6.5	6.1	6	6	5.8	5.1	3.6

A* Influent B+ Effluent

Table 4.3 : Physiochemical and Microbial component of Wastewater from Mogadishu Sewage Aerator (STP), Abuja

	PARAMAETER	OCT		NOV		DEC		JAN		FEB			EQUIPMENT	METHOD OF
		A*	B+	A*	B+	A*	B+	A*	B+	A*	B+	STD[a]	MODEL	ANALYSIS
1	pH	6.43	6.9	6.89	6.47	7.27	7.94	7.0	7.1	7.47	7.3	6-9	LOVIBOND TEST KIT	COLORITY
2	Temperature (oC)	34.2	34.4	26.3	26.3	28.6	27.9	28.8	28.7	27.2	27.3	40	CO150 (HACH)CONDUCTIVITY METER	
3	Salinity (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	"	
4	Dissolve oxygen (mg/L)	2.49	3.2	2.8	2.5	0.7	0.5	0.1	0.12	5.01	5.05	4		
5	Conductivity fus	902	811	860	851	469	609	286	291	453	321	50-125	CO150 (HACH)CONDUCTIVITY METER	
6	Total dissolve solid (mg/L	850	654	300	285	1172	901	136	128	854	710	2000	"	
7	Flow Rate (R/sec) m/s	1.79	1.67	1.64	1.60	1.89	1.76	1.36	0.58	0.54	0.52		0012B CURRENT FLOW METER	
8	Hardness (mg/L)	160	140	175	125	60	52	20	20	80	80	200	LOVIBOND TEST KIT	COLORITY
9	Nitrate (mg/L)	4.49	4.47	8.88	8.86	8.49	7.56	4.43	4.40	1.52	1.55	20	LOVIBOND TEST KIT	COLORITY
10	Iron (mg/L)	2.11	2.10	1	1	3.2	2.7	0.5	0.48	0.23	0.23	20	"	"
11	Chloride (mg/L)	221	210	50	47	-	-	101	100	101	112	600	"	"
12	Phosphate (mg/L)	1.88	1.82	4	3	10.2	10.0	3	3	2.76	0.08	5	"	"
13	Suphate (mg/L)	278	274	100	89	80	80	100	60	90.1	89.1	500	"	"
14	Aluminium (mg/L)	0.1	0.1	0	0	0	0	0.1	0.07	0	0	-	"	"
15	Copper (mg/L)	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.16	0.02	0.01	<1	"	
16	Hydrogen peroxide (mg/L)	0	0	0	0	0.0	0.0	0.1	0.0	0	0	-	"	"
17	Total Chlorine (mg/L)	1.5	1.8	1.5	0.9	0.80	0.60	0.79	0.40	0.5	1.2	-	"	"
18	Free Chlorine (mg/L)	1.5	1.8	0.05	0.04	0.08	0.06	0.07	0.07	0.1	0.1	1.0	"	"
19	Combine chlorine (mg/L)	0	0	1.45	0.86	0.72	0.54	0.72	0.67	0.4	1.1	-	"	
20	Amonia (mg/L)	-	-	-	-	-	-	0.10	0.08	-	-	-		
21	BOD (mg/L)	116	74	54	51	30	24	60	62	52	49	30	Iodometric method of Azide modification	
22	COD (mg/L)	730	610	197	192	87	68	365	370	330	230	80	OPEN REFLUX METHOD	
23	Fiterable solid (mg/L)					0.0810	0.08					-		
24	Suspended solid (mg/L)					-	-					30		
25	Total solid(g)					1.2530	0.99					-		
26	Gramic Matter (g)					0.0790	0790					-		
27	Inorganic Matter (g)					0.0020	0009					-		
28	MPN/100Ml	12.11X1(	1X10	240	210	1.6X10	1.6X10	1400	1240	40X10	11X10	400mpN/n	FERMENTATION TUBE METHOD	

A* Influent B+ Effluent STD[a] Acceptable Standard by Federal Ministry of Environment

Table 4.4: Flow rates for Wastewater to Mogadishu Barrack Sewage Treatment Plant

[Flow Rates X 10-3

TIME OF THE DAY FOR SAMPLING	OCT		NOV		DEC		JAN		FEB	
	A*	B+	A*	B+	A*	B+	A*	B+	A*	B+
MORNING 8.15am	9.9	9.5	8.7	8.1	9.5	8.6	9	3.5	3.2	3.2
AFTERNOON 12.15pm	5.1	4.5	6.5	6.3	7.2	6.7	4.9	0.7	1.9	1.8
EVENING 4.15pm	9.2	8.5	7	7.2	8.8	8.5	4.5	3.7	2.2	2.2
AVERAGE FLOW RATE PER DAY	8.1	7.5	7.4	7.2	8.5	7.9	6.1	2.6	2.4	2.4

A* Influent B+ Effluent

Table 4.5 : Physiochemical and Microbial component of Wastewater from Wuye Treatment Plant (STP), Abuja

	PARAMAETER	OCT		NOV		DEC		JAN		FEB			EQUIPMENT	METHOD OF
		A*	B+	A*	B+	A*	B+	A*	B+	A*	B+	STD[a]	MODEL	ANALYSIS
1	pH	7.5	7.2	6.66	5.67	5.97	5.97	7.0	7.2	7.1	7.9	6-9	LOVIBOND TEST KIT	COLORITY
2	Temperature (oC)	30.4	30.2	20.5	20.6	22.7	23.0	26.3	26.0	28.9	29	40	CO150 (HACH)CONDUCTIVITY METER	
3	Salinity (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	"	
4	Dissolve oxygen (mg/L)	3.5	4.2	0.91	0.7	4	3	1.5	1.4	2.5	3.8	4		
5	Conductivity fus	215	135	770	752	780	791	254	249	125	115	50-125	CO150 (HACH)CONDUCTIVITY METER	
6	Total dissolve solid (mg/L	910	8'90	404	290	201	282	120	107	208	198	2000	"	
7	Flow Rate (R/sec) m/s	1.05	1.56	1.26	1.20	0.79	1.57	1.48	1.45	1.40	1.26		0012B CURRENT FLOW METER	
8	Hardness (mg/L)	80	80	80	80	60	60	20	20	60	40	200	LOVIBOND TEST KIT	COLORITY
9	Nitrate (mg/L)	4.56	3.66	8.5	80	30	20	0	0.28	1.57	1.52	20	LOVIBOND TEST KIT	COLORITY
10	Iron (mg/L)	2.09	1.99	2	1	0.1	0.1	0.5	0.22	0.15	0.10	20	"	"
11	Chloride (mg/L)	350	201	120	50	40	40	-	-	102	98	600	"	"
12	Phosphate (mg/L)	12.2	10.9	13	10.3	18	16	20	20	17.6	18.8	5	"	"
13	Suphate (mg/L)	90.1	72.2	106	106	40	38	50	48	89.1	89.1	500	"	"
14	Suphide (mg/L)	-	-	-	-	-	-	26	24	-	-	0.2		
15	Aluminium (mg/L)	0.1	0.1	0.94	0.82	0.07	0.05	0.09	0	0.12	0.08	-	"	"
16	Copper (mg/L)	0.4	0.42	0.89	0.80	0.96	0.96	0.99	0	1.0	0.91	<1	"	
17	Hydrogen peroxide (mg/L)	0	0	0	0	0	0	0	0	0	0	-	"	"
18	Total Chlorine (mg/L)	1.0	0.98	0.2	0.2	0.1	0.1	0.2	0.2	0.5	0.5	-	"	"
19	Free Chlorine (mg/L)	0.5	0.5	0.2	0.2	0.1	0.1	0.2	0.2	0	0	1.0	"	"
20	Combine chlorine (mg/L)	0.5	0.48	0	0	0	0	0	0	0.5	0.5	-	"	
21	Amonia (mg/L)	-	-	-	-	-	-	-	-	-	-	-		
22	BOD (mg/L)	61	70	159	65	181	152	152	78	59	60	30	Iodometric method of Azide modification	
23	COD (mg/L)	320	246	672	752	736	651	424	197	128	118	80	OPEN REFLUX METHOD	
24	Suspended solid (mg/L)											30		
25	MPN/100Ml	1680	1600	840	800	1.6x10	1.6x10	1.6x10	1.6x10	1.6x10	1.6x10	400mpN/n	FERMENTATION TUBE METHOD	

A* Influent B[+] Effluent STD[a] Acceptable Standard by Federal Ministry of Environment

Table 4.6: Flow rates for Wastewater to Wuye Lagoon Sewage Aerator

[Flow Rates X 10-3 m3/sec]

TIME OF THE DAY	OCT		NOV		DEC		JAN		FEB	
FOR SAMPLING	A*	B+	A*	B+	A*	B+	A*	B+	A*	B+
MORNING 8.15am	209	108	196	190	97	211	218	209	200	190
AFTERNOON 12.15pm	111	107	125	120	69	148	69	67	61	50
EVENING 4.15pm	195	173	56	50	72	112	158	158	158	140
AVERAGE FLOW RATE PER DAY	172	129	126	120	79	157	148	145	140	127

A* Influent B^+ Effluent

Table 4.7 : Physiochemical and Microbial component of Wastewater from Sheraton Sewage Treatment Plant (STP), Abuja

	PARAMAETER	OCT		NOV		DEC		JAN		FEB			EQUIPMENT MODEL	METHOD OF ANALYSIS
		A*	B+	A*	B+	A*	B+	A*	B+	A*	B+	STD[a]		
1	pH	4.4	7.3	5.89	5.60	6.79	7.06	9.92	10	6.5	6.8	6-9	LOVIBOND TEST KIT	COLORITY
2	Temperature (oC)	18.4	18.5	26.1	26.3	27.0	27.0	28.4	29.1	30.1	30.1	40	CO150 (HACH)CONDUCTIVITY METER	
3	Salinity (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	"	
4	Dissolve oxygen (mg/L)	3	4.2	1.9	1.3	0.4	0.4	2.9	3.7	3.3	3.7	4		
5	Conductivity fus	2200	1800	750	691	8600	7700	8600	8466	1510	809	50-125	CO150 (HACH)CONDUCTIVITY METER	
6	Total dissolve solid (mg/L	135	120	205	201	104	102	95	91	142	102	2000	"	
7	Flow Rate (R/sec) m/s	1.66	1.51	1.63	1.44	1.85	1.46	1.51	1.46	1.10	0.68		0012B CURRENT FLOW METER	
8	Hardness (mg/L)	69	65	60	60	80	80	80	80	91	65	200	LOVIBOND TEST KIT	COLORITY
9	Nitrate (mg/L)	8	8	10	10	2.12	0.01	0.01	0	4.6	3.9	20	LOVIBOND TEST KIT	COLORITY
10	Iron (mg/L)	0.65	0.29	1.5	1.9	2.12	0.23	1	0.92	0.21	0.25	20	"	"
11	Chloride (mg/L)	235	100	130	110	220	101	60	50	92	94	600	"	"
12	Phosphate (mg/L)	3	3.2	2	1.5	4.82	2.88	1.5	0.7	1.7	1.5	5	"	"
13	Suphate (mg/L)	120	100	50	33.3	278	90.1	200	60	60	60	500	"	"
14	Aluminium (mg/L)			0	0	0.1	0	0	0	-	-	-	"	"
15	Copper (mg/L)	1.87	0.99	0.2	0.2	0.2	0.1	0.2	1	0.17	1.14	<1	"	
16	Hydrogen peroxide (mg/L)	0	0	0	0	0	0	0	0	0	0	-	"	"
17	Total Chlorine (mg/L)	2.6	2.4	1.5	1.0	0.92	0.61	0.3	0.2	1.98	1.96	-	"	"
18	Free Chlorine (mg/L)	0.07	0.04	0.09	0.06	0.03	0.02	0.08	0.04	0.01	1.00	1.0	"	"
19	Combine chlorine (mg/L)	2.53	2.36	1.41	0.94	0.89	0.59	0.22	0.16	0.97	0.96	-	"	
20	Amonia (mg/L)	-	-	-	-	-	-	-	-	-	-	-		
21	BOD (mg/L)	70	50	126	127	60	74	61	70	10.4	8.5	30	Iodometric method of Azide modification	
22	COD (mg/L)	230	732	300	309	109	134	124	138	150	78	80	OPEN REFLUX METHOD	
23	Fiterable solid (g)					0.03	0					-		
24	Suspended solid (mg/L)					-	-					30		
25	Total solid(g)					0.13	0.11					-		
26	Gramic Matter (g)					0.03	0					-		
27	Inorganic Matter (g)					0	0					-		
28	MPN/100Ml	1900	500	430	420	1.6X10	1.6X10	50	30	240	170	400mpN/n	FERMENTATION TUBE METHOD	

A* Influent B[+] Effluent STD[a] Acceptable Standard by Federal Ministry of Environment

Table 4.8: Flow rates for Wastewater to Sheraton Sewage Aerator

[Flow Rates X 10-3 m3/sec]

TIME OF THE DAY FOR SAMPLING	OCT A*	OCT B+	NOV A*	NOV B+	DEC A*	DEC B+	JAN A*	JAN B+	FEB A*	FEB B+
MORNING 8.15am	8.3	7.2	7.9	7.2	8.2	7.9	7.2	7.1	4.1	4
AFTERNOON 12.15pm	6.5	5.9	6	5.4	4.1	3.6	6.3	5.8	7.8	2.3
EVENING 4.15pm	7.7	7.3	7.1	6.8	8.2	8.1	6.9	6.8	2.9	2.7
AVERAGE FLOW RATE PER DAY	7.5	6.8	7	6.5	6.8	6.5	6.8	6.6	4.9	3

A* Influent B^+ Effluent

Table 4.9 : Physiochemical and Microbial component of Wastewater from Gudu Sewage Treatment Plant (STP), Abuja

	PARAMAETER	OCT		NOV		DEC		JAN		FEB			EQUIPMENT	METHOD OF
		A*	B+	A*	B+	A*	B+	A*	B+	A*	B+	STD[a]	MODEL	ANALYSIS
1	pH	11.0	11.5	7.27	7.10	6.7	6.6	7.4	7.3	7.0	7.0	6-9	LOVIBOND TEST KIT	COLORITY
2	Temperature (oC)	18.2	18.4	20.2	20.2	30	30	28	28.2	30.2	25.4	40	CO150 (HACH)CONDUCTIVITY METER	
3	Salinity (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	"	
4	Dissolve oxygen (mg/L)	1.3	4	1.0	0.7	1.4	0.8	1.2	1.09	1.3	3.7	4		
5	Conductivity fus	552	313	469	609.3	306	284	413	405	422	404	50-125	CO150 (HACH)CONDUCTIVITY METER	
6	Total dissolve solid (mg/L	140	131	223	220.10	147	138	196	194	200	192	2000	"	
7	Flow Rate (R/sec) m/s	2.16	2.13	1.26	1.22	2.31	1.95	2.34	2.12	1.66	1.20		0012B CURRENT FLOW METER	
8	Hardness (mg/L)	122	112	180	160	1800	1220	60	60	60	60	200	LOVIBOND TEST KIT	COLORITY
9	Nitrate (mg/L)	7.8	9.8	10	10	7	5	0.19	0.17	0.20	4.83	20	LOVIBOND TEST KIT	COLORITY
10	Iron (mg/L)	4.9	4.8	2	2	4	3	1	1	1	3.4	20	"	"
11	Chloride (mg/L)	162	154	170	120	78	62	100	100	97	109	600	"	"
12	Phosphate (mg/L)	6.2	8.1	10	6.5	18	13.6	20	20	22	34	5	"	"
13	Suphate (mg/L)	100	98.2	50	52	134	128	180	160	129	200	500	"	"
14	Suphide (mg/L)	-	-	-	-	-	-	22	20	-	-	0.2		"
15	Aluminium (mg/L)	0	0	0	0.001	0	0	0.009	0.08	0.06	0.12	-	"	
16	Copper (mg/L)	0.09	0.09	0.1	0.0	0.1	0.1	0	0	0	0.2	<1	"	"
17	Hydrogen peroxide (mg/L)	-	-	0	0	-	-	0.2	0.18	0.0	0.15	-	"	"
18	Total Chlorine (mg/L)	5.1	3.4	0.5	0.5	2.7	2.10	0.1	0.1	0.1	3.4	-	"	"
19	Free Chlorine (mg/L)	0.9	0.84	0.40	0.5	1.80	1.70	0.1	0.1	0.0	2.2	1.0	"	
20	Combine chlorine (mg/L)	4.2	2.56	1.10	0	0.90	1.40	0	0	0.1	1.2	-	"	
21	BOD (mg/L)	3.2	3.6	38	59	83	64	30	32	20	44	30	Iodometric method of Azide modification	
22	COD (mg/L)	20	30	109	138	199	161	64	68	136	192	80	OPEN REFLUX METHOD	
23	Fiterable solid (g)					0.08	0.06					-		
24	Suspended solid (mg/L)					-	-					30		
25	Total solid(g)					0.23	0.2					-		
26	Gramic Matter (g)					0.0810	0.06					-		
27	Inorganic Matter (g)					0	0					-		
28	MPN/100Ml		540	260	136	1.6X10	1.6X10	1.6X10	1.6X10	23		400mpN/n	FERMENTATION TUBE METHOD	

A* Influent B+ Effluent STD[a] Acceptable Standard by Federal Ministry of Environment

Table 4.10: Flow rates for Wastewater to Gudu Sewage Aerator

[Flow Rates X 10-3 m3/sec]

TIME OF THE DAY	OCT		NOV		DEC		JAN		FEB	
FOR SAMPLING	A*	B+	A*	B+	A*	B+	A*	B+	A*	B+
MORNING 8.15am	13.5	13.4	7.1	6.8	12.7	11.5	11.5	11.2	-	-
AFTERNOON 12.15pm	7.3	7.2	5.5	4.5	6	4.6	8.9	7.7	7.7	5.4
EVENING 4.15pm	8.3	8.1	4.4	5	12.5	3.1	11.1	9.5	8.8	2.3
AVERAGE FLOW RATE PER DAY	9.7	9.6	5.7	5.4	10.4	6.4	10.5	9.5	8.25	3.9

A* Influent B^+ Effluent

Table 4.11 : Physiochemical and Microbial component of Wastewater from Lungi Barrack Sewage Treatment Plant (STP), Abuja

	PARAMAETER	OCT		NOV		DEC		JAN		FEB			EQUIPMENT	METHOD OF
		A*	B+	A*	B+	A*	B+	A*	B+	A*	B+	STD[a]	MODEL	ANALYSIS
1	pH	5.89	6.88	7.93	7.01	7.5	6.5	6.42	6.40	6.91	6.70	6-9	LOVIBOND TEST KIT	COLORITY
2	Temperature (oC)	28.6	28.7	27.9	27.6	28.8	28.7	29.4	30.0	28.0	28.1	40	CO150 (HACH)CONDUCTIVITY METER	
3	Salinity (%)	0.2	0.2	0.2	0.2	2.3	0.3	0.2	0.2	0.2	0.1	0.2	"	
4	Dissolve oxygen (mg/L)	4	3	3.3	2.9	0	0	2.4	1.8	4.2	5.1	4		
5	Conductivity fus	1544	1423	515	502	369	551	514	497	752	600	50-125	CO150 (HACH)CONDUCTIVITY METER	
6	Total dissolve solid (mg/L	754	302	161	160	174	262	174	153	231	109	2000	"	
7	Flow Rate (R/sec) m/s	0.95	0.85	0.52	0.40	0.42	0.37	0.39	0.37	0.42	0.38		0012B CURRENT FLOW METER	
8	Hardness (mg/L)	100	80	60	60	20	20	20	20	20	20	200	LOVIBOND TEST KIT	COLORITY
9	Nitrate (mg/L)	10	8	9	5	0.5	0.45	5	8	4	6	20	LOVIBOND TEST KIT	COLORITY
10	Iron (mg/L)	0.5	0.5	0.2	0.2	0.5	0.5	0.2	0.3	0.4	0.31	20	"	"
11	Chloride (mg/L)	270	234	120	100	100	50	50	50	48	52	600	"	"
12	Phosphate (mg/L)	0.8	9.8	9.72	9.51	20	40	10.4	12.1	10.8	14.0	5	"	"
13	Suphate (mg/L)	178	174.0	200	120	160	80	40	40	90.1	89.1	500	"	"
14	Copper (mg/L)	0.02	0.09	1.0	0	1.0	1.0	1.0	1.0	0.12	0.0	<1	"	"
15	Hydrogen peroxide (mg/L)	0	0	0.06	0.04	0.04	0.08	0.1	0.09	0.10	0.08	-	"	
16	Total Chlorine (mg/L)	0.5	0.5	2	2	0.20	0.2	1.5	0.5	1.5	2	-	"	"
17	Free Chlorine (mg/L)	0.0	0	1.2	1.1	0.10	0.10	0.1	0.1	0.1	0	1.0	"	"
18	Combine chlorine (mg/L)	0.5	0.5	0.8	0.9	0.10	0.10	1.4	0.4	1.4	2	-	"	"
19	Amonia (mg/L)	-	-	-	-	-	-	-	-	-	-	-		
20	BOD (mg/L)	83	86.5	120	122	140	102	60	120	84.5	80.6	30	Iodometric method of Azide modification	
21	COD (mg/L)	199	272	214	672	615	510	208	240	271	261	80	OPEN REFLUX METHOD	
22	Fiterable solid (g)					0.05	0.01					-		
23	Suspended solid (mg/L)											30		
24	Total solid(g)					0.23	0.27					-		
25	Gramic Matter (g)					0.05	0.01					-		
26	Inorganic Matter (g)					0.0010	0					-		
27	MPN/100Ml	1300	390	1.6x10	1.6x10	≥9x10	1.6x10	1.7x10	1.6x10	250	174	400mpN/n	FERMENTATION TUBE METHOD	

A* Influent B+ Effluent STD[a] Acceptable Standard by Federal Ministry of Environment

Table 4.12: Flow rates for Wastewater to Lungi Barrack Sewage Aerator

[Flow Rates X 10-3 m3/sec]

TIME OF THE DAY	OCT		NOV		DEC		JAN		FEB	
FOR SAMPLING	A*	B+	A*	B+	A *	B+	A *	B+	A *	B+
MORNING 8.15am	5.3	5	2.5	1.8	2	1.8	2.2	2	2.3	2.3
AFTERNOON 12.15pm	3.3	2.6	2.3	1.4	0.6	0.5	0.4	0.3	0.8	0.9
EVENING 4.15pm	4.2	4.1	2.2	1.4	2.8	2.7	2.7	2.6	2.6	2.3
AVERAGE FLOW RATE PER DAY	4.3	3.9	2.3	1.5	1.8	1.7	1.8	1.6	1.9	1.8

A* Influent B^{+} Effluent

From the laboratory results shown in Table 4.1 to 4.12, it was observed that the results obtained do not depict the waste water characteristics expected from a functional Sewage Treatment Plant. Firstly, the average influent BOD_5 of 127.8mg/l at 20^oC is considerably low. This result is basically due to high infiltration of groundwater into the sewer lines from practically collapsed or broken down manholes. Another reason is illegal connection of storm water drain into public sewer lines by unskilled plumbers. These developments are currently being addressed by the local Authority (Abuja Environmental Protection Board) charged with maintenance of public sewers. In view of the low BOD_5 at 20^oC at influent, the resultant effluents which have undergone minimal treatment becomes low also with average BOD_5 at 20^oC reduction of only 4-10% instead of the expected 90-95%. The situation also applies to reduction level in other major pollutants such as nitrates, sulphates, COD, etc.

Secondly, none of the six sewage treatment plants evaluated are functioning effectively during the period of the research. Gudu sewage treatment Aerator had two installed submersible Aerators out of which only one is functional. The only functional one cannot be allowed to work day in day out, hence, it is operated only for about an hour a day to avoid odour. Irregular power supply sometimes makes it non-operational for days until power supply is restored. It is important to note that many suspended solids and particles of sizes 10-20mm are screened out at the inlets of the six sewage treatment plants. This primary treatment requires no power supply; therefore incoming sewage flows continuously through the screening device and the solids are trapped and removed at the screens. However, fine aggregates of sizes less than 10mm finds their way into the Aeration basin, thus interfering with the biological processes. This leads to a build-up of fine sand aggregates at the base of the Aeration basins. This situation requires that a better system be adopted for the handling or removal of fine particles in the wastewater treatment processes.

4.3 Results of Statistical Analysis

Descriptive Statistics

The descriptive statistical analysis serves to give simple quantitative summaries of the various concentrations of wastewater parameters that describe the various sewage treatment plants as presented in table 4.13.

Table 4.13: Descriptive Statistical Analysis of Sewage Treatment Plants in Abuja

	Number of Observation	Minimum	Maximum	Mean	Standard. Deviation	Variance
Influent Niger Barrack	80	0	1544	139.94	242.21	58664
Effluent Niger Barrack	80	0	771	107.35	168.04	28238.7
Influent Mangadishu Barrack	80	0	12110	306.07	1366.21	1866523
Effluent Mangadishu Barrack	80	0	1240	135.48	245.99	60510.2
Influent Wuye TP	80	0	1680	144.44	274.37	75276.6
Effluent Wuye TP	80	0	1600	130.86	262.77	69047.7
Influent Sheraton TP	80	0.01	8600	355.17	1378.02	1898945
Effluent Sheraton TP	79	0	8466	306.63	1287.19	1656846
Influent Gudu TP	80	0.19	1800	108.06	228.73	52317
Effluent Gudu TP	80	0.17	1220	94.34	169.29	28660.2
Influent Lungi TP	80	0	1544	146.45	277.55	77036
Effluent Lungi TP	80	0	1423	118.52	214.58	46044.8
Valid N (leastwise)	79					

From the Table 4.13, the high standard deviation indicates that the data points are spread out over a large range of values and hence less reliable.

Comparing means using One-Way ANOVA:

Considering five major consistent constituents of the collected and tested wastewater samples from the all the sewage plants, the output are presented in Table 4.14 as follows:

Table 4.14 One-way ANOVA of Sewage Treatment Plants

		SS(B) Sum of Squares	DF	SS (W) Mean Square	F	Significant
Influent Niger Barrack	Between Groups	251660.722	4	62915.18	16.797	0
	Within Groups	74912.228	20	3745.611		
	Total	326572.95	24			
Effluent Niger Barrack	Between Groups	269374.546	4	67343.637	9.146	0
	Within Groups	147262.182	20	7363.109		
	Total	416636.728	24			
Influent Mogadishu Barrack	Between Groups	3.07E+07	4	7667007.17	1.418	0.264
	Within Groups	1.08E+08	20	5407076.51		
	Total	1.39E+08	24			
Effluent Mogadishu Barrack	Between Groups	521226.138	4	130306.535	2.183	0.108
	Within Groups	1193582.48	20	59679.124		
	Total	1714808.62	24			
Influent Wuye TP	Between Groups	1411909.02	4	352977.255	3.401	0.028
	Within Groups	2075681.68	20	103784.084		
	Total	3487590.69	24			

Effluent Wuye TP	Between Groups	1260424.12	4	315106.029	3.216	0.034
	Within Groups	1959455.52	20	97972.776		
	Total	3219879.63	24			
Influent Sheraton TP	Between Groups	1040065.85	4	260016.461	2.196	0.106
	Within Groups	2367778.89	20	118388.944		
	Total	3407844.73	24			
Effluent Sheraton TP	Between Groups	348362.673	4	87090.668	3.875	0.017
	Within Groups	449549.188	20	22477.459		
	Total	797911.862	24			
Influent Gudu TP	Between Groups	170823.155	4	42705.789	6.009	0.002
	Within Groups	142132.929	20	7106.646		
	Total	312956.084	24			
Effluent Gudu TP	Between Groups	80748.569	4	20187.142	8.244	0
	Within Groups	48972.954	20	2448.648		
	Total	129721.523	24			
Influent Lungi TP	Between Groups	1073258.22	4	268314.555	4.466	0.01
	Within Groups	1201596.51	20	60079.826		
	Total	2274854.73	24			
Effluent Lungi TP	Between Groups	496983.434	4	124245.859	13.105	0
	Within Groups	189619.442	20	9480.972		
	Total	686602.876	24			

From the ANOVA table above, at 95% confident level and 5% level of significance, influent and effluent concentration at Niger barrack, Wuye, Gudu and Lungi treatment plants has their *significant-value* less than the 5% significance level. Mogadishu barrack treatment plant has its *significant-value* greater than 5% significance level.

From the earlier stated decision rule, if the between variance is smaller than the within variance, then the means are really close to each other and therefore, accept the claim that they are all equal. Furthermore, the decision will be to reject the null hypothesis if the test statistic from the table is greater than the F critical value.

From the ANOVA table, the between Variance is greater than the within Variance and based on this note, we accept the H_0 (null hypothesis). This therefore tells that there is no significant difference in the means of the samples concentration.

Furthermore, we can deduce that a significant result has been found $F(4, 20) = 16.8$, $p < 0.05$. Therefore, the calculated value 16.8 is greater than the table value 2.87, we therefore, accept the H_0 (null hypothesis). There is no significant difference in the mean of the samples.

Duncan Multiple Range Test or LSD

This test compares the mean of the constituents from the largest with the mean of the next constituent, on and on until there is no significant difference between the means compared. This procedure is repeated for the next largest mean. The constituents in the same group are not different significantly from each other but they are different from others that are not in the group. Therefore, the constituents not significantly different is responsible for the acceptance of H_0 (null hypothesis) in the ANOVA analysis. From the Post Hoc Test as shown in Appendix II and Table 4.15, temperature was significantly different to BOD, COD and MPN. Nitrate is significantly different to BOD, COD, and MPN, BOD and COD are significantly different to others while Microbial content (MPN) is significantly different to all but COD.

Table 4.15: **Tables of Homogeneous Subsets**

Influent for Niger Barrack Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05		
			1	2	3
Duncan[a]	NITRATE	5	5.48		
	TEMPERATURE	5	20.1		
	BOD	5		106.2	
	COD	5			194.6
	MICROBIAL CONTENT (MPN)	5			266.6
	Significant		0.71	1	0.08

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Effluent for Niger Barrack Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	5.65	
	TEMPERATURE	5	19.94	
	BOD	5	53.8	
	COD	5		188.4
	MICROBIAL CONTENT (MPN)	5		270
	Significant		0.412	0.15

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.00.

Influent for Mogadishu Barrack Treatment Plant			
	Major Sewage Components	N	Subset for alpha = 0.05
			1
Duncan[a]	NITRATE	5	5.56
	TEMPERATURE	5	29.02
	BOD	5	62.4
	COD	5	341.8
	MICROBIAL CONTENT (MPN)	5	2862
	Significant		0.1

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.00.

Effluent for Mogadishu Barrack Treatment Plant			
	Major Sewage Components	N	Subset for alpha = 0.05
			1
Duncan[a]	NITRATE	5	5.39
	TEMPERATURE	5	28.8
	BOD	5	52
	COD	5	294
	MICROBIAL CONTENT (MPN)	5	346
	Significant		0.06

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.00.

Influent for Wuye Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	24.23	
	TEMPERATURE	5	25.76	
	BOD	5	122.4	
	COD	5	456	456
	MICROBIAL CONTENT (MPN)	5		600
	Significant		0.06	0.49

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.

Effluent for Wuye Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	21.09	
	TEMPERATURE	5	25.84	
	BOD	5	85	
	COD	5	392.8	392.8
	MICROBIAL CONTENT (MPN)	5		576
	Significant		0.1	0.37

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Influent for Sheraton Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	4.95	
	TEMPERATURE	5	26	
	BOD	5	65.48	
	COD	5	182.6	182.6
	MICROBIAL CONTENT (MPN)	5		556
	Significant		0.46	0.1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Effluent for Sheraton Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05		
			1	2	3
Duncan[a]	NITRATE	5	4.38		
	TEMPERATURE	5	20.12		
	BOD	5	65.9	65.9	
	MICROBIAL CONTENT (MPN)	5		256	256
	COD	5			278.2
	Significant		0.547	0.06	0.82

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Influent for Gudu Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	5.04	
	TEMPERATURE	5	25.32	
	BOD	5	34.84	
	COD	5	105.6	
	MICROBIAL CONTENT (MPN)	5		231.2
	Significant		0.1	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Effluent for Gudu Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	5.95	
	TEMPERATURE	5	24.32	
	BOD	5	40.52	
	COD	5		117.8
	MICROBIAL CONTENT (MPN)	5		152.6
	Significant		0.31	0.28

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Influent for Lungi Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05	
			1	2
Duncan[a]	NITRATE	5	5.7	
	TEMPERATURE	5	28.54	
	BOD	5	97.5	
	COD	5	301.4	301.4
	MICROBIAL CONTENT (MPN)	5		556
	Significant		0.09	0.12

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Effluent for Lungi Treatment Plant

	Major Sewage Components	N	Subset for alpha = 0.05		
			1	2	3
Duncan[a]	NITRATE	5	5.49		
	TEMPERATURE	5	28.6		
	BOD	5	102.3	102.3	
	MICROBIAL CONTENT (MPN)	5		208.8	
	COD	5			391
	Significant		0.15	0.1	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.00.

Correlation Coefficient between Effluent Temperature, Sample BOD and Total Nitrogen (Ammonia, Nitrates)

The α-coefficient determines the significance of the predictors and how related it is to the dependent variable (effluent temperature), β-values can be used in comparing the contribution of each predictor (independent variables) while p-values determines the significance of the predictors.

Table 4.16: Table of Correlation Coefficients

Model	α (coefficient)	Std. Error	β	t-value	Sig. (p-value)
Nitrate	- 0.0981	0.5479	-0.3217	-179	0.085
Ammonia	36.7208	53.4564	0.1231	0.69	0.498
BOD_5^{20}	0.0311	0.0231	0.2418	1.35	0.190
Constant	24.2683	1.7482	-	13.88	0.000

Significant at 5% level

From Table 4.16, Nitrate has a negative α-value (coefficient). Ammonia and BOD have positive correlation coefficient with the effluent temperature.

Furthermore, the table reveals the β-value of each predictor which states the contributions of individual to the effluent temperature. BOD_5^{20} makes the strongest unique contribution to explaining the effluent temperature when the variance explained by all other variables in this model is controlled for. The p-value for the predictors is greater than the 5% significant level. Therefore, H_0 (null hypothesis) is not rejected.

The multiple correlation coefficients, (R) is the linear correlation between the observed and the model-predicted values of the dependent variable. The value of R-square (0.1667), the coefficient of determination show that about 16.7% of the variation in the effluent temperature is explained by the model while the remaining 83.3% is due to the random effect of the other data. For the probability value for F-test statistic (0.18) is greater than (0.05) level of significance, therefore, we do not reject hypothesis 2 (null-hypothesis). The fitted model is not significant. Therefore, the regression equation is represented as

Effluent Temperature = 36.7208AMMONIA + 0.0311BOD_5^{20} - 0.0981NITRATE + 24.2683

Table 4.17: Summary of Model Predictor and ANOVA

	SS	DF	MS	Num. of Obs. = 30
Model	91.71	3	30.5708	Prob. > F = 0.1847
Residual	458.50	26	17.6345	R-square = 0.1667
Total	550.21	29	18.9727	Adj. R-square= 0.0705

4.4 Compliance level to Wastewater Master Plan

The Abuja wastewater Master plan provides that the city shall be provided with central sewer network draining by gravity towards the sewage treatment plants at each drainage basin. A treatment plant is proposed for each of the five drainage basins in the Federal Capital Territory, Abuja. Currently, only the sewer network and sewage treatment plants serving the Federal Capital City that is, the Wupa Basin Sewage Treatment Plant is in place. The existing Sewage Treatment Aerators are also located in the Wupa drainage basins and no provision is made for other basins. The idea is that when the main Wupa basin sewage treatment plant is completed, these aerators can be disconnected and reconnected to the trunk sewer line leading to the Main Sewage Treatment Plant (MSTP).

The satellite towns that harbor most of the inhabitants of the city have no centralized sewage systems contrary to the Master Plan provision. Hence the level of compliance with the Abuja Master Plan is far below standard. At the satellite towns, cesspools, septic tanks and soak away are the main means of handling generated sewage from these areas which is contrary to the Master Plan provisions.

4.5 Effects of non-compliance to Master Plan

Non-compliance to the Abuja Master Plan in terms of the implementation of Wastewater management has resulted in the inhabitants of FCT providing soak away and septic tanks for sewage treatment. The use of septic tank and soak-away pits is becoming out of use and does not follow global developmental patterns expected of a modern city like Abuja.

Soak-away pits and septic tanks are known to have detrimental effects on the environment. It constitutes avenue for breeding of mosquitoes, causes ground water pollution, and when not properly constructed can lead to collapse which could cause injury when accidentally stepped upon by inhabitants.

The idea of building a modern Capital City for Nigeria that will be comparable to any city in the world will be a mirage if the wastewater Master Plan is not implemented as planned.

4.6 Technical Description of existing Sewage Treatment Plants in Abuja

In view of the delay in the completion of the main sewage treatment plant and sewer network for the city; and the fact that several important projects such as houses and public buildings of importance have been completed, simple sewage treatment schemes in the form of Aerators were designed and constructed in designated and isolated areas to enable the usage of these completed facilities. These facilities included Army Barracks, Staff Quarters, Federal

Secretariat, and Legislative Quarters in Gudu etc. Thus, there are thirteen wastewater treatment aerators all around the city handling wastewater generated from between 3000 to 10,000 inhabitants of F.C.T.

Aerators are recommended in the Abuja Master Plan for isolated areas located in sewer drainage basins which cannot be easily connected to the central sewerage. Also accelerated development of certain areas like the Army Barracks, Presidential Villa etc. which received urgent attention from government and were hurriedly constructed were served with aerators to make the projects habitable. Similarly, hotels and industries which discharge high concentration of sewage are expected to construct and operate the aerators to reduce the load to be transported to the main sewage treatment plant.

The running of these aerators was handled by the Federal Government through the Federal Capital Development Authority (FCDA); except those of the hotels and industries.

The existing sewage treatment Plants or Aerators in Abuja can be classified into three main categories based on their population equivalent or capacity as follows:

A. The 3,000 Population Equivalent Sewage Treatment Plant Aerator is designed and planned for a population of 3,000 inhabitants with a specific wastewater quantity of 210 L/c.d and 30% extraneous wastewater as provided in the Master Plan. Examples of this category of treatment plant evaluated in this report in Abuja include: Niger Barrack Sewage Treatment Aerator and Sheraton Sewage Treatment Aerator.

B. The 6,000 Population Equivalent Sewage Treatment Plant Aerator is designed and planned for a population of 6,000 inhabitants with a specific quantity of 210 L/c.d and 30% extraneous wastewater. Examples of this category of treatment plant in Abuja includes: Mogadishu Barrack Sewage Treatment Aerator, Gudu Sewage Treatment Aerator and Lungi Barrack Sewage Treatment Aerator.

C. The 50,000 Population Equivalent Sewage Treatment Plant Aerator is designed and planned for a population of 50,000 inhabitants with a specific quantity of 210 L/c.d and 30% extraneous wastewater. An example of this category in Abuja is Wuye Lagoon.

4.6.1 Niger Barrack Sewage Treatment Aerator

The Niger Barrack Sewage Treatment Aerator consists of an inlet chamber with a screen, Aeration Tank, Sedimentation Tank, effluent Weir, Return Sludge Pump compartment and control room.

Screening Chamber: This chamber is made of concrete of size 2.00m by 0.60m and serves to remove large particulate objects such as wood, polythene, paper, etc. which may come along with the wastewater. The screened wastewater is then allowed to flow into the aeration tank.

Aeration Tank: This has a dimension of 6.00m by 6.00m by 6.00m receiving the screened wastewater. Inside the Aeration tank is a submersible mechanical aerator. This aerator suck-in atmospheric air through a 150mm UPVC pipe connected to it. The air is circulated and distributed into the tank to provide oxygen for aerobic biodegradation of constituents of the wastewater. The operation of the submerged mechanical aerator is controlled by a timer at the control panel located in the control room.

Sedimentation Tank: In the sedimentation tank which measures 4.60m by 6.00m by 6.00m, effluent from the aeration tank flows into it. Settle-able solids form as a result of biological activities during aeration in the activated sludge pond is allowed to settle.

This settled matter is re-circulated to the inlet of the activated sludge by a return sludge pumped to the sludge pond. The supernatant water is retained for some time for further sedimentation and the supernatant water is finally discharged to the river through the effluent weir. The re-circulated sludge is to allow enough aerobic microbial biomass in the aeration tank for biodegradation of the wastewater. It is upon the principle of aerobic biodegradation that the Niger Barrack Sewage Aerator works.

Sludge Tank: The sludge tank is with a dimension 2.20m by 2.20m by 5.00m. Sludge which accumulates into it from the sedimentation tank is pumped out for recirculation through the inlet chamber. Figure 13 represent the flow chart of the treatment processes in the Niger Barrack Sewage Aerator.

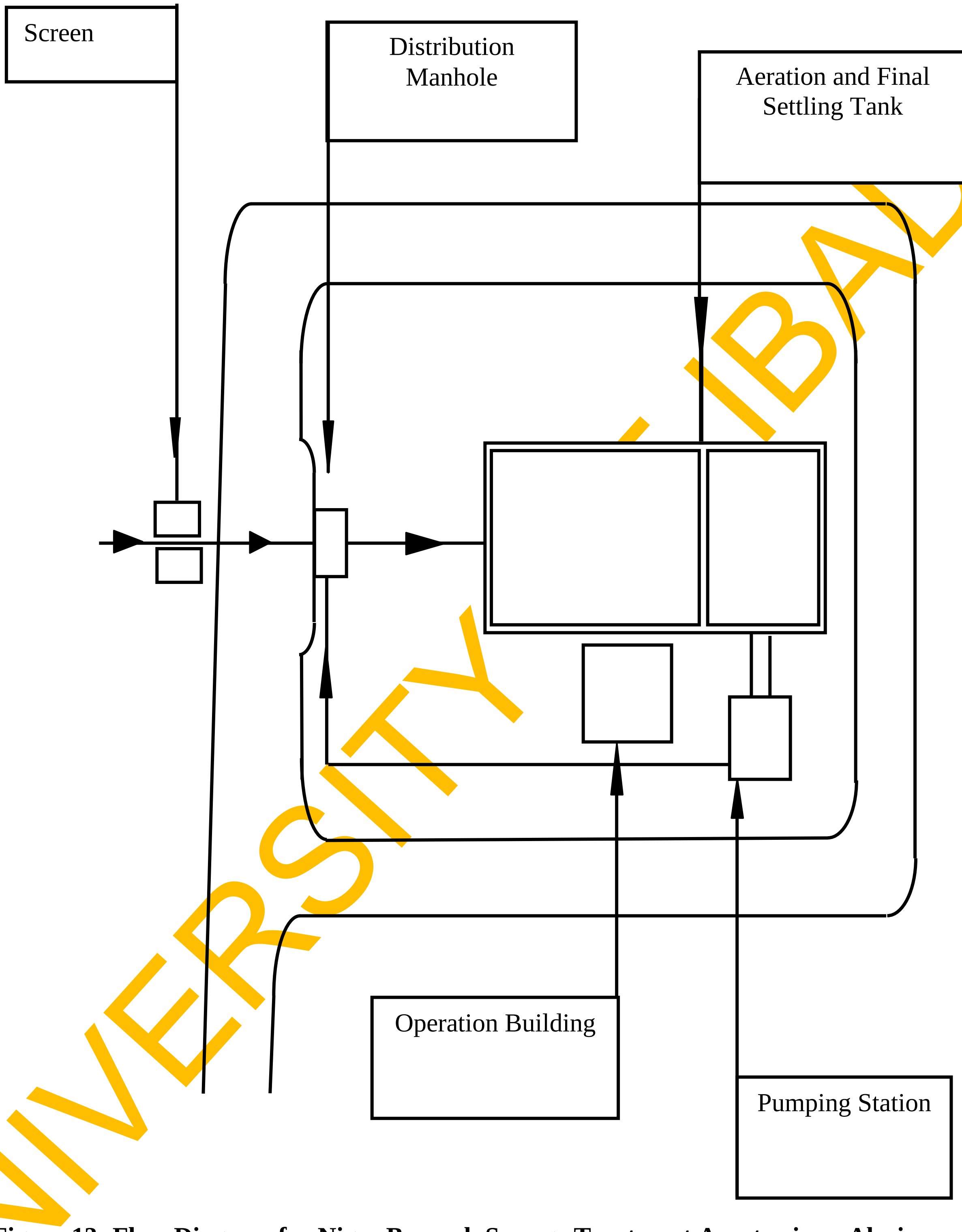

Figure 13: Flow Diagram for Niger Barrack Sewage Treatment Aerator in Abuja

4.6.2 Mogadishu Barrack Sewage Treatment Aerator

The Mogadishu Barrack Sewage Treatment Aerator consists of an inlet chamber with a screen, Aeration Tank, Sedimentation Tank, Effluent Weir, Return Sludge Pump compartment and control room. Screenings of large particles and substances that can damage aerator pumps are removed before the sewage is allowed into the aeration tank.

Screening Plant: The screen which is 4.00m by 1.20m in dimension is made of concrete. It serves to remove large particulate objects such as wood, polythene, paper, etc. which may come along with the wastewater.

Aeration Tank: This comprises of two separate chambers which operate independently for the treatment of the screened wastewater. The Aeration tank has a dimension of 21.00m by 22.50m each and 6.00m deep. There are two submersible aeration pumps in each of the two compartments to suck-in and distribute oxygen into the wastewater for aerobic biodegradation.

Sedimentation Tank: The sedimentation tank which is also separated into two compartments measures 10.00m by 22.50m, settleable solids which form as a result of biological activities during aeration in the aeration tank is allowed to settle. This settled sludge is re-circulated to the inlet of the plant for recirculation.

Sludge Tank: The sludge tank has a dimension of 3.00m by 3.00m and 6m deep. Sludge which accumulates into it from the sedimentation tank is pumped out for recirculation through the inlet chamber while excess sludge is pumped out. Figure 14 represent the flow chart of the treatment processes in the Mogadishu Barrack Sewage Aerator.

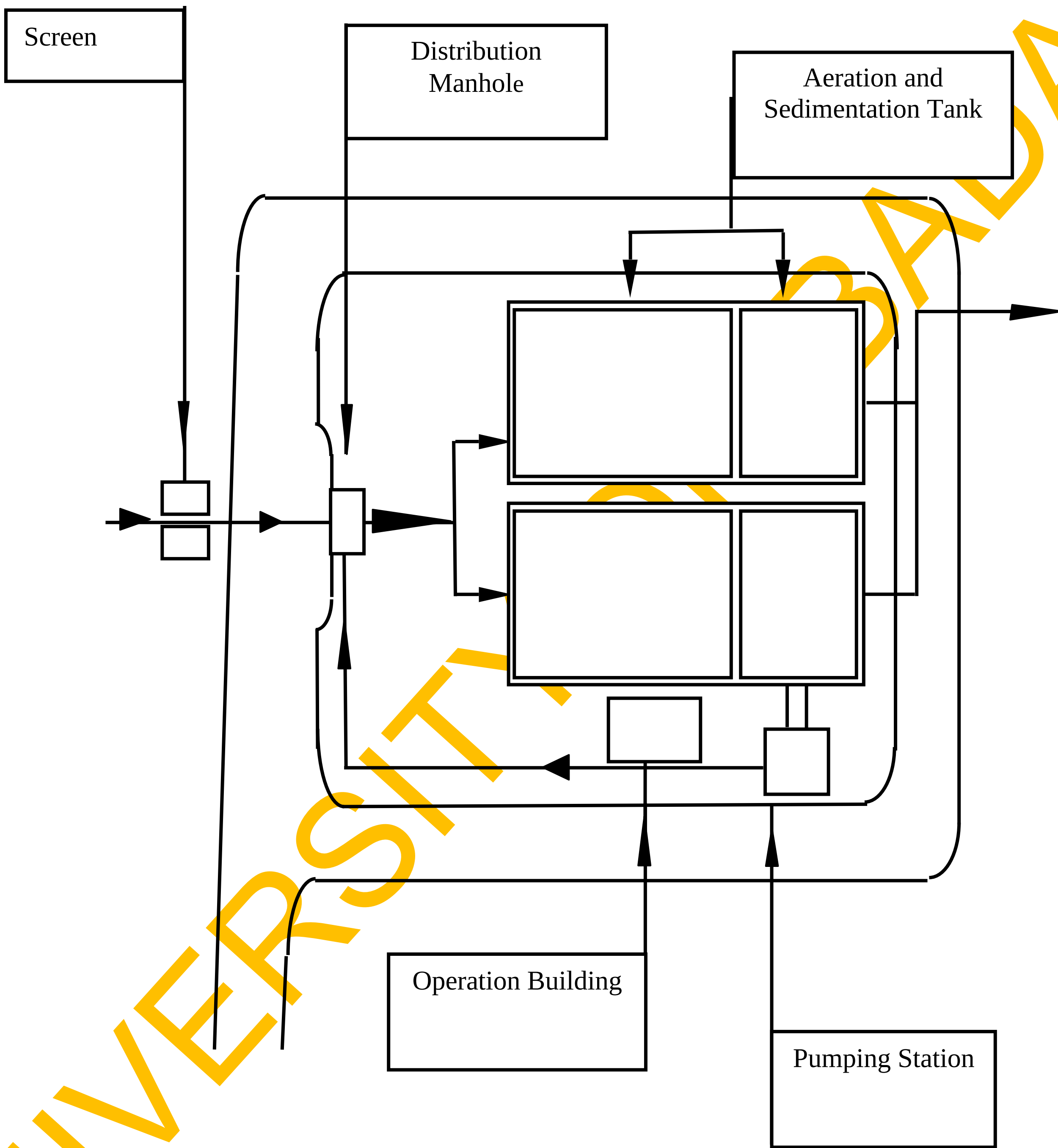

Figure 14: Flow Diagram for Mogadishu Barrack Sewage Treatment Aerator in Abuja

4.6.3 Wuye Lagoon Sewage Treatment Plant

The Wuye lagoon is the major Sewage Treatment system existing in Abuja prior to the completion of the Main Sewage Treatment Plant (MSTP). It receives wastewater from phase 1 mainly Wuse, Garki, Maitama, Asokoro and Central area through the Interceptor sewer lines; and treat the sewage biologically before the effluent is discharged into the river.

Wuye lagoon was basically developed from the Activated Sludge Treatment process. Around 1880 in England, aeration of sewage was found to reduce odour and decrease organic pollution with time, producing sludge which stimulated the process of biodegradation (Veenstra and van Duijl, 1995). This phenomenon led to the development of Activated treatment process in which organic matter is degraded, and partly transformed into sludge. It is upon this process that Wuye lagoon was designed. The treatment process is commonly preceded by primary treatment processes (i.e. screening, grit removal, primary settling etc) as also the case in Wuye Lagoon. Table 4.18 shows the design data or basis for the design calculations for the Wuye Lagoon.

Table 4.18: Design Data for Wuye Lagoon

S/N	Description of Parameter	Unit	Design data
1	Population Equivalent	P.E	50,000
2	Specific waste water quantity	l/E.d	210
3	Extraneous water	%	30
4	Total specific sewage inflow	m^3/d	14,000
5	Expected hourly inflow (1/10)	m^3/h	1200
6	Specific load BOD_5 @ 20^oC	g/E.d	70
7	Total BOD_5 @ 20^oC load	kg/d	3500
8	Specific load NH_4-N	g/E.d	12
9	Total load NH_4-N	kg/d	600
10	Specific load PO_4-P	g/E.d	3
11	Total load PO_4-P	kg/d	150

4.6.3.1 Technical basis for Planning Wuye Lagoon

- As shown in the design data table (Table 4.18), the plant is planned for a population of 50,000 inhabitants, with specific wastewater quantity of 210 L/c.d and 30% extraneous wastewater.
- A mechanical – biological treatment of the wastewater is planned.
- The plant is constructed with two flow lines to obtain the highest degree of safety.
- The wastewater in the treatment plant is cleaned mechanically to remove coarse and other substances likely to disrupt the functioning of the plant (pre-treatment processes).
- The biological phase is a single stage pond system with activated sludge and sludge stabilization.

During this process, hydro-carbon compounds of the pretreated raw sewage are degraded and nitrogen compounds oxidized into nitrites and finally nitrate (nitrification). The resulting sludge is then aerobically established.

- Biomass is produced in the activated tank (MLSS) and the excess is continually removed from the activated tank, some deposited in the sludge polder and others recirculate.

Figure 15 shows the functioning processes of the Wuye Lagoon

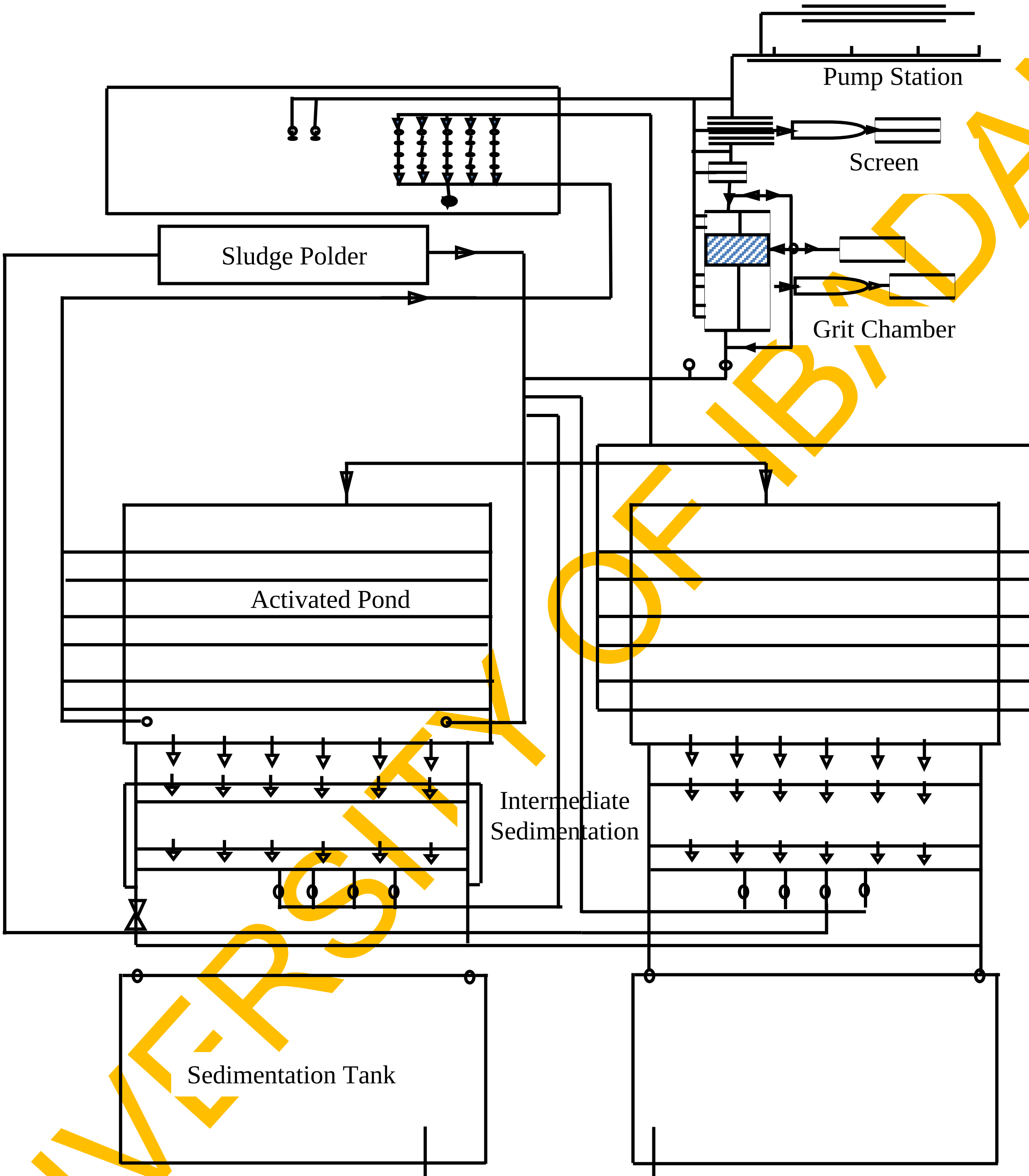

Figure 15: Flow diagram of the Wuye Lagoon wastewater treatment plant Abuja

4.6.3.2 Technical Description of the System

Sewage Pumping Station: The wastewater transported to Wuye lagoon through the Interceptor Sewer pipes of schedule I is pumped from the pumping station through four installed submersible sewage pumps of equal capacity. Three pumps are designed to be working simultaneously while one is on standby in case of technical breakdown of any of the pumps. Screenings of large particles and substances that can damage pumps are done before the sewage is pumped to the treatment plant.

Screening Plant: The plant which is 8.60m by 3.00m in dimension serves to remove large number of un-dissolved substances and particles; a rotating drum screen is installed as the screening plant into which the sewage is pumped through to the grit chamber.

Aerated grit chamber with grease trap: The grit chamber which is 3.00m by 3.00m is intended to allow for settling of grits and particles, and the grit chamber is aerated to allow for flotation of grease and its removal through the grease trap while grits/sand settle and are removed by the sand dredger. The grease chamber is 49.00m by 3.00m from which the pre-treated sewage flow into the Activation/Aeration tank.

Activation/Aeration Tank: This comprises of two separate chamber for further treatment of the pre-treated sewage from the grease chamber having a dimension of 65.00m by 65.00m each. A pump is connected to each tank which serves to pump the treated sludge into the sludge tank and the treated sewage back into activated tank for treatment again and finally into the sedimentation tank.

Activated Sludge Pond: In the activated sludge pond with the dimension 60.00m by 60.00m are micro-organisms (Nitrosamines, Nitrobacteria, Enterobacteria serogenes, protozoa etc.) which comes together in the form of flakes to act on the organic impurities (which are soluble and do not settle easily) and nutrients in the form of ammonium and phosphate compounds reduces them into insoluble nitrates etc.

Intermediate Sedimentation Tank: In the intermediate sedimentation tank which measures 65.00m by 65.00m, settleable solids form as a result of biological activities during aeration in the activated sludge pond is allowed to settle. This settled matter is re-circulated to the inlet of the activated sludge with some pumped to the sludge pond. The supernatant water is allowed to move to the final sedimentation tank.

Final Sedimentation Tank: The final sedimentation tank retains the supernatant water of the intermediate tank for some time for further sedimentation and its supernatant water is discharged to the river. The sewage treatment plant of Wuye lagoon is a mini-treatment process as it has no possibility for denitrification, digester, drying beds etc.

4.6.4 Sheraton Sewage Treatment Aerator

The Sheraton Sewage Treatment Aerator consists of an inlet chamber with a screen, Aeration Tank, Sedimentation Tank, effluent Weir, Return Sludge Pump compartment and control room.

Screening Chamber: This chamber is made of concrete of size 2.00m by 0.60m and serves to remove large particulate objects such as wood, polythene, paper, etc. which may come along with the wastewater. The screened wastewater is then allowed to flow into the Aeration tank.

Aeration Tank: This has a dimension of 6.00m by 6.00m by 6.00m receiving the screened sewage. Inside the aeration tank is a submersible mechanical aerators. This aerator suck-in atmospheric air through a 150mm UPVC pipe connected to it. The air is circulated and distributed into the tank to provide oxygen for aerobic biodegradation of constituents of the wastewater. The operation of the submerged mechanical aerator is controlled by a timer at the control panel.

Sedimentation Tank: The sedimentation tank in this plant measures 4.60m by 6.00m and 6.00m, Effluent from the aeration tank flows into it and allowed to settle. This settled matter is re-circulated to the inlet of the plant by a return sludge pumped. The supernatant water is finally discharged to the river through the effluent weir. The re-circulated sludge is to allow enough aerobic microbial biomass in the aeration tank for biodegradation of the wastewater. It is upon the principle of aerobic biodegradation that the Niger Barrack Sewage Aerator works.

Sludge Tank: The sludge tank is of the dimension 2.20m by 2.20m and 5.00m deep. Sludge which accumulates into it from the sedimentation tank settles while it is pumped out for recirculation through the inlet chamber and the excess sludge are pumped out. Figure 16 represent the flow chart of the treatment processes in the Sheraton Sewage Aerator.

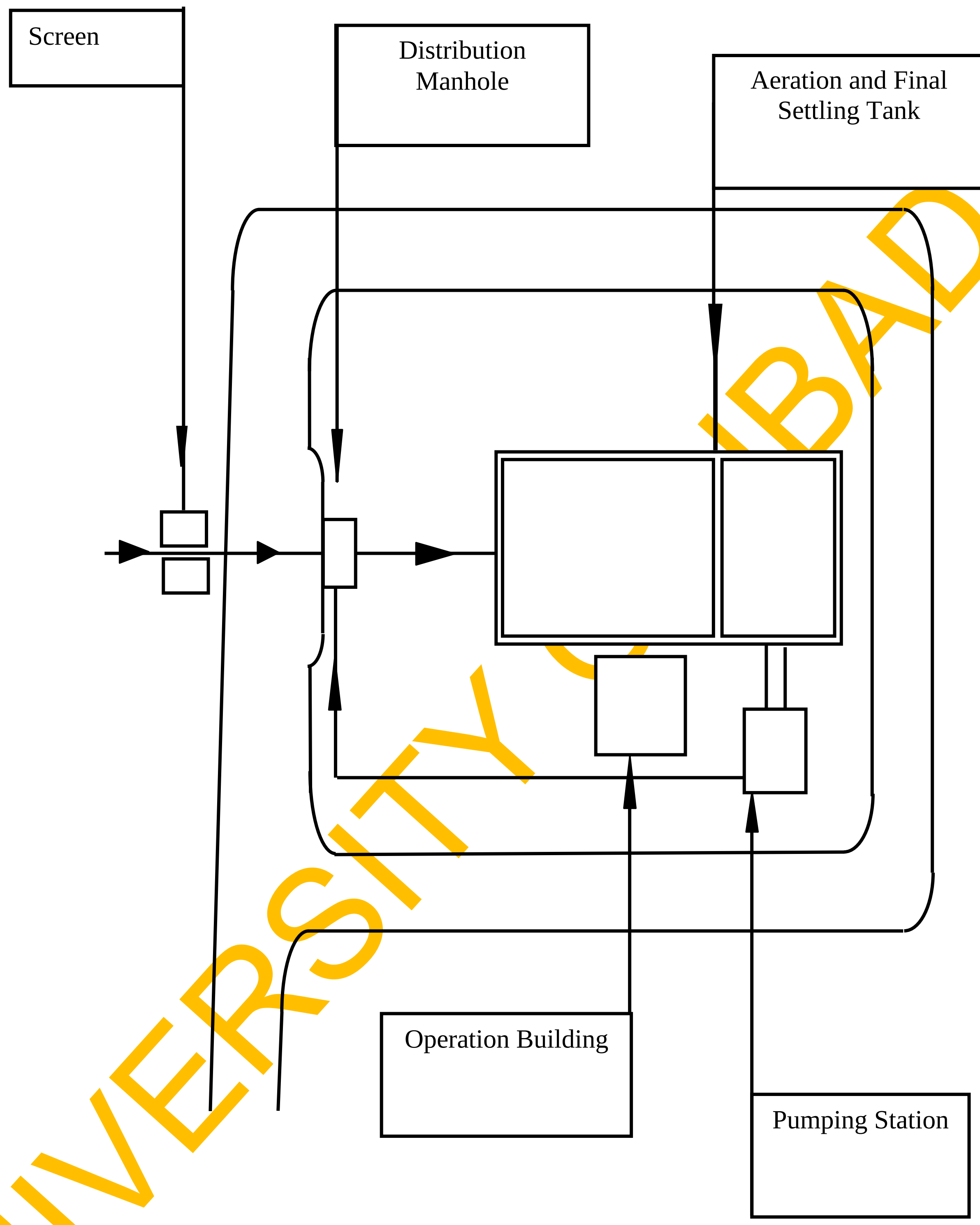

Figure 16: Flow Diagram for Sheraton Sewage Treatment Aerator in Abuja

4.6.5 Gudu Sewage Treatment Aerator

The Gudu Sewage Treatment Aerator consists of an inlet chamber with a screen, Aeration Tank, Sedimentation Tank, effluent Weir, Return Sludge Pump compartment and control room. Screenings of large particles and substances that can damage pumps are done before the sewage is pumped to the treatment plant.

Screening: The screening takes place in a concrete compartment of 4.00m by 1.20m in dimension. This serves to remove large particulate objects such as wood, polythene, paper, etc. which may come along with the wastewater. Aluminium bars at a spacing of 10mm is placed to prevent substances whose sizes are bigger from passing.

Aeration Tank: This comprises of two separate chambers which operate intermittently to allow for maintenance. It serves for further treatment of the screened sewage from the screening chamber. It has a dimension of 21.00m by 22.50m each and two submersible sewage Aerators are installed in the tank to suck-in atmospheric oxygen and distribute into the wastewater. This result in an aerobic biodegradation of the wastewater and thereafter, the wastewater flows into the sedimentation tank.

Sedimentation Tank: The sedimentation tank which is also separated into two compartments measures 10.00m by 22.50m, settleable solids which form as a result of biological activities during aeration in the aeration tank is allowed to settle. This settled sludge is re-circulated to the inlet of the plant for recirculation.

Sludge Tank: The sludge tank has a dimension of 3.00m by 3.00m and 6m deep. Sludge which accumulates into it from the sedimentation tank is pumped out for recirculation through the inlet chamber while excess sludge is pumped out. Figure 17 represent the flow chart of the treatment processes in the Gudu Sewage Aerator.

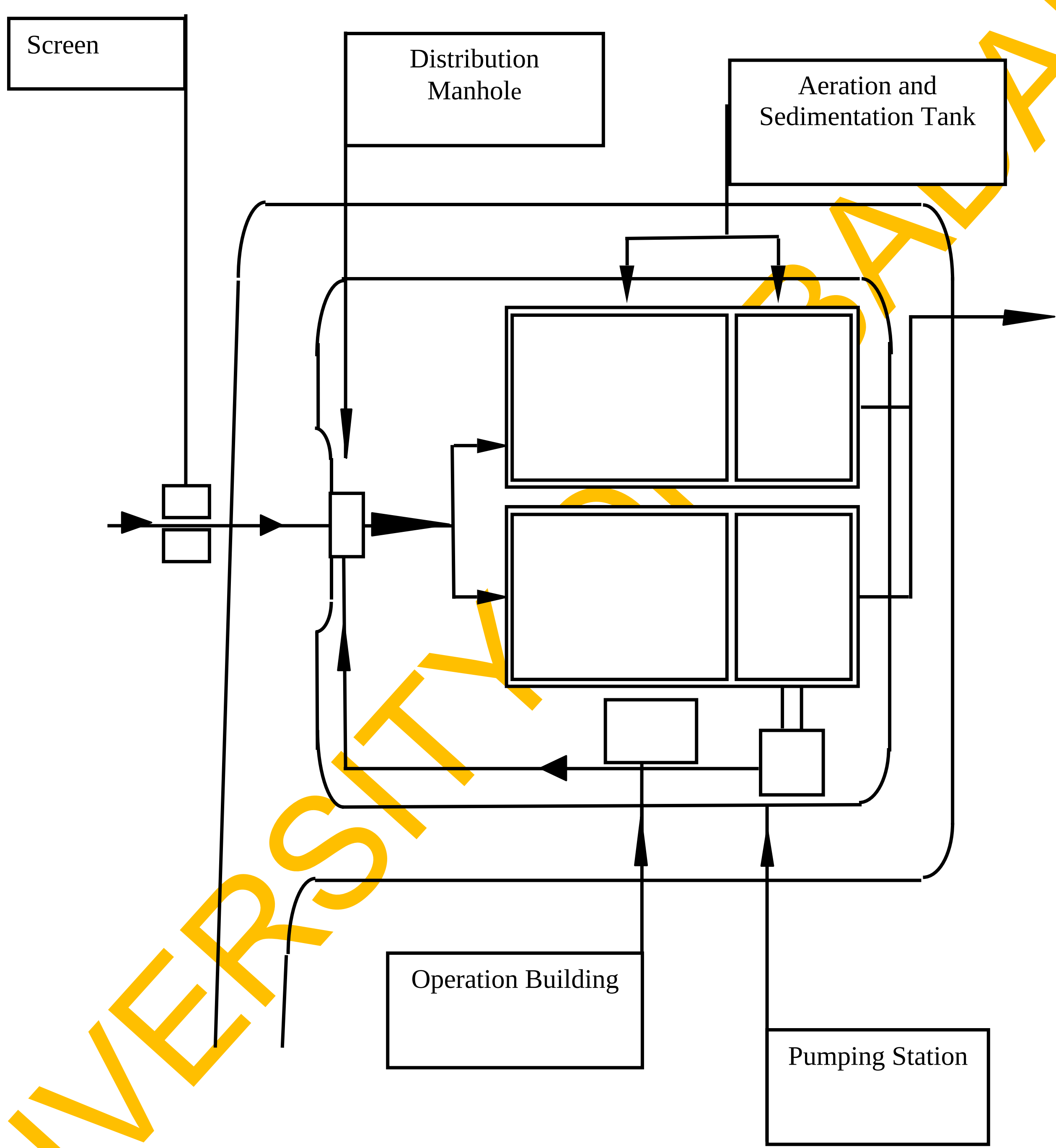

Figure 17: Flow Diagram for Gudu Sewage Treatment Aerator in Abuja

4.6.6 Lungi Barrack Sewage Treatment Aerator

The Lungi Barrack Sewage Treatment Aerator consists of an inlet chamber with a screen, Aeration Tank, Sedimentation Tank, Effluent Weir, Return Sludge Pump compartment and control room. Screenings of large particles and substances that can damage pumps are done before the sewage is pumped to the treatment plant.

Screening: The screening takes place in a concrete compartment of 4.00m by 1.20m in dimension. This serves to remove large particulate objects such as wood, polythene, paper, etc. which may come along with the wastewater. Aluminium bars at a spacing of 10mm is placed to prevent substances whose sizes are bigger from passing.

Aeration Tank: This comprises of two separate chambers which operate intermittently to allow for maintenance. It serves for further treatment of the screened sewage from the screening chamber. It has a dimension of 21.00m by 22.50m each and two submersible sewage Aerators are installed in the tank to suck-in atmospheric oxygen and distribute into the wastewater. This result in an aerobic biodegradation of the wastewater and thereafter, the wastewater flows into the sedimentation tank.

Sedimentation Tank: The sedimentation tank which is also separated into two compartments measures 10.00m by 22.50m, settleable solids which form as a result of biological activities during aeration in the aeration tank is allowed to settle. This settled sludge is re-circulated to the inlet of the plant for recirculation.

Sludge Tank: The sludge tank has a dimension of 3.00m by 3.00m and 6m deep. Sludge which accumulates into it from the sedimentation tank is pumped out for recirculation through the inlet chamber while excess sludge is pumped out. Figure 18 represent the flow chart of the treatment processes in the Lungi Barrack Sewage Aerator.

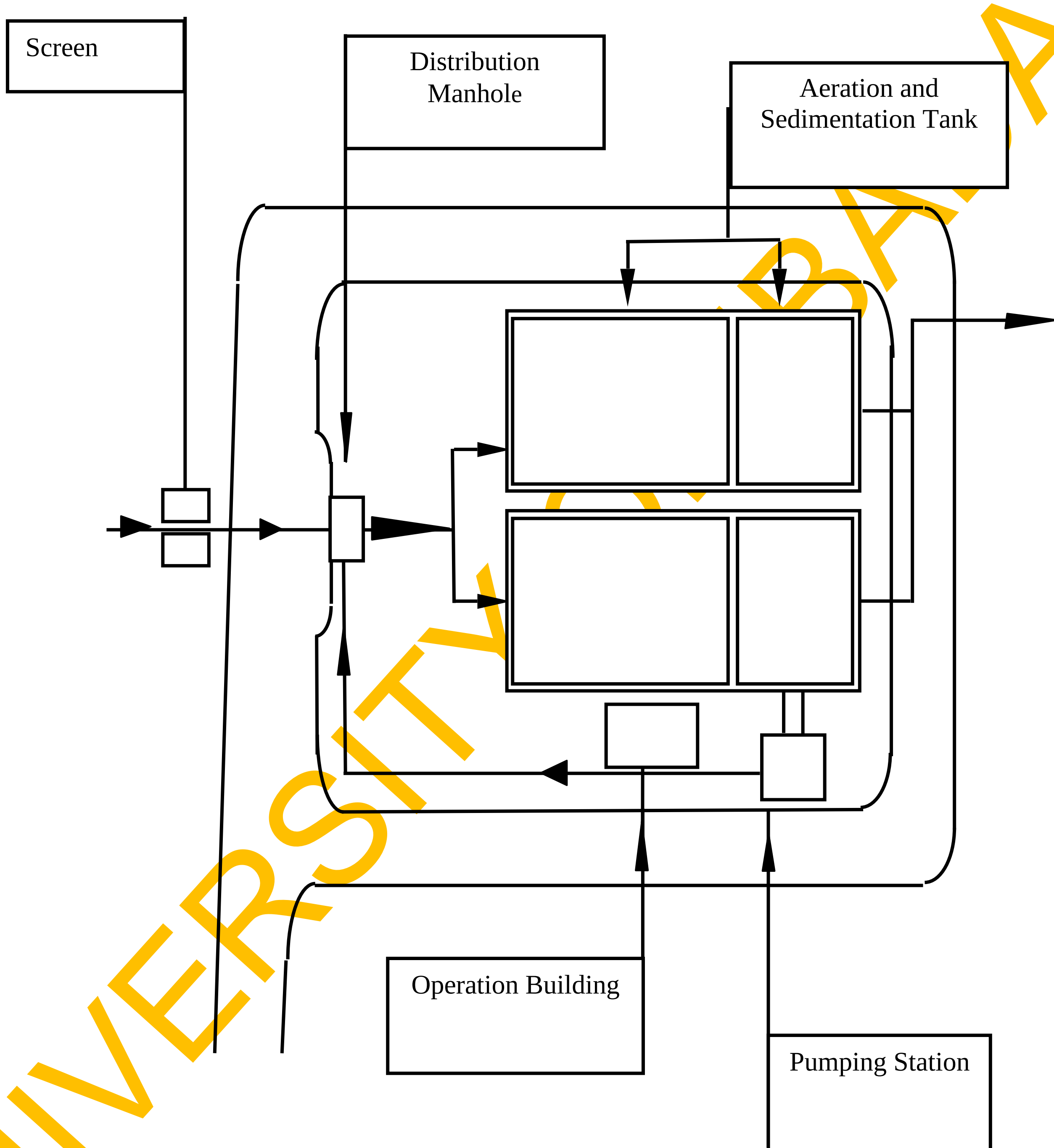

Figure 18: Flow Diagram for Lungi Barrack Sewage Treatment Aerator in Abuja

4.7 Design of an appropriate Sewage Treatment Plant

The conventional Activated Sludge Treatment Plant has failed in Abuja in view of poor electric power supply and inadequate funding for regular operation and maintenance.

As a way out of this problem, it is proposed in this work that combination treatment scheme be adopted for the Federal Capital Territory. The treatment schemes proposed would be the existing Activated Sludge and the use of Water hyacinth. In this scheme, the natural treatment using water hyacinth will be adopted for enhanced pre-treatment. Water hyacinth and sedimentation has a capacity to reduce BOD up to about 35% and suspended solids up to 50% (Hammer, 1986). With improved retention time, the same author specified that the treatment efficiency could rise up to above 90%.

The existing wastewater treatment plant is to be redesigned to accommodate additional treatment works before the aeration tank. To achieve this, a redesign of the 6000 equivalent wastewater treatment plant at Gudu is hereby presented:

A: **Design Data**

i) Population equivalent — 6000 PE

ii) Daily sewage Production — 230 L/c.day
(According to Abuja Master Plan provision)

iii) Total sewage Production = 6000 X 230 X 10^{-3} = 1380 m^3/day

iv) For this design, wastewater is assumed to be produced only within 12 hours of the day and therefore the Average hourly wastewater production is 1380 m^3/day X 1/12 = 115 m^3/hr

v) Design flow, Q = 1.5 X Q_{avg} = 1.5 X 115 = 172.5 m^3/hr

vi) Design flow for daily basis Q = 172.5 X 12 = 2070 m^3/day

For designing this plant, low strength sewage with assumed influent characteristics as presented by METCALF and EDDY (1991) is adopted.

- Suspended Solids 250 mg/l
- BOD (influent) 250 mg/l
- Organic Nitrogen (N-Kj) 30 mg/l
- Phosporus 20 mg/l
- E – Coli 10^6 N/100ml

i) Design flow $2070\ m^3/day$

ii) Suspended Solids $250 \times 2070 \times 10^{-3} = 517.5$ Kg SS/day

iii) BOD load $250 \times 2070 \times 10^{-3} = 517.5$ Kg BOD/day

iv) N – Kj $30 \times 2070 \times 10^{-3} = 62.1$ Kg N/day

v) Phosphorous $20 \times 2070 \times 10^{-3} = 41.4$ Kg P/day

The generated wastewater with the characteristics strength calculated above is allowed to undergo pre-treatment before discharge into the activated sludge treatment system. These pretreatment and other schemes include:

- Screening for grit removal
- Tanks with water hyacinth for settling and part nutrient removal
- Sedimentation
- Aeration Tanks
- Further Sedimentation and Recirculation
- Clarification Tank and effluent discharge

Design for each stage of the scheme is thus presented below:

Screening

Screening is Primary Treatment Processes in wastewater Treatment Plants to improve its quality and make it more acceptable for subsequent biological treatment. It is usually located at the beginning of the treatment scheme. Screening is necessary for safety of pumps and other electromechanical installations. It helps to remove and reduce solids that may interfere with the downstream operations of the treatment plant equipment. Depending on the clear distance between the bars of the screen, they can be classified as fine, medium or coarse screens. Screens can also be cleaned mechanically or manually.

In this design, a manually cleaned medium screen is proposed at the inlet. The screen design here includes the sizing of approach channel, design of the screen itself and the establishment/control of flow velocity between the bars.

The following design criteria were used based on experimental findings in screen design.

a) Approach velocity should be between 0.5 – 0.6m/s to prevent sediments settling in the channels.
b) The maximum flow velocity between the bars should be 0.6 – 1.2 m/s
c) For manual cleaning, the channel depth should be less than 1.5m
d) The minimum width of approach channel is 0.5m
e) The drainage plate should be large enough, more than $1m^2$ to allow sufficient storage.
f) The slope of the bars with the horizontal should be $30\text{-}40^o$
g) For medium screen, the clear distance between the bars should be 10-40mm
h) Bars of thickness 10-12mm are recommended.

- Approach Channel:

Take a maximum wastewater flow observed in Mogadishu Barrack Sewage Treatment Plant in Abuja of 9.9 X 10^{-3} m^3/sec and approach velocity of 0.5m/s

Hence cross sectional area of channel = $\frac{9.9 \times 10^{-3}}{0.5} = 0.02\ m^2$

An allowance of 25 - 30 cm height is given for the drainage plate and free board of 30 cm is also to be provided.

- **Screens:** Take 10mm diameter bars for the screens and assume a clear distance between medium screens of 15mm. Let X be the number of bars of the screen.

  300 = 10X + 15 (X+1)

  Therefore, X = 11.4 mm

  The number of bars become X = 12

  Therefore the actual opening = $\frac{300 - 12X10}{(12+1)}$ =13.8 approximately 14mm

Actual velocity between screens = $\frac{300X\ 0.5}{300 - 12X10} = 0.8$ m/sec (ok)

- **Water Hyacinth Tank**

  i) Effective treatment with water hyacinth, a retention time of 2 – 5 days is required.

  ii) To avoid anaerobic condition at the base of tanks, its depth should be between 1.5 – 2.0 m

  For a design flow of 2070 m^3/day, take a depth of 2m and retention time of 2 days.

  For an unrestricted flow system according to Reed et al (1988), retention time, t = L X W X d/Q

  Where, L = Length of system, m

  W = Width of system, m

  D = Depth of system, m and

  Q = Average Flow Rate

Taking a depth, d = 2 m and width W = 3 m, then

$$\text{Length of tank } L = \frac{t \times Q}{W \times D} = \frac{2 \text{ days} \times 2070}{3 \times 2} = 690 \text{ m}$$

Therefore the size of the tank would be:

L X W X D = 690m length X 3m width X 2m depth

After treatment or nutrient removal with the water hyacinth, the pre-treated wastewater is allowed to undergo the conventional treatment process. In case of power or system failure, the Aeration tanks will act as additional sedimentation tank which will further reduce nutrients and microbial content in the wastewater.

The proposed scheme will be in accordance with the flow diagram in Figure 19.

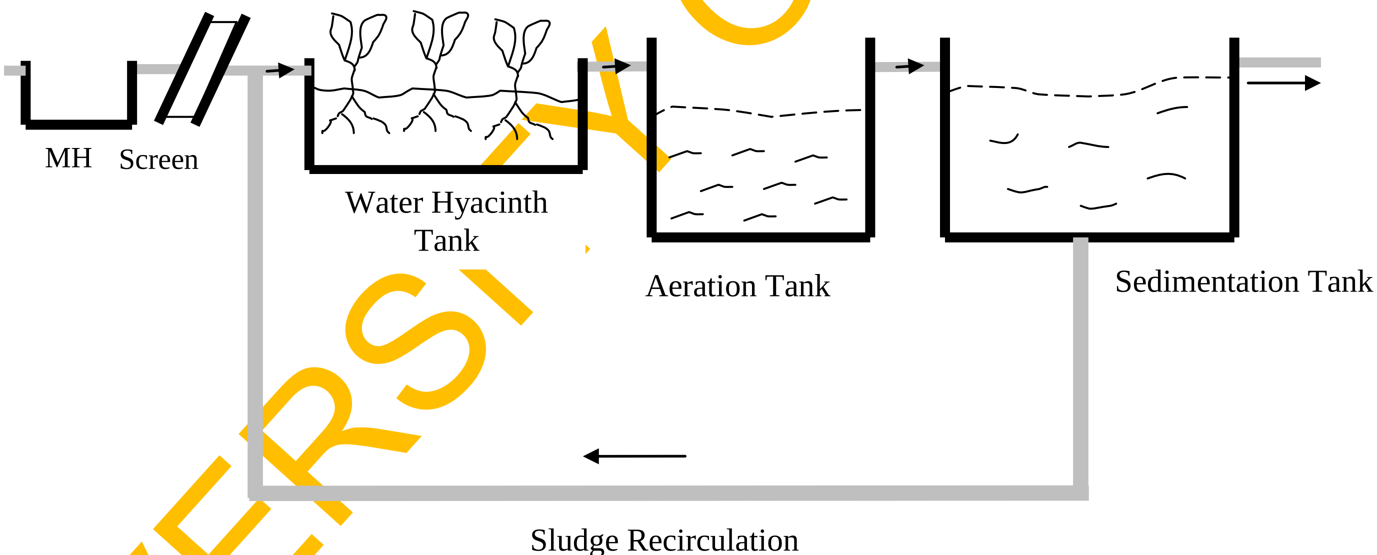

Figure 19: Flow diagram of a redesigned Wastewater Sewage Treatment Plant, Abuja - Nigeria

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The waste water management system in Abuja was evaluated. The evaluation included adopted methods for collection, transportation and treatment systems for the different areas of the city. The classification was based on the system used for the city center and the satellite towns. From the study conducted, the following conclusions were drawn.

i) The new Federal Capital Abuja is the only city in Nigeria currently planned to have a central sewerage system. This system of wastewater handling involves the collection and transportation of generated wastewater to a sewage treatment plant. After treatment, the effluent water is discharged to receiving water bodies. Inadequate treatment of the wastewater would lead to pollution of water bodies.

ii) In the study, it was observed that most of the wastewater treatment works are not functioning effectively due to lack of efficient maintenance of the plants. Poor power supply, inadequate funding amongst other issues. The level of BOD removal in the wastewater at the wastewater treatment plant after treatment ranges between 4 – 10% which is grossly inadequate compared to between 90 – 95% BOD removals expected. Therefore, public health and aquatic life is currently being threatened as the waste water is given little or no treatment at all before they are discharged to water ways.

iii) The sewer lines are similarly filled up with debris and wastes which are solid in nature and not supposed to be discharged into sewer lines. Thus, causing blockages of these lines and sometimes causing disruption at the treatment plants.

iv) It was observed that there were no wastewater treatment plants at the satellite towns. Hence inhabitants of these areas have no option than to construct septic tanks and soak-away pits. This is contrary to the provisions of the Abuja Master Plan. In some housing estates at the satellite towns, cesspools are sometimes constructed.

v) A design is proposed for Abuja which is a combination of natural and advanced electromechanical system wherein the natural system can serve when electric power supplies are not available.

5.2 Recommendations

In view of the observed wastewater management situation in Abuja and the current low level of wastewater management infrastructure, the following recommendations are hereby suggested to improve the level of wastewater management.

i) The current wastewater treatment plants in use should be re-designed where possible or the designs should be modified to reduce cost of operation and maintenance which is difficult to come by since government is funding their operations. Additionally, a review and adopting appropriate engineering strategies that would be utilized on the existing Sewage Treatment Plants used in Abuja to improve their performance.

ii) The associated infrastructure such as sewer lines, Manholes and Treatment works should be considered for the satellite towns instead of the Septic Tank/Soak-away pits currently being used by the inhabitants which are not in accordance with the Abuja Master Plan.

iii) A well-articulated management system should be developed wherein funding for operation and maintenance would not be dependent on government or National budget.

iv) Public Private Partnership (PPP) option for development and management of wastewater infrastructure should be considered and developed to enhance system efficiency.

v) The findings of this study can be used as a guide or step for further research in enhancing wastewater management in Abuja, FCT and indeed other upcoming Cities in Nigeria.

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APPENDIX 1

COLLECTION OF PHOTOGRAPHS DURING VISIT TO PROJECT SITE, ABUJA

Plate 9: Sample collection at Gudu Treatment Plant in Abuja

Plate 10: Apparatus used on site for reading of parameters at Gudu Treatment Plant in Abuja

Plate 11: Collection of samples into containers at Gudu Treatment Plant in Abuja

Plate 12: Labelling of samples and recording of some physical parameters at Gudu Treatment Plant in Abuja

Plate 13: Taking readings of paramters directly at the Gudu Sewage Treatment Plant, Abuja

Plate 14: Brainstorming on results at the research site in Abuja

Plate 15: BOD equipment used for the analysis

Plate 16: COD equipment for analysing samples in this study

Plate 17: LOVIBOND Kit used in carrying out analysis

Plate 18: Oven for sterilizing samples and keeping it in normal condition

Plate 19: Oxygen meter used in the determination of dissolved oxygen

Plate 20: Regulated water bath used in this study

APPENDIX II

Post HOC Test

Multiple Comparisons

Dependent Variable		(I) Major Sewage Components	(J) Major Sewage Components	Mean Difference (I-J)	Standard Error	Significant	95% Confidence Interval	
							Lower Bound	Upper Bound
Influent Niger Barrack	LSD	TEMPERATURE	NITRATE	14.62	38.70716	0.71	-66.1217	95.3617
			BOD	-86.10000*	38.70716	0.038	-166.8417	-5.3583
			COD	-174.50000*	38.70716	0	-255.2417	-93.7583
			MICROBIAL CONTENT (MPN)	-246.50000*	38.70716	0	-327.2417	-165.7583
		NITRATE	TEMPERATURE	-14.62	38.70716	0.71	-95.3617	66.1217
			BOD	-100.72000*	38.70716	0.017	-181.4617	-19.9783
			COD	-189.12000*	38.70716	0	-269.8617	-108.3783

			MICROBIAL CONTENT (MPN)	-261.12000*	38.70716	0	-341.8617	-180.3783
			TEMPERATURE	86.10000*	38.70716	0.038	5.3583	166.8417
			NITRATE	100.72000*	38.70716	0.017	19.9783	181.4617
		BOD	COD	-88.40000*	38.70716	0.033	-169.1417	-7.6583
			MICROBIAL CONTENT (MPN)	-160.40000*	38.70716	0.001	-241.1417	-79.6583
			TEMPERATURE	174.50000*	38.70716	0	93.7583	255.2417
			NITRATE	189.12000*	38.70716	0	108.3783	269.8617
		COD	BOD	88.40000*	38.70716	0.033	7.6583	169.1417
			MICROBIAL CONTENT (MPN)	-72	38.70716	0.078	-152.7417	8.7417
			TEMPERATURE	246.50000*	38.70716	0	165.7583	327.2417
		MICROBIAL CONTENT (MPN)	NITRATE	261.12000*	38.70716	0	180.3783	341.8617
			BOD	160.40000*	38.70716	0.001	79.6583	241.1417
			COD	72	38.70716	0.078	-8.7417	152.7417
Effluent	LSD	TEMPERATURE	NITRATE	14.29	54.2701	0.795	-98.9154	127.4954

Niger Barrack		BOD	-33.86	54.2701	0.54	-147.0654	79.3454
		COD	-168.46000*	54.2701	0.006	-281.6654	-55.2546
		MICROBIAL CONTENT (MPN)	-250.06000*	54.2701	0	-363.2654	-136.8546
		TEMPERATURE	-14.29	54.2701	0.795	-127.4954	98.9154
		BOD	-48.15	54.2701	0.386	-161.3554	65.0554
	NITRATE	COD	-182.75000*	54.2701	0.003	-295.9554	-69.5446
		MICROBIAL CONTENT (MPN)	-264.35000*	54.2701	0	-377.5554	-151.1446
		TEMPERATURE	33.86	54.2701	0.54	-79.3454	147.0654
		NITRATE	48.15	54.2701	0.386	-65.0554	161.3554
	BOD	COD	-134.60000*	54.2701	0.022	-247.8054	-21.3946
		MICROBIAL CONTENT (MPN)	-216.20000*	54.2701	0.001	-329.4054	-102.9946
	COD	TEMPERATURE	168.46000*	54.2701	0.006	55.2546	281.6654

			NITRATE	182.75000*	54.2701	0.003	69.5446	295.9554
			BOD	134.60000*	54.2701	0.022	21.3946	247.8054
			MICROBIAL CONTENT (MPN)	-81.6	54.2701	0.148	-194.8054	31.6054
			TEMPERATURE	250.06000*	54.2701	0	136.8546	363.2654
		MICROBIAL CONTENT (MPN)	NITRATE	264.35000*	54.2701	0	151.1446	377.5554
			BOD	216.20000*	54.2701	0.001	102.9946	329.4054
			COD	81.6	54.2701	0.148	-31.6054	194.8054
			NITRATE	23.458	1470.6565	0.987	-3044.278	3091.194
			BOD	-33.38	1470.6565	0.982	-3101.116	3034.356
		TEMPERATURE	COD	-312.78	1470.6565	0.834	-3380.516	2754.956
Influent Mogadishu barrack	LSD		MICROBIAL CONTENT (MPN)	-2832.98	1470.6565	0.068	-5900.716	234.7557
			TEMPERATURE	-23.458	1470.6565	0.987	-3091.194	3044.278
		NITRATE	BOD	-56.838	1470.6565	0.97	-3124.574	3010.898
			COD	-336.238	1470.6565	0.821	-3403.974	2731.498

			MICROBIAL CONTENT (MPN)	-2856.44	1470.6565	0.066	-5924.174	211.2977
		BOD	TEMPERATURE	33.38	1470.6565	0.982	-3034.356	3101.116
			NITRATE	56.838	1470.6565	0.97	-3010.898	3124.574
			COD	-279.4	1470.6565	0.851	-3347.136	2788.336
			MICROBIAL CONTENT (MPN)	-2799.6	1470.6565	0.071	-5867.336	268.1357
		COD	TEMPERATURE	312.78	1470.6565	0.834	-2754.956	3380.516
			NITRATE	336.238	1470.6565	0.821	-2731.498	3403.974
			BOD	279.4	1470.6565	0.851	-2788.336	3347.136
			MICROBIAL CONTENT (MPN)	-2520.2	1470.6565	0.102	-5587.936	547.5357
		MICROBIAL CONTENT (MPN)	TEMPERATURE	2832.98	1470.6565	0.068	-234.7557	5900.716
			NITRATE	2856.438	1470.6565	0.066	-211.2977	5924.174
			BOD	2799.6	1470.6565	0.071	-268.1357	5867.336
			COD	2520.2	1470.6565	0.102	-547.5357	5587.936
Effluent Mogadishu Barrack	LSD	TEMPERATURE	NITRATE	23.414	154.50453	0.881	-298.8768	345.7048
			BOD	-23.2	154.50453	0.882	-345.4908	299.0908

	COD	-265.2	154.50453	0.102	-587.4908	57.0908
	MICROBIAL CONTENT (MPN)	-317.2	154.50453	0.053	-639.4908	5.0908
NITRATE	TEMPERATURE	-23.414	154.50453	0.881	-345.7048	298.8768
	BOD	-46.614	154.50453	0.766	-368.9048	275.6768
	COD	-288.614	154.50453	0.076	-610.9048	33.6768
	MICROBIAL CONTENT (MPN)	-340.61400*	154.50453	0.039	-662.9048	-18.3232
BOD	TEMPERATURE	23.2	154.50453	0.882	-299.0908	345.4908
	NITRATE	46.614	154.50453	0.766	-275.6768	368.9048
	COD	-242	154.50453	0.133	-564.2908	80.2908
	MICROBIAL CONTENT (MPN)	-294	154.50453	0.072	-616.2908	28.2908
COD	TEMPERATURE	265.2	154.50453	0.102	-57.0908	587.4908
	NITRATE	288.614	154.50453	0.076	-33.6768	610.9048
	BOD	242	154.50453	0.133	-80.2908	564.2908
	MICROBIAL CONTENT (MPN)	-52	154.50453	0.74	-374.2908	270.2908
MICROBIAL CONTENT (MPN)	TEMPERATURE	317.2	154.50453	0.053	-5.0908	639.4908
	NITRATE	340.61400*	154.50453	0.039	18.3232	662.9048

			BOD	294	154.50453	0.072	-28.2908	616.2908
			COD	52	154.50453	0.74	-270.2908	374.2908
			NITRATE	1.534	203.74895	0.994	-423.4789	426.5469
			BOD	-96.64	203.74895	0.64	-521.6529	328.3729
		TEMPERATURE	COD	-430.24000*	203.74895	0.047	-855.2529	-5.2271
			MICROBIAL CONTENT (MPN)	-574.24000*	203.74895	0.011	-999.2529	-149.2271
			TEMPERATURE	-1.534	203.74895	0.994	-426.5469	423.4789
Influent Wuye TP	LSD		BOD	-98.174	203.74895	0.635	-523.1869	326.8389
		NITRATE	COD	-431.77400*	203.74895	0.047	-856.7869	-6.7611
			MICROBIAL CONTENT (MPN)	-575.77400*	203.74895	0.01	-1000.787	-150.7611
			TEMPERATURE	96.64	203.74895	0.64	-328.3729	521.6529
		BOD	NITRATE	98.174	203.74895	0.635	-326.8389	523.1869
			COD	-333.6	203.74895	0.117	-758.6129	91.4129

			MICROBIAL CONTENT (MPN)	-477.60000*	203.74895	0.03	-902.6129	-52.5871
		COD	TEMPERATURE	430.24000*	203.74895	0.047	5.2271	855.2529
			NITRATE	431.77400*	203.74895	0.047	6.7611	856.7869
			BOD	333.6	203.74895	0.117	-91.4129	758.6129
			MICROBIAL CONTENT (MPN)	-144	203.74895	0.488	-569.0129	281.0129
		MICROBIAL CONTENT (MPN)	TEMPERATURE	574.24000*	203.74895	0.011	149.2271	999.2529
			NITRATE	575.77400*	203.74895	0.01	150.7611	1000.787
			BOD	477.60000*	203.74895	0.03	52.5871	902.6129
			COD	144	203.74895	0.488	-281.0129	569.0129
Effluent Wuye TP	LSD	TEMPERATURE	NITRATE	4.752	197.9624	0.981	-408.1903	417.6943
			BOD	-59.16	197.9624	0.768	-472.1023	353.7823
			COD	-366.96	197.9624	0.079	-779.9023	45.9823
			MICROBIAL CONTENT (MPN)	-550.16000*	197.9624	0.012	-963.1023	-137.2177
		NITRATE	TEMPERATURE	-4.752	197.9624	0.981	-	408.1903

					417.6943	
	BOD	-63.912	197.9624	0.75	-476.8543	349.0303
	COD	-371.712	197.9624	0.075	-784.6543	41.2303
	MICROBIAL CONTENT (MPN)	-554.91200*	197.9624	0.011	-967.8543	-141.9697
	TEMPERATURE	59.16	197.9624	0.768	-353.7823	472.1023
	NITRATE	63.912	197.9624	0.75	-349.0303	476.8543
BOD	COD	-307.8	197.9624	0.136	-720.7423	105.1423
	MICROBIAL CONTENT (MPN)	-491.00000*	197.9624	0.022	-903.9423	-78.0577
	TEMPERATURE	366.96	197.9624	0.079	-45.9823	779.9023
	NITRATE	371.712	197.9624	0.075	-41.2303	784.6543
COD	BOD	307.8	197.9624	0.136	-105.1423	720.7423
	MICROBIAL CONTENT (MPN)	-183.2	197.9624	0.366	-596.1423	229.7423
	TEMPERATURE	550.16000*	197.9624	0.012	137.2177	963.1023
MICROBIAL CONTENT (MPN)	NITRATE	554.91200*	197.9624	0.011	141.9697	967.8543
	BOD	491.00000*	197.9624	0.022	78.0577	903.9423

			COD	183.2	197.9624	0.366	-229.7423	596.1423
		TEMPERATURE	NITRATE	21.054	217.61337	0.924	-432.8795	474.9875
			BOD	-39.48	217.61337	0.858	-493.4135	414.4535
			COD	-156.6	217.61337	0.48	-610.5335	297.3335
			MICROBIAL CONTENT (MPN)	-530.00000*	217.61337	0.024	-983.9335	-76.0665
Influent Sheraton TP	LSD	NITRATE	TEMPERATURE	-21.054	217.61337	0.924	-474.9875	432.8795
			BOD	-60.534	217.61337	0.784	-514.4675	393.3995
			COD	-177.654	217.61337	0.424	-631.5875	276.2795
			MICROBIAL CONTENT (MPN)	-551.05400*	217.61337	0.02	-1004.988	-97.1205
		BOD	TEMPERATURE	39.48	217.61337	0.858	-414.4535	493.4135
			NITRATE	60.534	217.61337	0.784	-393.3995	514.4675
			COD	-117.12	217.61337	0.596	-571.0535	336.8135
			MICROBIAL CONTENT (MPN)	-490.52000*	217.61337	0.036	-944.4535	-36.5865
		COD	TEMPERATURE	156.6	217.61337	0.48	-297.3335	610.5335

			NITRATE	177.654	217.61337	0.424	-276.2795	631.5875
			BOD	117.12	217.61337	0.596	-336.8135	571.0535
			MICROBIAL CONTENT (MPN)	-373.4	217.61337	0.102	-827.3335	80.5335
		MICROBIAL CONTENT (MPN)	TEMPERATURE	530.00000*	217.61337	0.024	76.0665	983.9335
			NITRATE	551.05400*	217.61337	0.02	97.1205	1004.988
			BOD	490.52000*	217.61337	0.036	36.5865	944.4535
			COD	373.4	217.61337	0.102	-80.5335	827.3335
Effluent SheratonTP	LSD	TEMPERATURE	NITRATE	15.738	94.8208	0.87	-182.0547	213.5307
			BOD	-45.78	94.8208	0.634	-243.5727	152.0127
			COD	-258.08000*	94.8208	0.013	-455.8727	-60.2873
			MICROBIAL CONTENT (MPN)	-235.88000*	94.8208	0.022	-433.6727	-38.0873
		NITRATE	TEMPERATURE	-15.738	94.8208	0.87	-213.5307	182.0547
			BOD	-61.518	94.8208	0.524	-259.3107	136.2747

	COD	-273.81800*	94.8208	0.009	-471.6107	-76.0253
	MICROBIAL CONTENT (MPN)	-251.61800*	94.8208	0.015	-449.4107	-53.8253
	TEMPERATURE	45.78	94.8208	0.634	-152.0127	243.5727
	NITRATE	61.518	94.8208	0.524	-136.2747	259.3107
BOD	COD	-212.30000*	94.8208	0.037	-410.0927	-14.5073
	MICROBIAL CONTENT (MPN)	-190.1	94.8208	0.059	-387.8927	7.6927
	TEMPERATURE	258.08000*	94.8208	0.013	60.2873	455.8727
	NITRATE	273.81800*	94.8208	0.009	76.0253	471.6107
COD	BOD	212.30000*	94.8208	0.037	14.5073	410.0927
	MICROBIAL CONTENT (MPN)	22.2	94.8208	0.817	-175.5927	219.9927
MICROBIAL CONTENT (MPN)	TEMPERATURE	235.88000*	94.8208	0.022	38.0873	433.6727
	NITRATE	251.61800*	94.8208	0.015	53.8253	449.4107

			BOD	190.1	94.8208	0.059	-7.6927	387.8927
			COD	-22.2	94.8208	0.817	-219.9927	175.5927
		TEMPERATURE	NITRATE	20.282	53.31659	0.708	-90.9345	131.4985
			BOD	-9.52	53.31659	0.86	-120.7365	101.6965
			COD	-80.28	53.31659	0.148	-191.4965	30.9365
			MICROBIAL CONTENT (MPN)	-205.88000*	53.31659	0.001	-317.0965	-94.6635
		NITRATE	TEMPERATURE	-20.282	53.31659	0.708	-131.4985	90.9345
			BOD	-29.802	53.31659	0.582	-141.0185	81.4145
			COD	-100.562	53.31659	0.074	-211.7785	10.6545
Influent Gudu TP	LSD		MICROBIAL CONTENT (MPN)	-226.16200*	53.31659	0	-337.3785	-114.9455
		BOD	TEMPERATURE	9.52	53.31659	0.86	-101.6965	120.7365
			NITRATE	29.802	53.31659	0.582	-81.4145	141.0185
			COD	-70.76	53.31659	0.199	-181.9765	40.4565
			MICROBIAL CONTENT (MPN)	-196.36000*	53.31659	0.001	-307.5765	-85.1435
		COD	TEMPERATURE	80.28	53.31659	0.148	-30.9365	191.4965
			NITRATE	100.562	53.31659	0.074	-10.6545	211.7785
			BOD	70.76	53.31659	0.199	-40.4565	181.9765

			MICROBIAL CONTENT (MPN)	-125.60000*	53.31659	0.029	-236.8165	-14.3835
			TEMPERATURE	205.88000*	53.31659	0.001	94.6635	317.0965
		MICROBIAL CONTENT (MPN)	NITRATE	226.16200*	53.31659	0	114.9455	337.3785
			BOD	196.36000*	53.31659	0.001	85.1435	307.5765
			COD	125.60000*	53.31659	0.029	14.3835	236.8165
		TEMPERATURE	NITRATE	18.366	31.29631	0.564	-46.917	83.649
			BOD	-16.2	31.29631	0.61	-81.483	49.083
			COD	-93.48000*	31.29631	0.007	-158.763	-28.197
			MICROBIAL CONTENT (MPN)	-128.28000*	31.29631	0.001	-193.563	-62.997
Effluent Gudu TP	LSD	NITRATE	TEMPERATURE	-18.366	31.29631	0.564	-83.649	46.917
			BOD	-34.566	31.29631	0.282	-99.849	30.717
			COD	-111.84600*	31.29631	0.002	-177.129	-46.563
			MICROBIAL CONTENT (MPN)	-146.64600*	31.29631	0	-211.929	-81.363
		BOD	TEMPERATURE	16.2	31.29631	0.61	-49.083	81.483
			NITRATE	34.566	31.29631	0.282	-30.717	99.849

			COD	-77.28000*	31.29631	0.023	-142.563	-11.997
			MICROBIAL CONTENT (MPN)	-112.08000*	31.29631	0.002	-177.363	-46.797
		COD	TEMPERATURE	93.48000*	31.29631	0.007	28.197	158.763
			NITRATE	111.84600*	31.29631	0.002	46.563	177.129
			BOD	77.28000*	31.29631	0.023	11.997	142.563
			MICROBIAL CONTENT (MPN)	-34.8	31.29631	0.279	-100.083	30.483
		MICROBIAL CONTENT (MPN)	TEMPERATURE	128.28000*	31.29631	0.001	62.997	193.563
			NITRATE	146.64600*	31.29631	0	81.363	211.929
			BOD	112.08000*	31.29631	0.002	46.797	177.363
			COD	34.8	31.29631	0.279	-30.483	100.083
Influent Lungi TP	LSD	TEMPERATURE	NITRATE	22.84	155.02235	0.884	-300.531	346.211
			BOD	-68.96	155.02235	0.661	-392.331	254.411
			COD	-272.86	155.02235	0.094	-596.231	50.511
			MICROBIAL CONTENT (MPN)	-527.46000*	155.02235	0.003	-850.831	-204.089
		NITRATE	TEMPERATURE	-22.84	155.02235	0.884	-346.211	300.531
			BOD	-91.8	155.02235	0.56	-415.171	231.571
			COD	-295.7	155.02235	0.071	-619.071	27.671

			MICROBIAL CONTENT (MPN)	-550.30000*	155.02235	0.002	-873.671	-226.929
		BOD	TEMPERATURE	68.96	155.02235	0.661	-254.411	392.331
			NITRATE	91.8	155.02235	0.56	-231.571	415.171
			COD	-203.9	155.02235	0.203	-527.271	119.471
			MICROBIAL CONTENT (MPN)	-458.50000*	155.02235	0.008	-781.871	-135.129
		COD	TEMPERATURE	272.86	155.02235	0.094	-50.511	596.231
			NITRATE	295.7	155.02235	0.071	-27.671	619.071
			BOD	203.9	155.02235	0.203	-119.471	527.271
			MICROBIAL CONTENT (MPN)	-254.6	155.02235	0.116	-577.971	68.771
		MICROBIAL CONTENT (MPN)	TEMPERATURE	527.46000*	155.02235	0.003	204.089	850.831
			NITRATE	550.30000*	155.02235	0.002	226.929	873.671
			BOD	458.50000*	155.02235	0.008	135.129	781.871
			COD	254.6	155.02235	0.116	-68.771	577.971
Effluent Lungi TP	LSD	TEMPERATURE	NITRATE	23.11	61.58237	0.711	-105.3486	151.5686
			BOD	-73.7	61.58237	0.245	-202.1586	54.7586
			COD	-362.40000*	61.58237	0	-490.8586	-233.9414

	MICROBIAL CONTENT (MPN)	-180.20000*	61.58237	0.008	-308.6586	-51.7414
NITRATE	TEMPERATURE	-23.11	61.58237	0.711	-151.5686	105.3486
	BOD	-96.81	61.58237	0.132	-225.2686	31.6486
	COD	-385.51000*	61.58237	0	-513.9686	-257.0514
	MICROBIAL CONTENT (MPN)	-203.31000*	61.58237	0.004	-331.7686	-74.8514
BOD	TEMPERATURE	73.7	61.58237	0.245	-54.7586	202.1586
	NITRATE	96.81	61.58237	0.132	-31.6486	225.2686
	COD	-288.70000*	61.58237	0	-417.1586	-160.2414
	MICROBIAL CONTENT (MPN)	-106.5	61.58237	0.099	-234.9586	21.9586
COD	TEMPERATURE	362.40000*	61.58237	0	233.9414	490.8586
	NITRATE	385.51000*	61.58237	0	257.0514	513.9686
	BOD	288.70000*	61.58237	0	160.2414	417.1586

	MICROBIAL CONTENT (MPN)	182.20000*	61.58237	0.008	53.7414	310.6586
	TEMPERATURE	180.20000*	61.58237	0.008	51.7414	308.6586
MICROBIAL CONTENT (MPN)	NITRATE	203.31000*	61.58237	0.004	74.8514	331.7686
	BOD	106.5	61.58237	0.099	-21.9586	234.9586
	COD	-182.20000*	61.58237	0.008	-310.6586	-53.7414

*. The mean difference is significant at the 0.05 level.