GROUNDWATER CONTAMINATION BY SANITARY LANDFILL AT OLUSOSUN (OJOTA) IN LAGOS STATE OF NIGERIA

BY

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A THESIS IN THE DEPARTMENT OF CIVIL ENGINEERING SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL EULFILMENT OF THE AWARD OF MASTER OF ENGINEERING DEGREE IN CIVIL ENGINEERING (WATER RESOURCES AND ENVIRONMENTAL ENGINEERING OPTION) FEDERAL UNIVERSITY OF TECHNOLOGY AKURE, NIGERIA

November, 2004

CERTIFICATION

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DEDICATION

This project is dedicated to the Almighty God for His mercy and unfailing love to me in all my endeavours. I give Him the glory, honour and adoration.

ACKNOWLEDGEMENT

I give God all glory for the successful completion of this project work.

I would like to express my sincere gratitude and appreciation to my Supervisor, Dr. A. M. Oguntuase who is also Head of Department for his guidance and encouragement. It has been a great privilege for me to work under his guidance. I sincerely express my heartfelt gratitude to him. .

I also wish to express my appreciation to all those who has contributed in one way or the other to the success of this work among whom my special thanks go to are Engr. J. O. Babatola of Civil Engineering Department, F.U.TA.Akure, Engr. A. O. Owolabi, Mrs. D. B. Oluyemi – Ayibiowu, Pastor Alex Omosekeji and other members of Civil Engineering Department for their cooperation and useful advice during the course of my studies. I am also grateful to my colleagues in M.Eng. Class for their understanding and support in working together as a team.

ABSTRACT

The study was an evaluation of the ground water contamination by the sanitary landfill at Olusosun (Ojota) in Ikeja Local Government area of Lagos State, Nigeria. The landfill at Olusosun (Ojota) has been turned to open dump, due to the poor operation management. Wastes were buried without treating the bottom and sides of the trenches with sealant to control the leachate movement . Also wastes were left fallow for several months and not buried and whenever rain falls the wastes would be soaked, leading to production of leachate. The continuous generation of leachate without corresponding containment of leachate within the landfill in Olusosun (Ojota) constitute a major threat to the quality of groundwater and public health in Olusosun in Lagos state.

Water samples were taken from wells around the dumpsite for a period of eight months and analyzed to determine the physical, chemical and biological characteristics. The results obtained were compared with WHO international standards on potable water. The average value for the parameters that reflects leachate pollution for the contaminated wells varied during the dry and wet season. The average BOD concentration of the contaminated wells at the dry season varies between 8.3mg/l - 37.8mg/l and wet season values varies between 8.3mg/l - 31mg/l. The zinc concentration at the dry season varied between 15.8mg/l - 20.1mg/l and at the wet season it varies between 15.2mg/l – 21.1mg/l. The chloride concentration at the wet season varied between 368.6mg/l - 709.4mg/l. The nitrate concentration at the wet season varied between 52.5mg/l - 54.6mg/l.

Wells sited very close to the sanitary landfill had suffered contamination from the leachate of landfill and had concentration of some elements exceeding the maximum concentration limits. Some of these wells were sited on a reclaimed land,

formerly used for refuse dump. Some of this contamination are causing heritable genetic diseases, birth defect and sudden death. Data on hydrogeological features of Olusosun (Ojota) were collected from the Lagos State Ministry of Water Resources to determine the alternation of layers of sand bands, their thickness and identification of aquifer horizons.

Structural and non-structural solutions to problems of contamination of wells at Olusosun (Ojota) are required to protect public health. These include the redesign of the landfill with underground protective membrane (bentonite, clayslurry, bituminous felt) laid under the sanitary trenches, and the construction of a collection pit for the leachate. Control of leachate production discharge from the landfill, collection of the leachate with final treatment and or disposal. Formulate a policy on management strategies of municipal sanitary landfill, putting in place institutional and legal instruments for the management of sanitary landfill and environment. The decaying refuse is also raw material for a fertilizer company.

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INTRODUCTION

1.1 General

Olusosun (Ojota) sanitary landfill was created in 1985 by the Lagos State government, located at that time at the outskirts of the township. It is now practically in the center of the city as a result of urbanization.

Industrialization has led to the large influx of people to Lagos State. This in turn has resulted in the generation of enormous wastes from homes and offices (Nigerian Water and Sanitation Association; 2003). Also, clusters of buildings have been built around the sanitary landfill and several shallow wells have been sunk for domestic consumption because of the inability of government to provide pipe-borne water supply. Therefore, unknowingly the greatest danger of groundwater pollution in this area is from this unlined landfill.

Groundwater has been the major source of drinking water for the people that dwell in Olusosun (Ojota) in Lagos. Water drawn from wells are used directly without treatment. A significant proportion of the water has suffered contamination from the leachate of landfill. Given that some of the contaminations are carcinogeous (cancer causing), mutagenic (causing heritable genetic diseases), tetratogenic (causing birth defects), neurotoxin (destroying nerve tissues) or just plain toxic, short and long term exposures to them may result in untimely death, or deleterious health effect. (Nigerian Water and Sanitation Association; 2003). Unfortunately, there are no hard data such as causes of death in our society, from autopsies to determine effects of pollution in Nigeria. Based on the data from other countries, one can conclude that adverse effect of water pollution couldn't be different at the study area.

According to Hamill and Bell, (1986), it was estimated in 1984 that more than 900 million people in Africa were without public water service of any kind while by 1992 the situation had deteriorated and many people were affected by water related diseases.

Usually, when groundwater is contaminated, it is very difficult and expensive to clean up, thus it is better to adopt pollution prevention and conservation practices in order to protect important groundwater supplies. In this study, the groundwater contamination of Olusosun (Ojota) wells in Lagos State by the landfill (owned by the State Government) is evaluated and possible techniques and solutions for elimination of the source of the contaminants which pose threat to public health are suggested.

1.2 Objectives of the Study

The general objective of this study is to determine the extent of groundwater contamination by landfills at Olusosun (Ojota) in Lagos State and proffer solutions to control and eliminate the contaminants.

The specific objectives of the research are to:

i. determine the concentration of groundwater contaminants at Olusosun wells in Lagos State due to landfill;

ii. compare the level of concentration of the contaminants with the WHO standards for drinking water;

iii. determine the depth at which safe good quality drinking groundwater can be obtained in the study area.; and

iv. formulate management strategies of municipal sanitary landfill and planning for control and elimination of contaminants.

1.3 Scope of the Work

The study is limited to the examination of wells that are close to the sanitary landfill at Olusosun (Ojota) area of Lagos State. The scope of examination is for a period of 8 months to over a typical wet and dry season to determine their physical chemical and biological characteristics.

1.4 Justification of the Study

Environmental hazards caused by the landfills in Olusosun in Lagos State are enormous. Apart from the obnoxious odours and smokes being generated due to open dump and burning practice, the landfill is poorly managed and under-funded by the government. The singular operation of burning causes bronchio constriction, carbon-oxyhaemoglobin and other health related hazards. The landfill has also contaminated the surrounding wells that serve as the major source of drinking water for the people of Olusosun.

According to Wright, (1995); pathogens are not visibly seen and does not kill immediately but at the long run it has a chronic effect on human health. Therefore, there is need for immediate action to protect the people of Olusosun from dying gradually and unknowingly due to lack of knowledge on the level of contamination of groundwater they depend on for their drinking. This study will provide information to the pubic on the level of contamination of wells at Olusosun (Ojota) in Lagos State by landfill which can thereafter assist in decision-making policy for the control and elimination of contaminants.

CHAPTER TWO
LITERATURE REVIEW

2.1 Groundwater Fundamentals

Groundwater is the water in the subsoil or water below the surface of the ground, formed as a result of precipitation of rain, snow, drizzle, etc. which infiltrate downward as flowing water through the aeration or vadose zone, (Funk and McClenaghan, 1992). During this infiltration process some water is dispersed through the soil and held by capillary forces in smaller pores or by molecular attraction around the particles. If the retention capacity of the soil in the zone of aeration is satisfied or saturated, water moves downward into regions where pores of the soil or rocks are completely filled with water. The water in this zone is called groundwater, (Gibb and O'Hearn, 2000).

The top of this zone is called water table. The water table may be a shallow one, just a metre or less below the ground's surface or it may be hundred of metres below. Therefore, groundwater can be found almost everywhere at any depth and is stored in layers of soil and sand, moving slowly through these layers of sand band.

An aquifer is the term given to a rock or soil which not only contains water, but from which water can be readily abstracted in significant quantities. The ability of an aquifer to transmit water is governed by its permeability. The permeability of an aquifer usually is in excess of 10^{-5}m/s. By contrast, a formation of soil layers regarded as impermeable is referred to as an aquiclude. Even when such rocks are saturated they tend to impede the flow of water through stratal sequences (Bouwer, 1992).

According to Fuhriman (1999), an aquitard is a geological formation which transmits water at a very slow rate but which over a large area of contact may permit the passage of large amounts of water between adjacent aquifers which it separates. Sandy clay is an example. A rock which neither transmits nor stores water is called an aquifuge.

2.1.1 Types of Aquifer

An aquifer is described as unconfined when the water table is open to the atmosphere, that is, the aquifer is not overlain by material of lower permeability as shown in Fig. 2.1a. Conversely a confined aquifer is one which is overlain by impermeable rocks. An aquifer which is overlain and / or underlain by an aquitard(s) is described as a leaky aquifer as shown in fig. 2.1b. (Hamill and Bell, 1986).

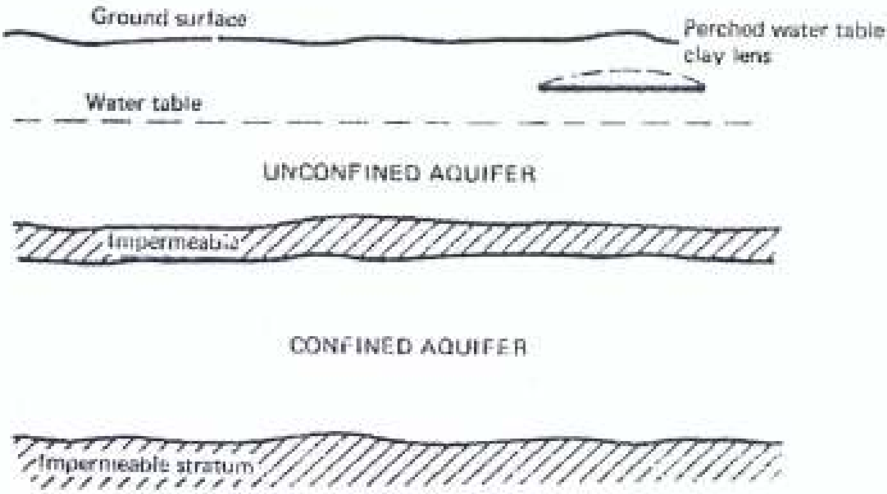


Fig. 2.1a *Confined and Unconfined Aquifers*

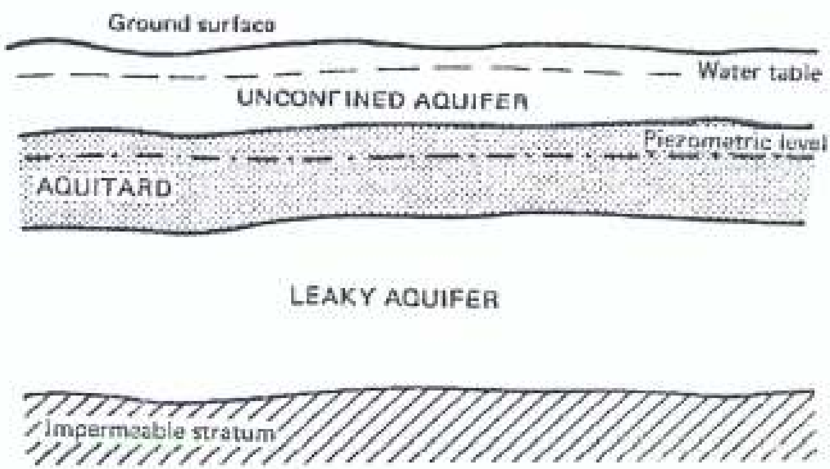


Fig 2.1b *Leaky Aquifer*

Moriber (1988) stated that very often the water in a confined aquifer is under piezometric pressure, that is, there is an excess of pressure sufficient to raise the water above the base of the overlying bed when the aquifer is penetrated by a well. Piezometric pressure is developed when the buried upper surface of a confined aquifer is lower than the water table in the aquifer at its recharge area. Where the piezometric surface is above ground level then water overflows from a well. Such well are described as artesian as shown in Fig.2.2. The term subartesian is used to describe those conditions in which the water is not under sufficient piezometric pressure to rise to the ground surface.

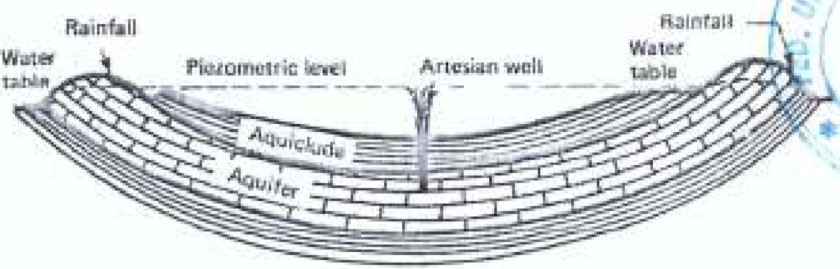


Fig. 2.2 ***An Artesian Basin*** *(Source: Bouwer 1992)*

2.2 Groundwater Contamination

According to Palanichami (2002), groundwater contamination is the addition of elements, compounds and or pathogen to groundwater, which alter its composition, and renders it unfit for drinking. Groundwater contamination occurs through the following sources: Septic tank, unlined sanitary landfill, leaky storage tank, hazardous waste sites and use of chemicals as shown in fig.2.3. Other sources resulting from human activities include accidental spills, mining, atmospheric contaminant and acid rain, surface water, improperly planned groundwater development leading to salt intrusion and improper well construction and maintenance. Since groundwater is a part of the hydrologic cycle, what can contaminate other parts of the cycle such as the air or surface water can eventually get into the groundwater (Funk and Mcclenaghan, 1992).

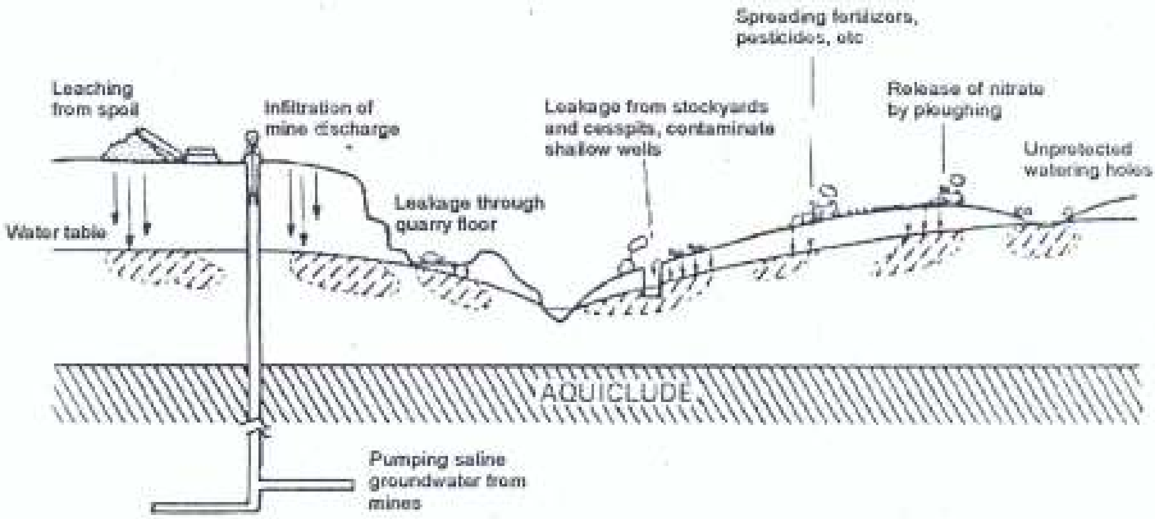


Fig 2.3 ***Sources of contamination*** *(Source: Hamill and Bell 1986)*

Once a well or well field has been successfully put into supply, it must be recognized that there exists the strong possibility that groundwater pollution may occur at some time in the future. Certainly groundwater pollution is not an abstract concept, it is of common occurrence. A survey of recent literature shows for instance, that the problems facing Dade County in Florida, USA are high nitrate level and volatile organic pollution, (Esca, et al., 1995). In Nigeria, at Lagos island, and at the coastal areas, there is also a problem of saltwater intrusion which affects the groundwater quality.

Steiner (1979), defined pollution as an impairment of water quality by chemicals, heat or bacteria to a degree that create an actual public health hazard. Thus, the purity of groundwater should not be taken for granted and untreated water should not be put directly into supply. Some form of chlorination or other type of disinfection is at least necessary for the water to be used for domestic purpose.

According to Hamill and Bell (1986), as many as 500 million people per year were affected by water-borne or water related disease in the developing countries. By 1990 the situation had deteriorated. The World Health Organization (WHO) then estimated that 1320 million people (57%) of the developing world (excluding China) were without potable water supply, while 1730 million (75%) were without adequate sanitation. At least 30,000 people per day die in the Third World because they have inadequate water and sanitation facilities. Therefore, the control of water pollution in developing countries is a necessity.

The greatest danger of groundwater pollution is from surface sources such as farm animal, man wastes, sewers, polluted streams and sanitary landfill. Therefore, the obvious precaution against pollution is to locate the wells as far from any potential source of contamination as possible and to fence off the tops of well so that animal cannot defecate adjacent to the well. Good well design and construction is also important, (Oteze 1983).

According to Walton (1985), contaminated groundwater is very difficult and expensive to clean, thus it is better to adopt pollution prevention and conservation practices in other to protect important groundwater supplies. Contaminant source control and elimination technologies are groundwater interception, hydraulic barrier, dewatering trench (water treatment plant), Adsorption (activated carbon and resin), chemical addition (coagulation and precipitations), filtration, chemical oxidation, ion exchange, excavation and disposal of contaminated soil. The efficacy of the process for the ultimate prevention or reduction of groundwater contamination relies on the formulation of policies that are scientifically and technologically sound, economically and financially feasible, socially equitable environmentally safe and legally compliant.

2.3 Components of the Contaminants.

The types of chemicals that emanate from anthropogenic sources of contamination are listed in table 2.1. They range from simple inorganic ions such as nitrates (from septic tanks, feedlots, and fertilizer use), chloride (from highway de-icing salt, saltwater intrusion, certain industrial processes), radioactive materials and heavy – metal ions (e.g. chromium from plating works) to complex organic compounds resulting from manufacturing and industrial activities and household wastewater, (Fuhriman and Barton 1999). When the constituents of such wastes interact, new compounds may be formed, but that would not appear on the original waste content inventory. Many industrial waste disposal practices involve stabilization of waste, thereby rendering it less chemically active, but leachate product may still alter some of these chemicals, (Lindorff and Cartwright, 1992). The degradation of contaminants by microbial organisms in the soils also changes the chemical composition, thus making it almost impossible to predict precisely what contaminants reach the aquifer, (Hammer 1977).

Table 2.1 : **Components of the Contaminants**

Elements & Compounds of Contamination	Comment
Arsenic As	Usually causes severe poisoning
Antimony Sb	Similar to Arsenic but less severe
Barium Ba	Muscle stimulant
Beryllium Be	Causes illness
Boron B	Ingestion of large amounts can affect central nervous system
Cadmium Cd	Causes illness (13-15ppm)
Chromium	Carcinogenic
Copper	In large amount causes health hazard
Fluoride	Dose above 2250mg can cause death
Iron, lead, manganese and mercury	Serious cumulative body poison.
(Sodium, Calcium, Magnesium Bicarbonate)	Serious cumulative body poison
(Iron, Strontium, Potassium Carbonate)	Causes health hazard
(Nitrate, Boron)	Causes illness

Source: (Hamill and Bell 1986)

2.4 Attenuation of a Pollution

The attenuation of a pollutant as it enters and moves through the ground occurs as a result of four major process:

i. Biological Process: Soil has an enormous purifying power as a result of the communities of bacteria and fungi which live in the soil. These organism are capable of attacking pathogenic bacteria and can also react with certain other harmful substances, (Gibb and O'Hearn, 2000).

ii. Physical Process: As water passes through a relatively fine grained porous media such as soil and rock, suspended impurities are removed by filtration (Gibb and O'Hearn, 2000).

iii. Chemical Process: Some substances react with minerals in the soil / rock, and are oxidized and precipitated from solution. Adsorption may also occur in argillaceous or organic material.

iv. Dilution and Dispersion: The traditional method of disposing of effluent has generally been to dilute it with a large quantity of relatively pure water so that the concentration of the pollutant eventually becomes negligible at some distance from the source, (Cooper, 1989).

2.5 Source of Groundwater Contamination

Some of the major sources of these contamination are :

(a) Storage tanks;

(b) Septic tank systems;

(c) Hazardous waste sites;

(d) Landfills;

(e) Wide spread use of road salts;

(f) Chemicals, and

(e) Faulty well design and construction.

(a). Storage Tanks

Storage tanks may contain gasoline, oil, chemicals, or other types of liquids and they can either be above or below ground. It is estimated that over 10 million storage tanks are buried in Nigeria. After some time the tanks can corrode and crack and leakage can develop. If the contaminants leak out and get into the groundwater, serious contamination can occur, (Fuhriman and Barton, 1999).

(b). **Septic Systems**

Septic systems can be another serious contamination source. Septic systems are for homes, offices or other buildings that are not connected to a city sewer. Septic systems are designed to slowly drain away human waste underground at a slow, harmless rate. An improperly designed, wrongly located, poorly constructed or maintained septic systems can leak bacteria, viruses, household chemicals and other contaminants into the groundwater causing serious problems, (Ethler and Steel, 1998).

(c). **Hazardous Waste Sites**

Abandoned and uncontrolled hazardous waste sites grow in numbers every year. Hazardous waste sites can lead to groundwater contamination if there are barrels or other containers lying around, that are full of hazardous materials. If there is a leakage, these contaminants can eventually make their way down through the soil and into the groundwater, (Moriber, 1988).

(d). **Landfills**

Landfills are another major source of contamination. Landfills are the sites where garbage is taken to be buried. Landfills are supposed to have a protective bottom layer to prevent contaminants from getting into the water as shown in fig 2.4. However, if there is no protective bottom layer or it is cracked, contaminants from the Landfill (car battery acid, paint, household cleaners, detergent, plastic etc.) can make their way down into the underground, (Tchobanoglous, 1977).

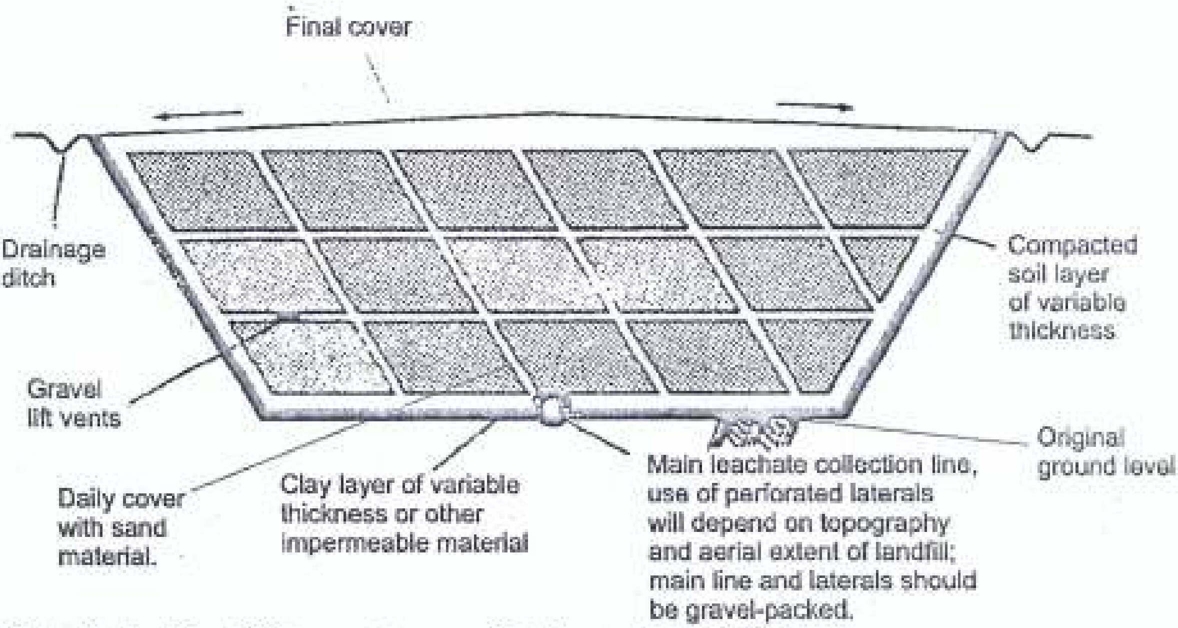


Fig 2.4 ***Typical landfill*** *(source: Tchobanoglous, 1977)*

(e). **Widespread Use Of Road Salts.**

The widespread use of road salts and chemicals can also lead to ground water contamination. Road salts are used in the wintertime in the temperate countries to put on melting ice on roads to reduce slippery condition. When ice melts, the salt gets washed off the roads and eventually ends up in the water and causes serious contamination to the groundwater (Johnson and Cartwright 1990).

f. **Chemicals**

Chemicals include products used on lawns and farm fields to kill weeds and insects and to fertilize the plants i.e. insecticides, herbicides, pesticides and fertilizers (Warren 1981).

Other sources of groundwater contamination are human activities which includes accidental spills, mining and atmospheric contaminants, acid rain, improperly planned groundwater development leading to salt water intrusion, and improper well construction and maintenance as shown in fig 2.5. (Hamill and Bell, 1986).

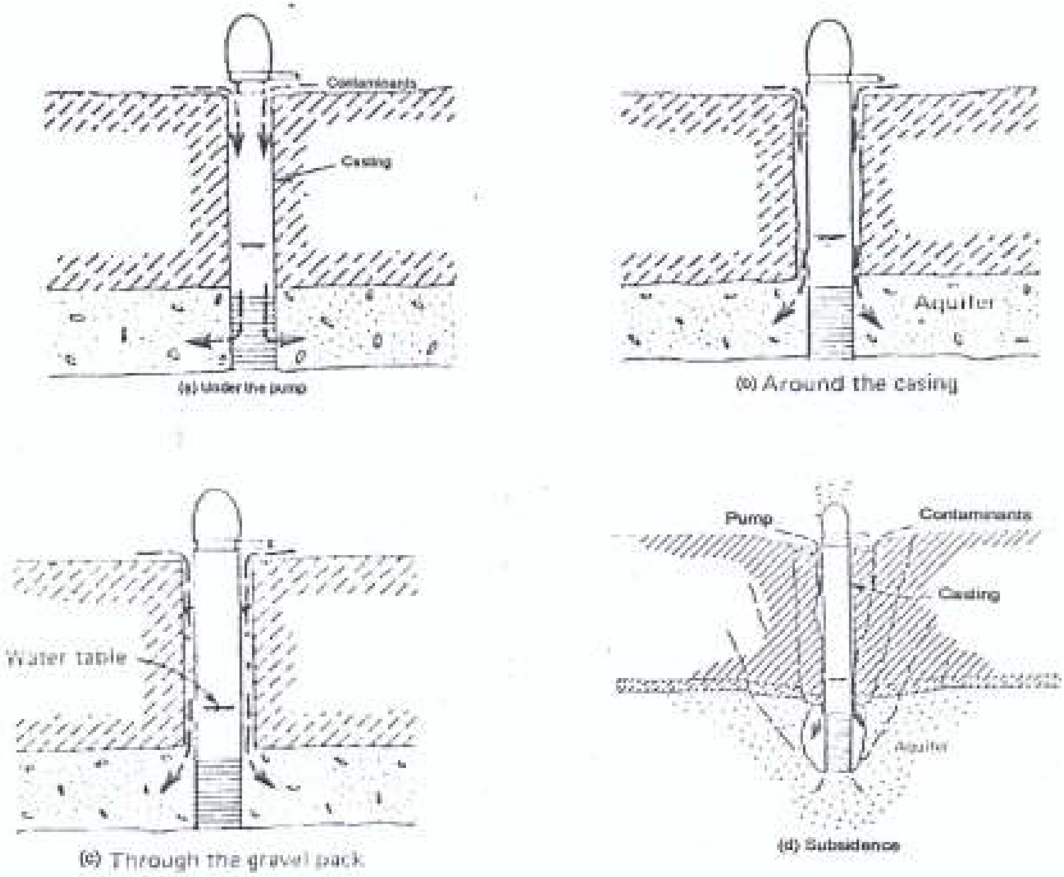


Fig 2.5 ***Means by which contaminants can enter an aquifer via a well***
(Source: Hamill and Bell, 1986)

As groundwater is a part of the hydrologic circle, what can contaminate other parts of the cycle, such as the air or surface water can eventually get into the groundwater as shown in Fig. 2.6. (Linsley et al., 1988).

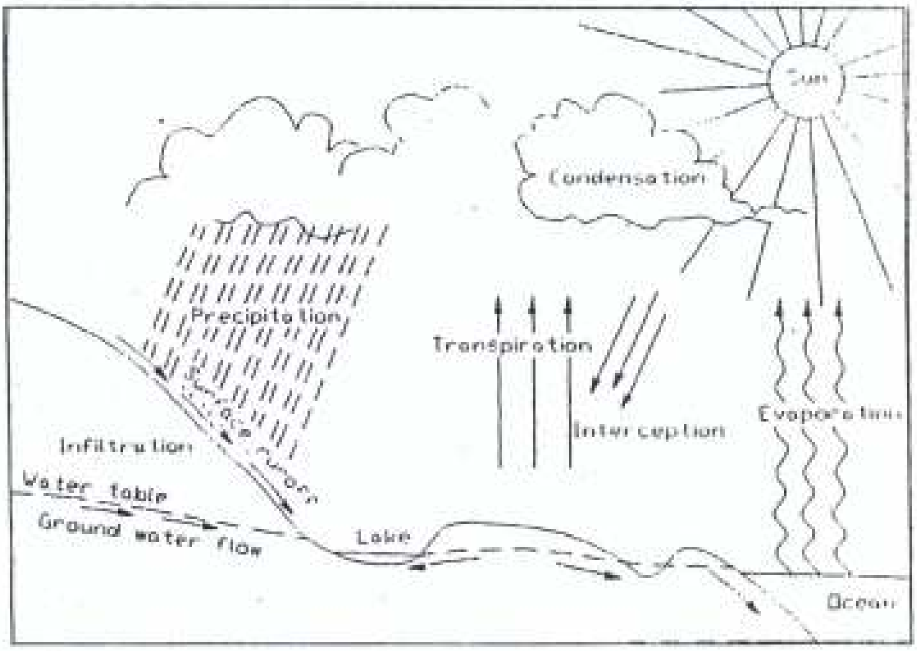


Fig. 2.6 ***The hydrological cycle*** ***(Source: Linsley et al, 1988)***

2.6 Land Disposal of Solid Waste

Land disposal of solid wastes from domestic and industrial concerns has been practiced for many years. Over the past 20 years the open burning dump has gradually been replaced by the sanitary landfill because of increasing volume of waste generated by human activities. The increasingly strict regulations passed in the 1980s and 1990s by U.S Environmental Protection Agency (USEPA) that govern the discharge of pollutants to the air and surface water, placed increased emphasis on land disposal. (Gibb and O'Hearn, 2000).

There are four types of land disposal sites namely: Open dump, landfills, sanitary landfills and secured landfills. Open dumps are uncovered solid waste with little or no regards for pollution or aesthetics. There is very high risk of environmental pollution. In open dumps, no consideration is given to possible effects on water resources. There may be daily or intermittent cover, which reduces activities of scavengers, aesthetics and air pollution problem (Steiner et al, 1979). Sanitary landfills are engineered sites where environmental problems are minimized by spreading waste in layers, compacting to smallest volume and applying material daily. The secured landfills (used especially for hazardous wastes) have no hydraulic connection with natural waters and wastes are segregated. Access to the site is restricted and is continually monitored (Johnson and Cartwright, 1990).

Sanitary landfill has become the preferred method for the elimination of solid urban wastes worldwide. In a sanitary landfill, the refuse is deposited at a carefully chosen site then spread and compacted into layers usually 2 to 3m thick. The waste is then covered each day with a layer of earth 15cm thick as shown in fig 2.7. No open burning is permitted at the site and site is also fenced to hide it from view and to trap blowing paper and other refuse (Tchobanoglous, et al. 1977).

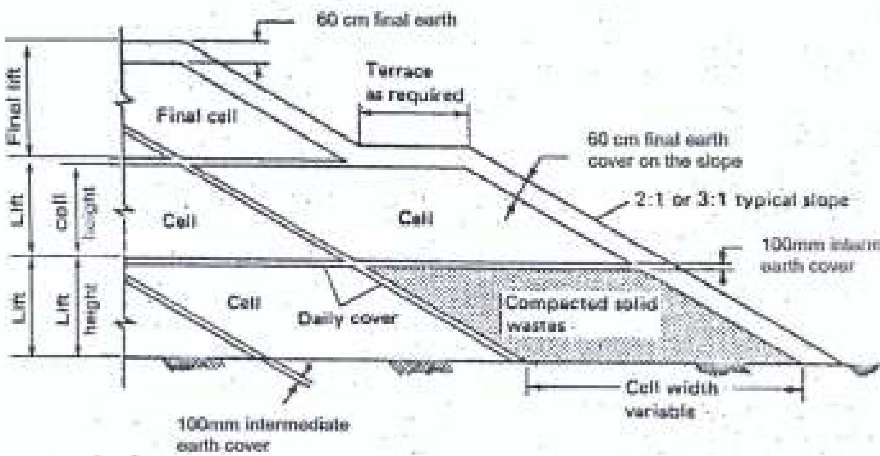


Fig. 2.7 ***Section view of a sanitary landfill***

(Source: Tchobanoglous, et al. 1977).

Open dumping as distinguished from sanitary landfilling is still in use in parts of the country especially at the study area (Olusosun, Ojota) where the landfill has been turned to open dumping due to poor sanitation management and poor finance. Open dumping is no longer an acceptable means of land disposal from aesthetic, environmental or sanitary standpoint. Modern landfills are well-engineered facilities that are designed, operated, monitored, cleaned up when necessary and financed to ensure compliance with government regulations to protect human health and the environment, especially, groundwater resources (USEPA 1989).

2.6.1 Ways in which Sanitary Landfill can Pollute Groundwater

There are 4 major ways in which a sanitary landfill can pollute groundwater.

i. When the landfill is situated on permeable soil and rock, pollutants will leak from the landfill into the groundwater

ii. If the landfill is built on a layer of impermeable shale, pollutant flows downhill over the surface to pollute the groundwater.

iii. A modern landfill built over an artificial impermeable barrier may pollute groundwater if the artificial liner weakens or cracks.

iv. If the bottom and sides of landfills were without liner (geomemebrane of plastic sheets, bentolite, kaolite, clayslurry, bituminous felt, etc) then the leachate will flow and pollute the groundwater (Tchobanoglous 1977).

2.6.2 General Landfill Standards

James and Get (2003), stated that the following factors must be considered in ensuring landfill standards

i. Location Restrictions: Ensure that landfill are built in suitable geological areas away from faults, wetlands and flood plains.

ii. Liners: Geomembrane of plastic sheets must be reinforced with 60cm thickness of clay on the bottom and sides of landfills.

iii. Operating Practices: The practice of compacting and covering waste frequently with at least 20cm of soil, help reduce odour, control litter, insects, rodent and protect public health.

iv. Groundwater Monitoring: It requires testing groundwater wells to determine whether waste materials (leachate) have escaped from the landfill. (Palanichami, 2002).

v. Corrective measures: Controls and clean up of landfill are necessary to achieve groundwater protection standards, (James and Get, 2003).

2.6.3 Advantages of Sanitary Landfill

(i) It is the most economical method of solid waste disposal where land is available.

(ii) Initial investment is low compared with other disposal methods.

(iii) A sanitary landfill can receive all types of solid wastes, eliminating the necessity of separate collections.

(iv) Submarginal land formerly used as landfills may be reclaimed for use as parking lots, playgrounds, golf courses, airport etc.

2.6.4 Disadvantages of Sanitary Landfill

(i) In densely populated areas, suitable land may not be available at economic hauling distances.

(ii) Proper sanitary landfill standards must be adhered to or the operation may result in an open dump.

(iii) A completed landfill will settle and requires periodic maintenance.

(iv) Unless properly engineered, leachate may be a continuing problem for years.

2.7 Criteria for Site Selection of Waste Disposal

According to James and Get (2003), total isolation of wastes from the environment is not possible; some migration of leachate from wastes buried in the ground will always occur. Disposal sites should be judged on a site-by-site basis rather than by rigid criteria for site selection and design. The performance should take into account several factors, such as:

(a) the nature of the wastes,

(b) the site hydrogeology,

(c) the attenuation of contaminants by geologic materials, and

(d) the release of unattenuated contaminants to surface waters or groundwater.

According to Steiner, et al. (1979), the site must be carefully selected, keeping in mind, the possible impact on groundwater development and geological conditions. For example it is important that:

i. the base of the fill should rest on impermeable materials and some meters 4-6m above the ground surface,

ii. there should be sufficient nearby cover materials, and

iii. the topography should be conducive to isolate all contaminants.

Larger disposal sites increase the environmental stress, since the attenuation capacity of the geologic materials has a finite limit, though generally not well defined, therefore, fine-grained geologic materials, which have low hydraulic conductivities and attenuating characteristics are geologic conditions generally considered suitable and favourable for disposal of wastes. This concern, in turn, has led to a variety of developments for control and treatment; including the concept of total isolation. (Fuhriman and Barton, 1999).

2.8 Regulations Governing Disposal Of Waste

Regulations governing the disposal of wastes – including hazardous wastes are designed to protect human health and ensure the quality of our water resources. It is unrealistic to assume that rigid geologic and hydrogeologic criteria can be applied over the entire single state. Strict application of some criteria, such as the depth from the bottom of the waste to the water table can actually lead to the selection of suitable sites. (Fuhriman and Barton, 1999).

Regulations governing the disposal of wastes should be applied on a site-by-site basis and should provide performance standards that the disposal site must meet. In evaluating a site, the possible effect on the environment is the most important consideration. For example there is need to regulating the distance between a landfill and water well unless other factors critical to the protection of the well such as well construction, well depth, groundwater gradient and the hydraulic conductivity of the intervening earth materials are also considered in the regulation. (U.S Environmental Protection Agency, 1989).

A performance standard should stipulate the maximum effective disposal on the surrounding land uses. For example, a standard might be written to limit the volume and concentration of the contaminant allowed to be discharged from the landfill and specify the water quality criteria as related to a specific water use and or the degree to which ambient water quality can be altered.(Lindorff and Cartwright, 1992).

Regulatory agency had different rules, regulations and guidelines that categorize wastes and landfills according to the type of wastes to be received, geologic setting, or engineering specifications. For example, landfill sites in Illinois USA are divided into five classes on the basis of geologic and groundwater conditions. Illinois regulations require disposal of hazardous wastes in class I and possibly class II sites. A class I site requires a permeability barrier at the bottom and sides of the trenches consisting of 3m of material with a hydraulic conductivity of 1×10^{-8}cm/sec or less. Class II sites require the same thickness of material, but the material must have a hydraulic conductivity of 5×10^{-8}cm/sec or less. (Johnson and Cartwright, 1990).

Other hydro geological requirements (such as required depth from the trenches to the water table) are subjective; some are based on misconceptions rather than on scientific principles, but be sufficiently knowledgeable in its field to ensure that the particular method or design specified is the only appropriate means of achieving the desired result. Therefore, where design criteria are stipulated, deficiencies are generally present in regulations and guidelines, thus each site will be different and must be considered on site-by-site basis. (Johnson and Cartwright, 1990).

2.9 Leachate in Landfills

Leachate is formed when liquids such as rainfall infiltrate the landfill and dissolve the soluble fraction of the waste and the soluble products formed as a result of the chemical and biochemical processes occurring within the decaying wastes In most landfills the liquid portion of the leachate is composed of the liquid produced from the decomposition of the wastes and liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater and water from underground springs. When leachate percolates through solid wastes that are undergoing decomposition both biological materials and chemical constituents are picked up. (Hudson and Fennel, 2001).

Representative data on the chemical characteristics of leachate indicate that the range of concentration values for the various constituents is rather extreme. For this reason, no average value can be given for leachate. The typical values reported in Table 2.2 are intended to be used only as a guide. In general, it has been found that the quantity of leachate is a direct function of the amount of external water entering the landfill. Infact, if a landfill is constructed properly, the production of measurable quantities of leachate can be eliminated. (Johnson and Cartwright, 1990).

TABLE 2.2: Data on The Composition of Leachate from Landfills

	Unit value(mg/l) Range
BOD_5 (5- day Biochemical Oxygen Demand	2,000 – 30,000
TOC (Total Organic Carbon)	1,500 – 20,000
COD (Chemical Oxygen Demand)	3,000 – 45,000
Total Suspended Solids	200 – 1,000
Organic Nitrogen	10 –600
Ammonia Nitrogen	10 – 800
Nitrate	5 – 40
Total Phosphorous	1 – 70
Alkalinity as $CaCo_3$	1,000 – 10,000
PH pH	5.3 – 8.5
Total Hardness as $CaCo_3$	300 – 10,000
Calcium	200 – 3,000
Magnesium	50 – 1,500
Sodium	200 – 2,000
Chloride	100 – 3,000
Sulphate	100 – 1,500
Total Iron	50 – 600

(Source: Tchobanoglous, et al.1977)

2.10 Gas And Leachate Movement

Under ideal conditions, the gases generated from a landfill should be either vented to the atmosphere or (in larger landfills) collected for the production of energy. Therefore, the leachate should be either contained within the landfill or removed for treatment. Unfortunately, these conditions are found only in a few modern landfills and so the movement of gases and leachate from landfills is an important aspect of solid waste disposal. (Cartwright, et al. 1999).

In most cases over 90 percent of the gas volume produced from the decomposition of solid wastes consists of methane and carbon (IV)oxide (see table 2.3) Carbon (IV)oxide is about 1.5 times as dense as air and 2.8 times as dense as methane, thus it moves to the bottom of the landfill. As a result, the concentration of carbon dioxide in the lower portions of a landfill may be high for years. Therefore, because of its density carbon (IV)oxide will also move downward through the underlying formation until its reaches the groundwater. Carbon (IV)oxide is readily soluble in water, it usually lowers the pH of water, which in turn can increase the hardness and mineral content of the groundwater through solubilization.(Johnson and Cartwright, 1990). The reaction of carbon (IV)oxide with water to produce trioxocarbonate (IV) acid can be written thus:

$$\underset{\text{(Carbon (IV) oxide)}}{Co_2} + \underset{\text{(Water)}}{H_2O} \longrightarrow \underset{\text{(trioxocarbonate (IV) acid)}}{H_2Co_3} \quad \text{------------------- (2 – 1)}$$

If calcium trioxocarbonate (IV) is present in the soil structure, the trioxocarbonate (IV) acid will react with it to form soluble calcium hydrogentrioxocarbonate (IV) according to the following reaction. (Ababio, 2000).

$$\underset{\text{(calcium trioxocarbonate (IV))}}{CaCo_3} + H_2Co_3 \longrightarrow \underset{\text{calcium hydrogentrioxocarbonate (IV)}}{Ca(HCo_3)_2} \quad \text{-------------(2 –2)}$$

Similarly reactions that occurs with magnesium trioxocarbonate (IV) are the same. If a given free carbon dioxide concentration is present, the reaction will proceed until equilibrium is reached. i.e.

$$H_2o + Co_2 \updownarrow$$

$$CaCo_3 + H_2Co_3 \rightleftharpoons Ca^{2}+ + 2Hco_3^{-} \qquad \text{-------------------} \qquad (2-3)$$

Any process that increase the free carbon dioxide available to the solutions will cause more calcium trioxocarbonate (IV) to dissolve. The resulting increase in hardness is the principal effect of the present of carbon dioxide in groundwater (Hammer, 1977).

TABLE 2:3: Molecular Weight and Density of Gases Found in Sanitary Landfills at Standard Conditions(O^0C, 1 atm)*

GAS	FORMULA	MOLECULAR WEIGHT	*DENSITY g/L*
Air			1.2928
Ammonia	NH_3	17.03	0.7708
Carbon dioxide	Co_2	44.00	1.9768
Carbon monoxide	Co	28.00	1.501
Hydrogen	H_2	2.016	0.0896
Hydrogen sulphate	H_2S	34.08	1.5392
Methane	CH_4	16.03	0.7167
Nitrogen	N_2	28.02	1.2507
Oxygen	O_2	32.00	1.4289

(Source: Tchobanoglous, et al.1977)

2.11 Leachate Movement (SeePage)

Under normal conditions, leachate is found in the bottom of landfills. From there its movement is through the underlying strata, although some lateral movement may also occur, depending on the characteristics of the surrounding materials.

Darcy' Law can be used to estimate the rate of seepage of leachate from the bottom of a landfill. This can be expressed as:

$$\dot{Q} = - KA \ dh/dL \quad \text{-----------------------------------} \ (2\text{-}4)$$

where Q = leachate discharge per unit time

K = coefficient of permeability

A = cross – sectional area through which the leachate flows

dh/dL = the hydraulic gradient.

According to Bear (1989), the minus sign in Darcy's equation arises from the fact that head loss dh is always negative. The coefficient of permeability is also known as the hydraulic conductivity, the effective permeability, or the seepage coefficient. The permeability of a soil is influenced by particle size, void ratio, composition, degree of saturation and temperature.

From empirical observations it has been found that the coefficient of permeability can be defined in terms of some characteristic size of the porous medium and the properties of the fluid. The relationship is:

$$K = Cd^2 \frac{\gamma}{\mu} \quad \text{------------} \quad (2\text{-}5)$$

where C = dimensionless constant

d = diameter of pores

γ = specific weight of water

μ = viscosity of water

The term Cd^2 is known as the specific (or intrinsic) permeability K and is thought to be a characteristic of the medium alone. Neglecting the effects of temperature on density we find that:

$K_s/K_t = m_t/m_{60}$

where K_s = laboratory standard coefficient of permeability defined as the flow of water at 60^0C in m^3 per day through a medium having a cross-sectional area of $1m^2$ under a hydraulic gradient of $1^m/_m$

K_t = coefficient of permeability at temp. t

M_{60} = viscosity at 60^0C

M_t = viscosity at temperation t

The coefficient of permeability is expressed in m^3 per day, per square metre or metre per day, (Tchobanoglous, et al., 1977). The typical values of the coefficients are given in table 2.4.

TABLE 2.4: Typical Permeability Coefficients for Various Soils (Laminar Flow)

Material	Coefficient of permeability K	
	m/day	m^3/day/ m^2
Uniform coarse sand	406.3	406.8
Uniform medium sand	101.5	101.6
Clean well-graded sand and gravel	101.5	101.6
Uniform fine sand	4.05	4.08
Well – graded silty sand and gravel	0.4	0.4
Silty sand	0.09	0.09
Uniform silt	0.05	0.05
Sandy clay	0.005	0.005
Silty clay	0.0009	0.0009
Clay (30 to 50 percent to clay size)	0.00009	0.00009
Colloidal clay	0.0000009	0.0000009

(Source: Tchobanoglous, et al.1977)

2.12 Groundwater Water Quality

The quality of water is assessed in terms of its physical, chemical and biological characteristics. For example distilled water is physically, chemically and bacteriologically pure. A complete chemical analysis of a sample of groundwater includes the determination of the concentration of all the inorganic constituents present, the pH value, oxidation –reduction potential (ORP), hardness, chemical oxygen demand, Alkalinity and acidity. Concentrations of the common ions found in groundwater are reported by weight in parts per million (ppm). This is the same as concentration in milligram per litre (mg/l). Physical properties of a groundwater are colour, temperature, turbidity, odour and taste, (Krusenan, 1995).

Bacteriological analysis consists of test to detect the presence of coliform organisms. Coliform organism are normally found in intestines of man and animals, the presence of these in groundwater is tantamount to its contact with sewage sources. Coliform test results are reported as the Most Probable Number (MPN) of coliform group organism in a given volume of water, (Fair, et al., 1988).

2.13 Water Quality Criteria

Determination of the suitability of groundwater for a particular purpose depends on the criteria or standards of acceptable quality as listed in Table 2.6. Drinking water supplies in Nigeria conforms to the standards established by WHO (World Health Organization, 1992). Exceeding WHO standard of acceptable quality for drinking water can lead to health hazard, and possible ill-effect are listed in Table 2.5.

TABLE 2:5: Possible ill-Effect of Exceeding Maximum WHO Standard Level

Substance of Characteristics	Highest Desirable Level	Maximum Permissible Level	Possible Ill-Effect of Exceeding Maximum Level
Calcium (Ca)	75mg/l	200mg/l	Excessive scale formation
Iron (Fe)	0.1mg/l	0.3mg/l	Taste discoloration deposit and growth of iron bacteria turbidity.
Magnesium (Mg)	30mg/l t	150mg/l	Hardness, taste gastrointestinal irritation.
pH	7 – 8.5	6.0-9.0	Taste corrosive
Total Dissolves Solids	100mg/l caco3	1500mg/l	Taste, gastrointestinal irritation, cathartic effects
Total Hardness	5units turbidity	500mg/l caco3	Lack of lather with soap
Suspended Matter	5units (onthe flat in um-cobalt scale)	50 units (on the pt co scale)	Turbidity possible gastrointestinal irritation
Colony Counts	NIL	10/100ml	Colouration aesthetic effective
Manganese	0.5mg/l	0.2mg/l	Taste, discotoration deposits in pipes turbidity.

(Source: WHO, 1992)

TABLE 2.6 WHO Standards for Drinking Water

	PARAMETER	RECOMMENDED LIMITS	
		Maximum Recommended Concentration	Maximum Permissible Concentration
1	Total solids	500mg/l	1500mg/l
2	Colour	5TCU	50TCU
3	Turbidity	5 Units	25 Units
4	Taste	Subjective limit of acceptance	----
5	Odour	Subjective limit of acceptance	----
6	Iron (Fe)	0.3mg/l	1.0mg/l
7	Manganese (Mn)	0.1mg/l	0.5mg/l
8	Copper (Cu)	1.0mg/l	1.5mg/l
9	Zinc (Zn)	50mg/l	15mg/l
10	Calcium (Ca)	75mg/l	200 mg/l
11	Magnesium (Mg)	50ppm	150ppm
12	Sulphate (So_4)	200ppm	400ppm
13	Chloride	200mg/l	600 mg/l
14	pH	7.0 – 8.5	6.5 – 9.2
15	Magnesium sulphate, sodium sulphate	500ppm	1000ppm
16	Phenolic compound as phenol	0.1ppm	0.002ppm
17.	Chloroform extraction coal CCE organic pollution	0.2ppm	0.5ppm
18.	Mineral oils	0.01ppm	0.3ppm
19.	Total hardness	100mg/l Caco3	500mg/l Caco3
20	Chemical oxygen demand	100ppm Caco3ppm	10ppm
21	Nitrate	10mg/l	45mg/l
22	Fluoride	0.7mg/l	0.8mg/l
23	Phosphate	--------	--------
24	Total Alkalinity	--------	--------
25	Silica	-------	--------
26	Lead (Pb)	0.05mg/l	--------

(Source: WHO, 1992)

2.14 Water Quality Parameters

2.14.1 Colour

Clour is important from the aesthetic point of view and it is measured in TCU. water that is coloured is unpleasant when used for domestic and particularly for drinking as it always gives rise to doubt regarding its potability. (Funk and McClenaghan, 1992).

2.14.2 pH

pH value indicates whether the water is acidic or alkaline. pH values less than 7 points to acidity and values greater than 7 points to alkalinity. The regular measurement of pH is an essential factor in water treatment practice. In particular, it plays an important part in the efficiency of the coagulation process (Esca, et.al., 1995).

2.14.3 Iron

Iron ranks next to aluminum in abundance of metals in the earth crust. Natural waters contain variables but minor amount of iron. Iron's presence in water is observed from the stains impacted to laundry and porcelain and also the bittersweet, astringent taste, which may be detectable at level above 2mg/l (WHO, 1992).

2.14.4 Chlorides

Chlorides are present in all natural waters. Sources of this anions are numerous and these includes many sedimentary rocks, oil field drainage, domestic and industrial wastes. High concentrations of chlorides on both surface and groundwater are often due to contamination from ocean and many brackish supplies.

The sudden increase of chloride in water above their natural level indicates pollution. A high concentration of chlorides impacts a salty taste to water. Chlorides have corrosive effect on various domestic and industrial equipment (WHO, 1971).

2.14.5 Sulphate

Sulphate is mostly derived form evaporated sediments such as gypsum and anhydrite. Other sources are; oxide anion of sulphur containing organic compounds, sulphides and sulphite, Sodium sulphate deposits and industrial waste. Certain cations, namely barium, strontium and lead, form fairly insoluble sulphate salts and significant concentrations are in the presence of these cations. Sulphate causes odour problem as it is converted to hydrogen sulphide under anaerobic condtions. Sulphate in excess of 250mg/l as magnesium salt may cause diarrhea or other disorder of the alimentary tract in person not accustomed to the water. The level of sulphate is important in determining the suitability of water for drinking.(Ababio, 2000).

2.14.6 Nitrate and Nitrite

These anions are usually found in water contaminated with nitrogenous materials, such as farmyard wastes, nitrite oxidized by bacteria and industrial wastes containing nitrite. The use of fertilizer may also add nitrate to both surface and groundwater. Groundwater may contain very little nitrate or as much as several hundred part per million in some cases. The presence of nitrate and nitrite causes disease called infantile cynopsis and it occur mainly in infants. The nitrite reacts with haemoglobin and formed methienoglobin. Also, excessive amounts of nitrite may lead to prolific and objectionable growth of aquatic plants. Irrigation water containing nitrate generally stimulate plants growth because of the fertilizer value impacted by this constituents. (Esca, et.al. , 1995).

2.14.7 Phosphate

Phosphate like nitrate, are utilized by plants and usually found in significant concentrations in surface water. Sources of these anions includes fertilizer, dissolution from phosphate rocks, and industrial effluents as wastes.

The major sources are the urban and agricultural run off. At a concentration up to 0.01mg/l phosophate aids fish propagation by improving the growth of food organism. However, at concentration above 0.01mg/l, it promotes algae growth in surface water, leading to eutrophication. (Linsley, et al., 1992).

2.14.8 Odour and Taste

The taste and odour problems in water can be to the presence of actinomycetes and certain species of algae. Odour can also be produced due to anaerobic oxidation of some compound (e.g suphur containing compounds) by biological organisms e.g bacteria. These are subjective properties which are difficult to measure and affect the potability of water. However, they are due to dissolve impurities and leachates, often organic in nature e.g. phenols and chlorophenols.

2.14.9 Biochemical Oxygen Demand

Biochemical oxygen demand, or BOD as it is often referred to, is another aspect of water analyses. BOD is a laboratory estimation of the oxygen required for the biochemical breakdown of certain organic matter present in the water.

2.14.10 Chemical Oxygen Demand

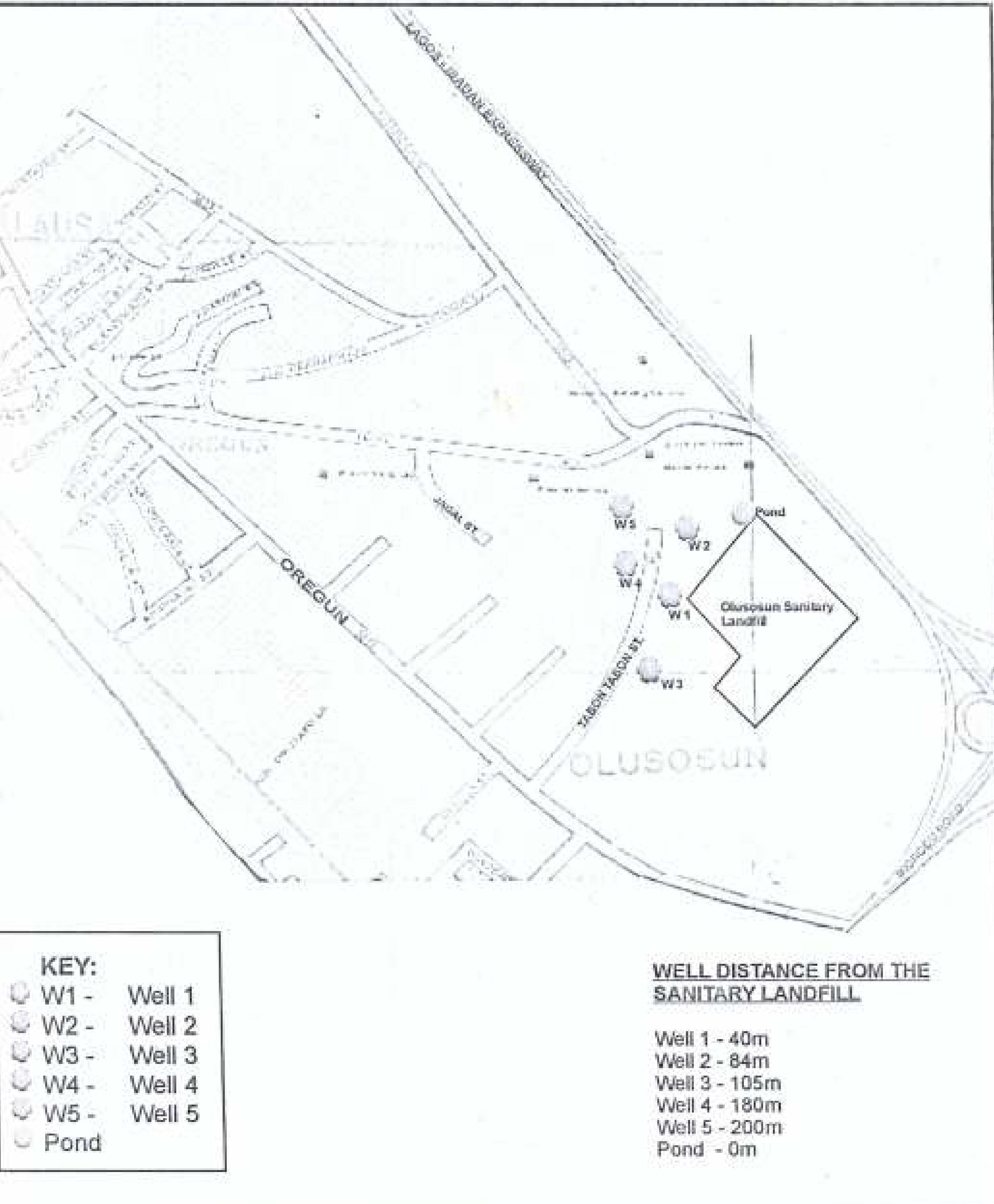
The COD can be used to determine the organic load of a water body. It is a measure of the oxygen required when certain portions of organic matter undergo oxidation by some strong chemical oxidant. Although it would be expected that the value of the ultimate BOD would approximate the COD, this is seldom the case. Some of the reasons for the observed differences are as follows: (1) many organic substances can be oxidized chemically but cannot be oxidized biologically; (2) inorganic substances that are oxidized by the dichromate increase the apparent organic content of the sample; (3) certain organic substances may be toxic to the microorganisms used in the BOD test; and (4) high COD values may occur because of the presence of interfering substances.(Linsley, et al., 1992).

CHAPTER THREE
METHODOLOGY

3.1 Description of the study Area

Lagos State was one of the states created in 1967 and shares boundaries with Ogun State, Benin Republic and Atlantic Ocean. It is in the western part of Nigeria, a conurbation i.e. city of cities and highly congested because of mass migration of people from rural to urban city coupled with industrialization of the city. High volume of wastes are generated and can be categorized as domestic, industrial, municipal and hospital. The study area Olusosun (Ojota) is in Ikeja Local Government area in Lagos State, located on Latitude 6°37"30"N and Longitude 3°22'30"E.

In order to economically and effectively dispose these solid wastes, a landfill was located at Olusosun (Ojota) by the Lagos State Government, and occupies an area of about 64.1ha. It can easily be seen while passing on the Lagos-Ibadan expressway at Ojota as shown in Fig. 3.1 and Fig. 3.2 respectively. It poses a threat to the quality of groundwater that has been the only source of drinking water for Olusosun inhabitants. After the reconnaissance surveys it was hypothesized that there was every tendency for leachate to occur and pollute the inhabitants shallow wells because of the topographic nature of the site which permit excess rainfall - runoff into the nearby Lagoon or swamps. As the waste at the landfill were buried without treating the bottom and sides of the trenches with sealant (compacted clay i.e Bentonite, kaolinites, liners i.e. polyethylene and asphalt), there was no control of leachate movement.



REA MAP INDICATING THE RELATIVE LOCATION OF THE WELLS AND IE SANITARY LANDFILL AT OLUSOSUN (OJOTA), LAGOS STATE.

OURCE: IKEJA LOCAL GOVERNMENT COUNCIL, LAGOS STATE OF NIGERIA

IG. 3.2 SURVEY SHEET OF LAGOS STATE SHOWING OLUSOSUN TOPOGRAPHIC MAP AND ITS ENVIRONMENT

SOURCE: FEDERAL SURVEYS, NIGERIA

3.1.1 Climate of the Area

The climate can be considered tropical with two distinctive seasons namely, wet and dry. The wet season runs from April to October and is characterized by intensive showers of prolong duration. The dry season is from November to March. Mean annual rainfall is above 1700mm, and this serves as major source of groundwater replenishment. The temperature is high but uniform with a mean of about 25°C. Normally the humidity is high and ranges from 70 to 100%.

3.1.2 Geology of the Study Area

The geology of the study area is characterized at the surface and near the surface by alluvial, littoral and lagoonal sediments of recent age overlying the coastal plain sands of the tertiary age,(Jones and Hockey, 1964). More light was shed on the geology of the area by the Lagos State Ministry of Water Resources using data obtained during the construction of borehole in Lagos mini-waterworks programme.(Lagos State Ministry of Water Resources, Water Survey, 2000). The collated results indicate that the area were underlain by clay to a depth of 11m followed by the alternations of layers of sand bands with clays and silts where thicker layers are formed by the merging together of sand bands.

According to Lagos State Ministry of Water Resources, on "Borehole Program 2000", four aquifer horizons were identified. The bulk of groundwater resources in the state is exploited from coastal plain sands and recent alluvial deposit. The level of freshwater accumulation discovered was at a depth of 11m and the second aquifer which was recommended for exploitation was at depth 200m to 300m.

A summary of the geology as given by Jones and Hockey in 1964 is reproduced in Table 3.1 showing general geological section.

Table 3.1 **General Geological Section**

AGE	FORMATION	ESTIMATED THICKNESS (M)	ESTIMATED DEPTH (M)	LITHOLOGICAL DESCRIPTION
Recent	Alluvial, lithoral and lagoonal deposit	200	200	Gravels and sand series alternating with sand, silt and clay (upper storey) mangrove relics
Tertiary Oligocene Pleistocene	Coastal plain sands	150	350	Two to three sand series with silt and clay (middle storey)
Tertiary Eocene	Ilaro formation	70	420	Mainly clay with minor sands
Tertiary paleocene	Ewekoro formation	150	570	Mostly shale with minor sands
Cretaceous sand stone	Abeokuta formation	180	1500	Upper and lower parts mainly sand middle part clayey and silty
Palaeozoie to pre-cambian	Complex crystalline basement			GRANITES MIGMATITES

(Source: Jones and Hockey, 1964)

3.1.3 Hydrogeology of the Area

Lagos State incorporates several aquifer systems in which coastal plain sands and recent alluvial deposits form the most exploit aquifer systems. Water surveys by the state grouped the aquifer in the order of age as the recent aquifer, late tertiary to early quaternary aquifers and the cretaceous and stone aquifers, *(*Lagos State Ministry of Water Resources, Water Survey 2000*)*. Therefore, from the collation of previous work done on the geology of Lagos metropolis and the study area, it was discovered that Olusosun is underlain by four aquifer horizon.

3.1 .4 Composition of Disposed Waste at the Study Area.

Wastes being disposed in Olusosun sanitary landfill are solid wastes. It encompasses the heterogenous mass of throwaways from residences and commercial activities as well as the more homogenous accumulations of a single industrial activity. The composition of the disposed wastes as classified by Tchobanoglous et al., 1997 is detailed in Table 3.2

Table 3.2 Classification of Materials Comprising Disposed Solid Waste

COMPONENTS	DESCRIPTION
Food waste	The animal fruit, vegetable residue (also called garbage) resulting from the handling, preparation, cooking and eating of foods. Because food wastes are putrescible they will decompose rapidly especially in warm weather.
Rubbish	Combustible and noncombustible solid waste excluding food wastes or other putrescible materials. Typical combustible rubbish consists of materials such as paper, cardboard, plastic, textile, rubber, leather, and wood furniture, garden trimmings. Non-combustible rubbish consists of items such as glass, tin, cans, ferrous and non-ferrous metal, aluminum can.
Demolition and construction wastes	Wastes from razed building and other structures are classified as demolition wastes. Waste from construction remodeling e.g. stones bricks, ceiling boards, and timbers.
Special waste	Waste such as street sweepings, roadside litter, and catch basin debris, dead animal, abandoned vehicle parts, are classified as special waste.
Ashes and residues	Materials remaining from burning of woods, coal.

(Source: Tchobanoglous, et al., 1977)

3.1.5 Physical Operation

The Management of the principal wastes at Olusosun in Ojota is illustrated in the Plates 3.1 - 3.4.

Plate 3.1 **Heaps of Burnt Wastes left uncovered with Laterite soil.**

Plate 3.1 shows the burnt, uncovered solid waste at Olusosun (Ojota) landfill with little or no regards for pollution and aesthetic. Scavengers take the advantage of poor sanitation management to retrieve raw materials for companies. There is very high risk of environmental pollution. No consideration is given to possible effects on water resources and there was no daily or intermittent cover with laterite soil. Whenever rain falls the water infiltrates into the decayed dump and mix with the organic matter in the refuse to produce leachate which sink into the subsurface and contaminate the surrounding wells.

Plate 3.2 : **Landfill Pit without sealant, prepared to receive waste.**

Plate 3.2 shows landfill pit at Olusosun (Ojota) landfill to receive solid wastes, The bottom and side of the landfill pit has no protective liner (geomembrane of plastic sheet, clay slurry, bentonite, kaolite, bituminous felt, etc.) to prevent leachate from percolating into nearby groundwater. Therefore, developed cracks at the bottom of the landfill serve as a passage for the contaminants to make their way down into the subsurface and cause serious contamination to the groundwater at Olusosun environment.

Plate 3.3 **Landfill with obnoxious fume and scavengers**

Plate 3.3 shows that landfill at Olusosun has been turned to a home of scavengers, materials that considered to be reuse were selected and gathered together as raw materials for companies. The landfill has been turned to open dump, due to the poor operational management. The heaps of wastes were reduced by burning, a practice that pollutes the atmosphere with smokes, obnoxious odour and breeding of flies.

Plate 3.4 Consolidated buried waste and few residential buildings

Plate 3.4 shows the consolidated burnt waste which had been left uncovered for years and clusters of buildings that are not far from the sanitary landfill. The residents of these building depend on wells as drinking water source. Therefore, due to the proximity of these wells to the sanitary landfill, leachate could easily migrate through such distance to contaminate the inhabitant wells.

3.2 Field Work

Field investigations were carried out in order to achieve the objectives of this research project. The methodology adopted were in stages as defined below.

3.2.1 Reconnaissance Survey

The detailed reconnaissance survey was carried out by walking round the environment and familiarizing with the physical features, identification of sampling points, identification of wells around the landfill, general observation of the environment, physical operation of the management of the principal wastes and level of urbanization of the environment.

3.2.2 Insight to the Management of the Landfill

The landfill operations were critically understudied and it was observed that wastes were buried without treating the bottom and sides of the trenches with sealant (compacted clay, liner, polyethylene, asphalt etc.) so as to control the leachate movement. Also, some wastes were left fallow for several months and not buried and whenever rain falls the wastes would be soaked, leading to production of leachate.

The unburied waste accumulated as heaps. The heaps of wastes were reduced by burning, a practice that pollutes the atmosphere with smoke, obnoxious odour, breading of flies and scanvengers. Landfill at Olusosun (Ojota) has been turned to open dump, due to the poor operational management coupled with under funding by Lagos State Government. Covering the wastes with laterite after daily operation was not done, instead , they were stockpiled and later burnt openly.

3.2.3 Available Information

Available information such as topographic map were collected from the Federal Ministry of Land and Surveys. Street guide map of the area was obtained from the Ikeja Local Government Council. The log data of the boreholes around the site, sunk during the mini-water works programme were collected from Lagos State Ministry of Water Resources.

3.2.4 Water Sample

Sterilized bottles were used to collect water samples from five representative wells. The samples were analyzed to determine their physical, chemical and biological characteristics.

Physical analyses involve the determination of temperature, colour, odour, taste and turbidity. The biological analyses involve the detection and determination of biological life, animal or plant, present in water. The chemical analysis involves the measurement of cations (metallic ions), anions (non-metallic ions), toxic and non-toxic compounds. The parameters of the water samples were carried out in accordance to standard method of examination of water and wastewater. The results were compared with the WHO drinking standards.

3.2.5 Soil Sample

Soil samples were collected from five representative locations in and around the landfill. Samples were collected at a depth of 1.5m on the landfills which had consolidated for years and assumed to give a true picture of wastes buried several metres below the surface.

3.2.6 Other Field Investigation

Other field investigation involved determination of the depth of sampled wells, observation of the topography, classification of buried wastes and photographs of the study area..

3.2.6.1 Depth of Sample Wells

The depth of the sampled wells were observed and measured by throwing drawing bucket into the well and allowing the bucket to sink down and use measuring tape to determine the accurate depth. The depth of shallow dug wells measured are between 6 and10m. Being close to sanitary landfill, it was hypothesized that they were liable to pollution by landfill leachate.

3.2.6.2 Topography

The topography of the site was observed. The site was sloppy enough to permit excess rainfall to run off easily into the lagoon or swamps. Thus, part of the contaminants were transported into the existing shallow well through surface and subsurface runoff.

3.2.6.3 Classification of Buried Waste

Waste generated in Lagos metropolis and buried in Olusosun landfills were categorized during the course of study as municipal waste, industrial wastes and hospital wastes. Their components were food wastes, rubbish, demolition and construction wastes.

CHAPTER FOUR

RESULTS AND DISCUSSION

Physical, Chemical And Bacteriological Quality Of Sampled Wells

Table A1 – A8 as shown in appendix, contain the results of physical, chemical and bacteriology quality of sampled well at Olusosun, (Ojota) for a period of eight months. The depth and distance of each well were indicated in the tables as shown in the appendix, the results of the samples analyzed were compared with the WHO standard for potable water.

Data Analysis and Presentation

The monthly variation of the parameters that reflect leachate pollution are estimated and the results are presented in the tables and graphically represented in the figures below:

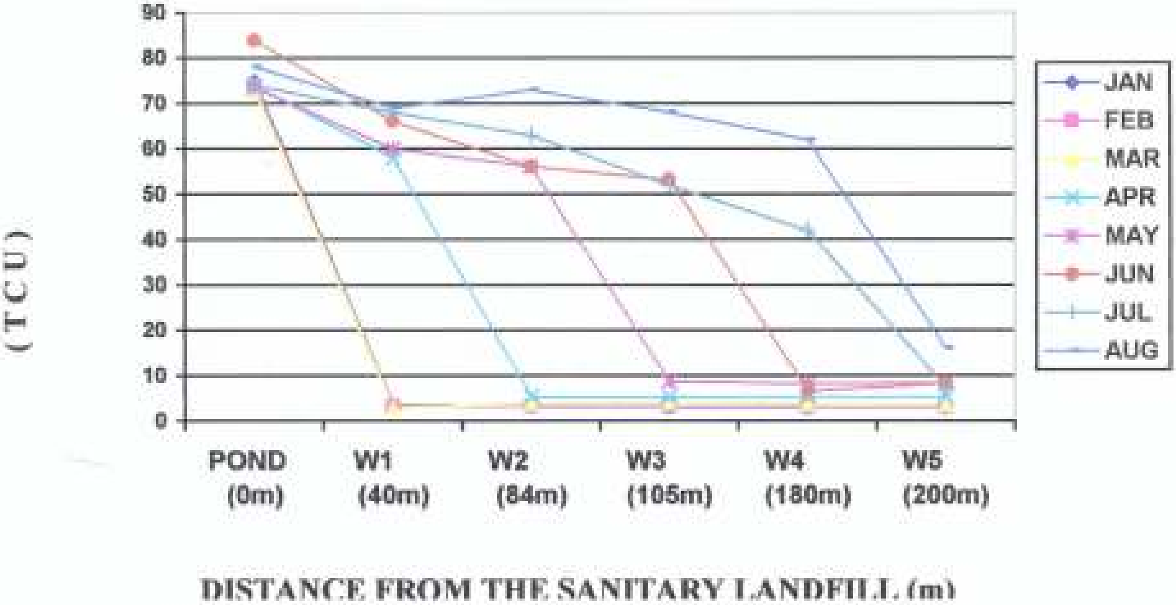


Fig. 4.1: Monthly Variation for Colour

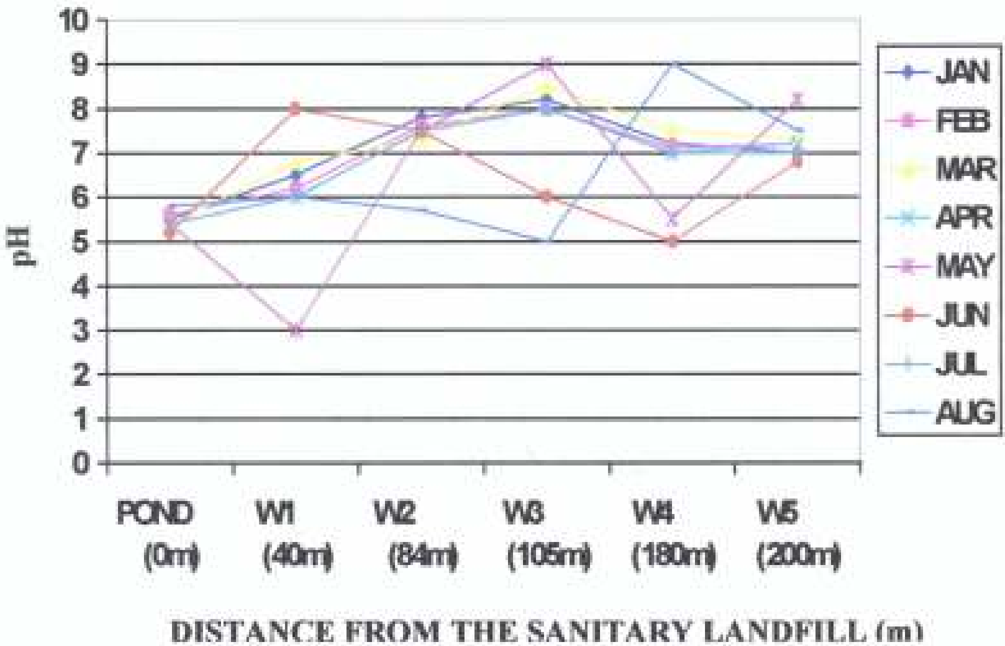


Fig. 4.2: Monthly Variation for pH

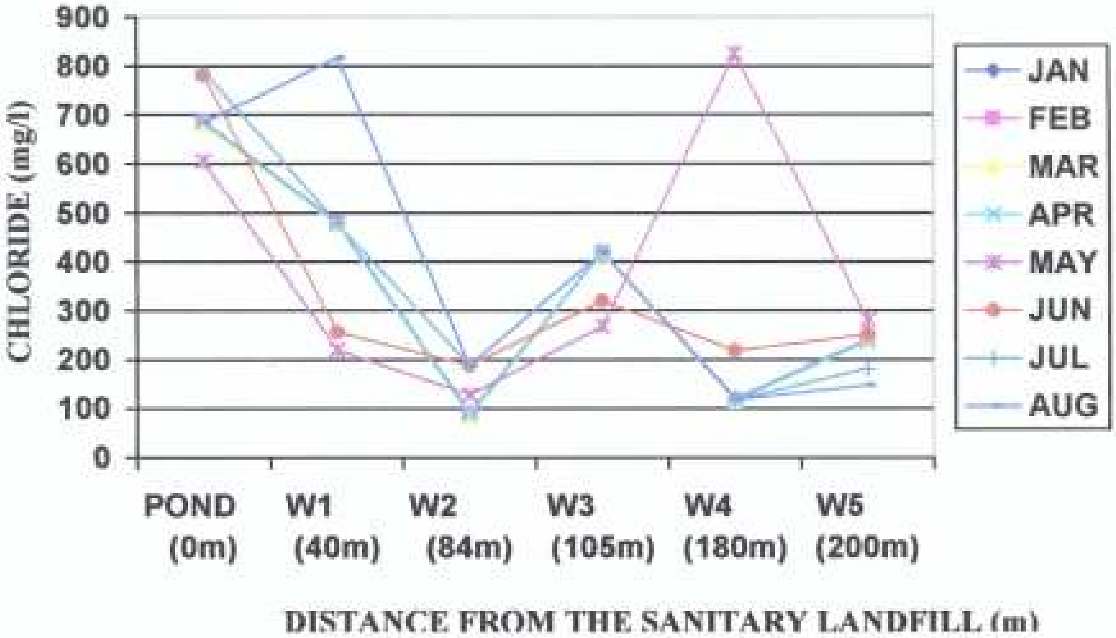


Fig. 4.3: Monthly Variation for Chloride

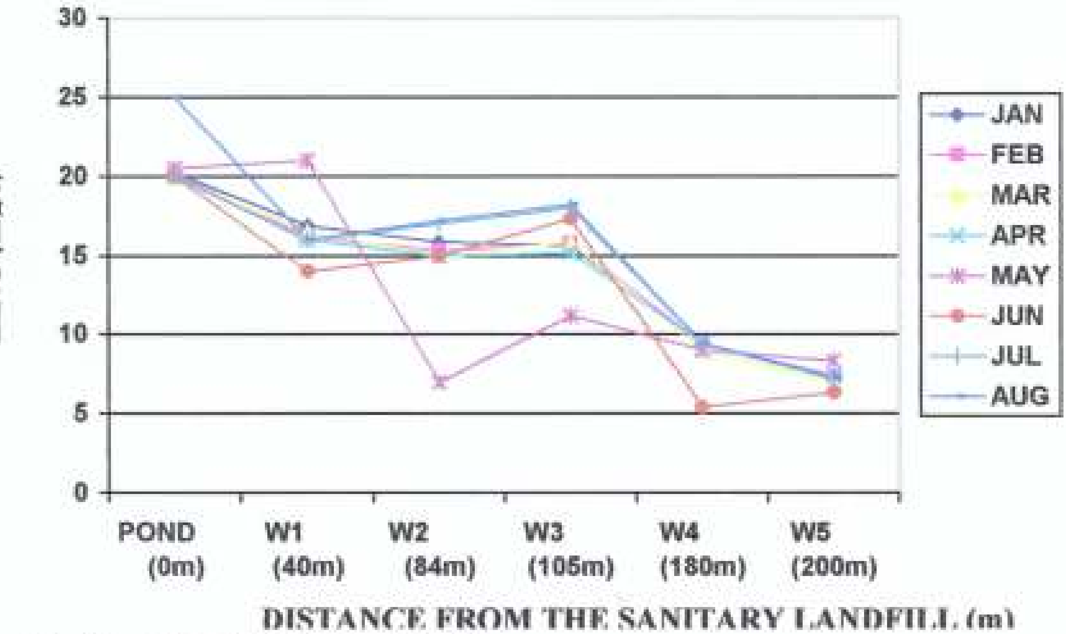


Fig. 4.4: Monthly Variation for Zinc

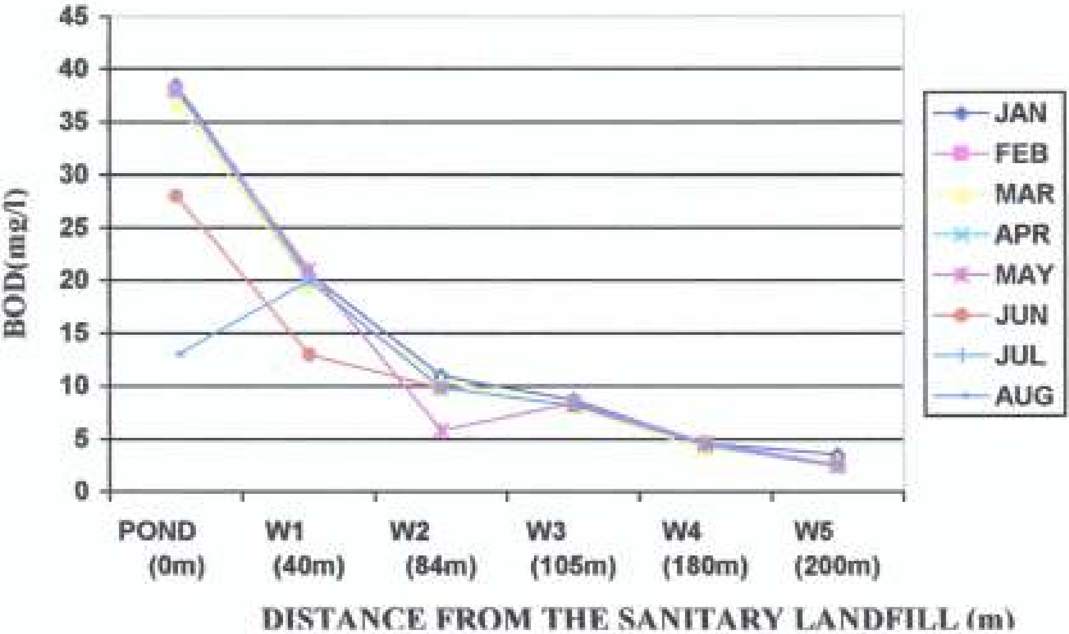


Fig. 4.5: Monthly Variation for BOD

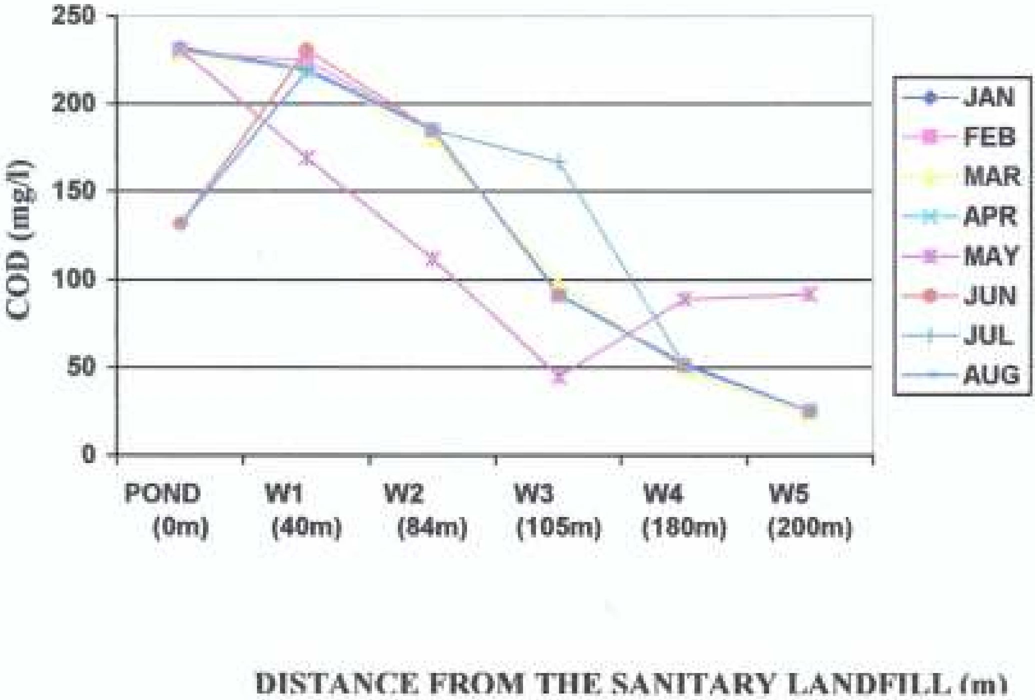


Fig. 4.6: Monthly Variation for COD

Table 4.1 **Monthly Variation for Turbidity (NTU)**

	POND	W1	W2	W3	W4	W5
JAN	140	20	16	18	9	8
FEB	139.5	31	16.5	18.5	7.5	8.5
MAR	141	9	7	8	8	5
APR	142	32	7.5	9	8	5
MAY	138	29	29	15	12	8
JUNE	162	44	37.55	25.8	8	4
JULY	142	62	47.5	79	18	5
AUG	142	72	75	89	38	18

Table 4.2 **Monthly Variation for Total Hardness (mg/l)**

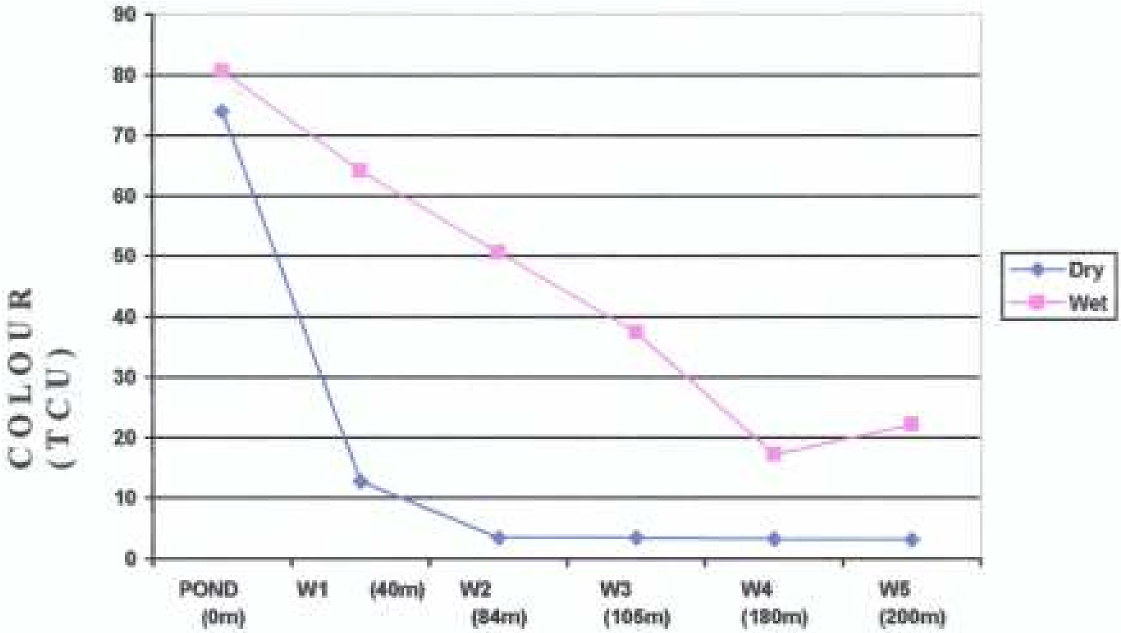
	POND	W1	W2	W3	W4	W5
JAN	480	208	180	70	50	33
FEB	475	210	179	70	50	33
MAR	478	200	177	72	58	32
APR	485	213	178	68	49	32.5
MAY	498	220	185	128	66	44.5
JUNE	498	253	188	130	54	51.5
JULY	499	255	198	168	49	32.5
AUG	498	317	210	16	41	19.8

Table 4.3 **Monthly Variation for Calcium Hardness (mg/l)**

	POND	W1	W2	W3	W4	W5
JAN	320	280	240	58	74	68
FEB	318	278	238	58	74	67
MAR	305	2709	235	58.6\5	73	65
APR	315	275	238	57	72	66
MAY	318	311	189	29	74	25
JUNE	375	568	268	47	62	56
JULY	672	375	288	57	72	11
AUG	695	391	308	57	75	86

Wet and Dry Season Variation of Parameters

The raw data were divided into two dinstinct seasons e.g Jan.-Mar.(Dry season) and Apr.-Aug.(Wet season). The average value of the parameters is determine as shown in the appendix (Tables A9-A10) and Graphically shown in Figs.4.7-4.13.



DISTANCE FROM THE SANITARY LANDFILL (m)

Fig 4.7 Wet And Dry Season Variation For Colour

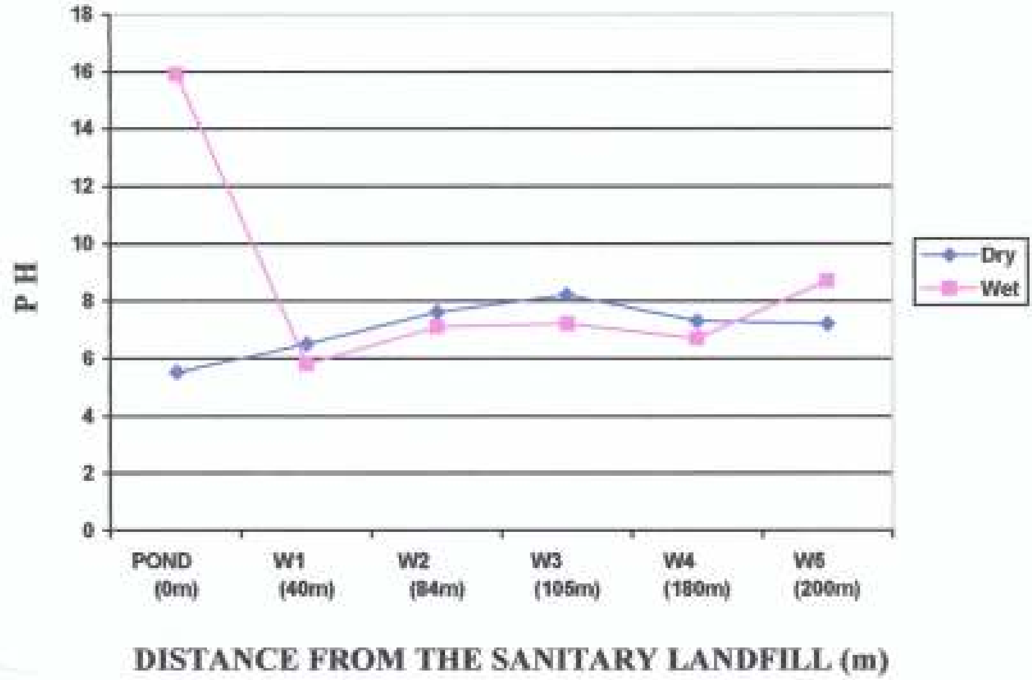


Fig 4. 8 Wet And Dry Season Variation For PH

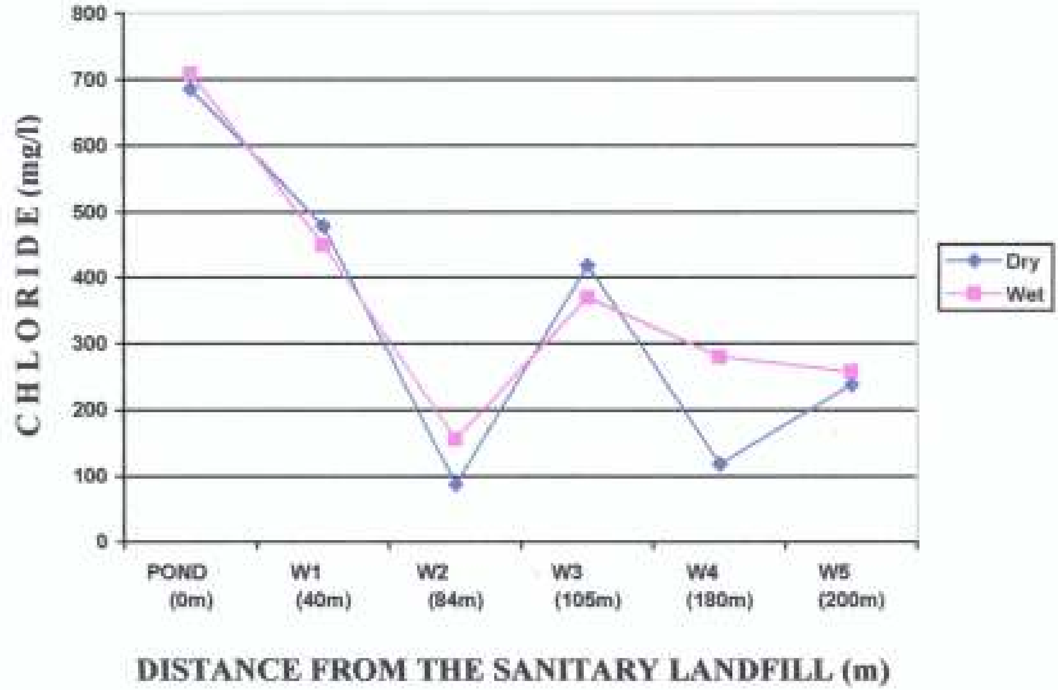


Fig 4.9 Wet And Dry Season Variation For Chloride

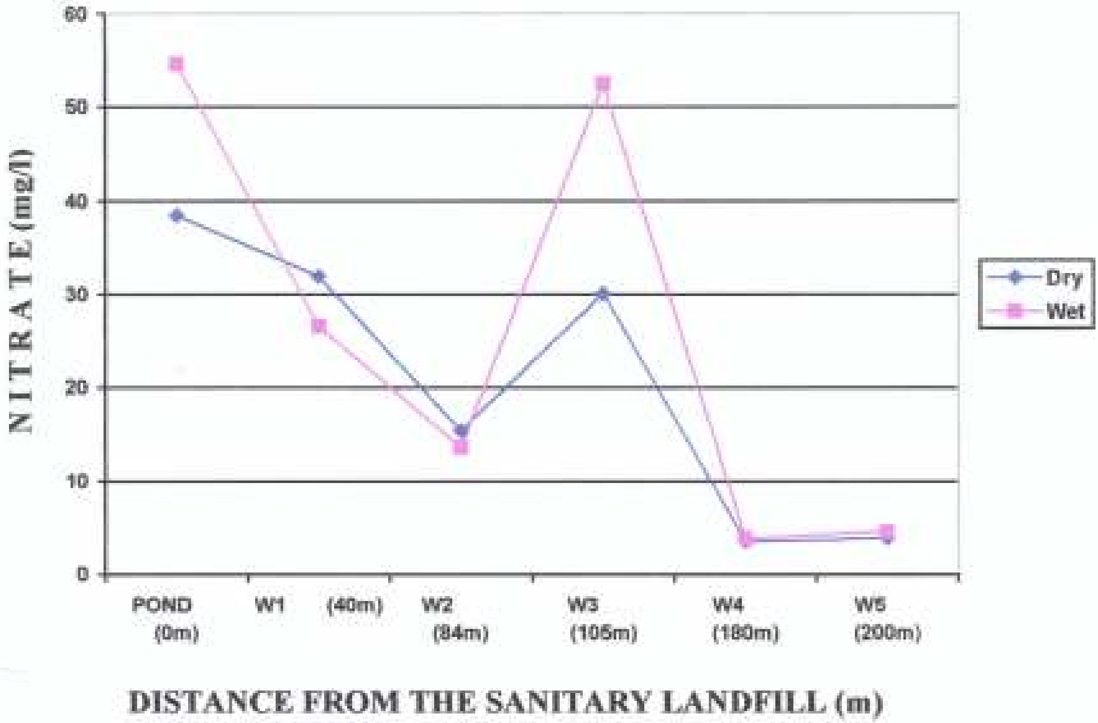


Fig 4.10 Wet And Dry Season Variation For Nitrate

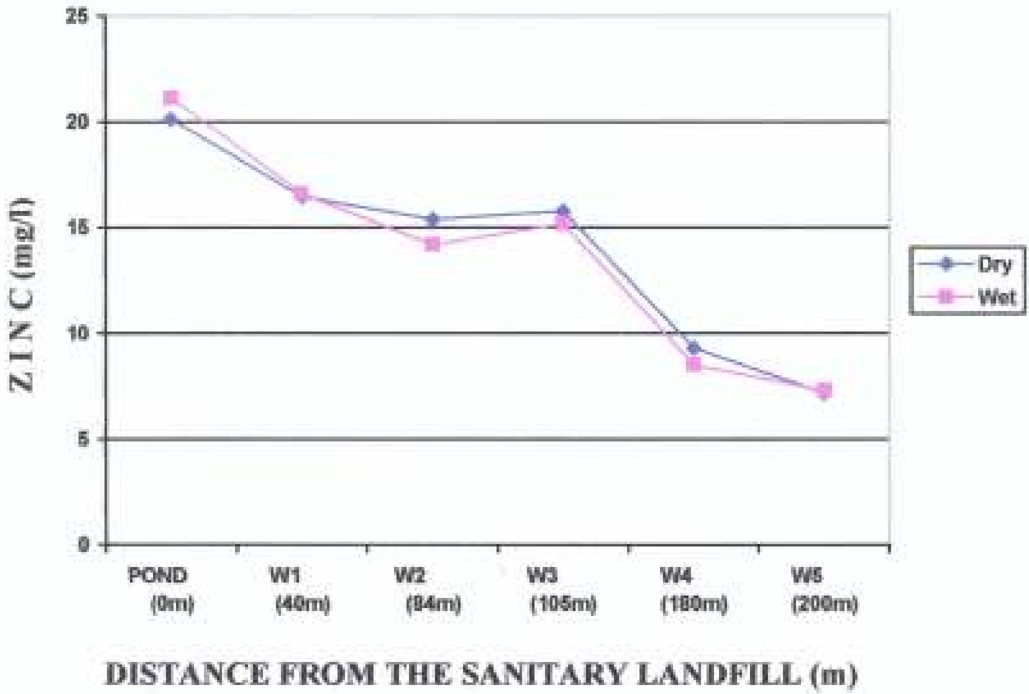


Fig 4.11 Wet And Dry Season Variation For Zinc

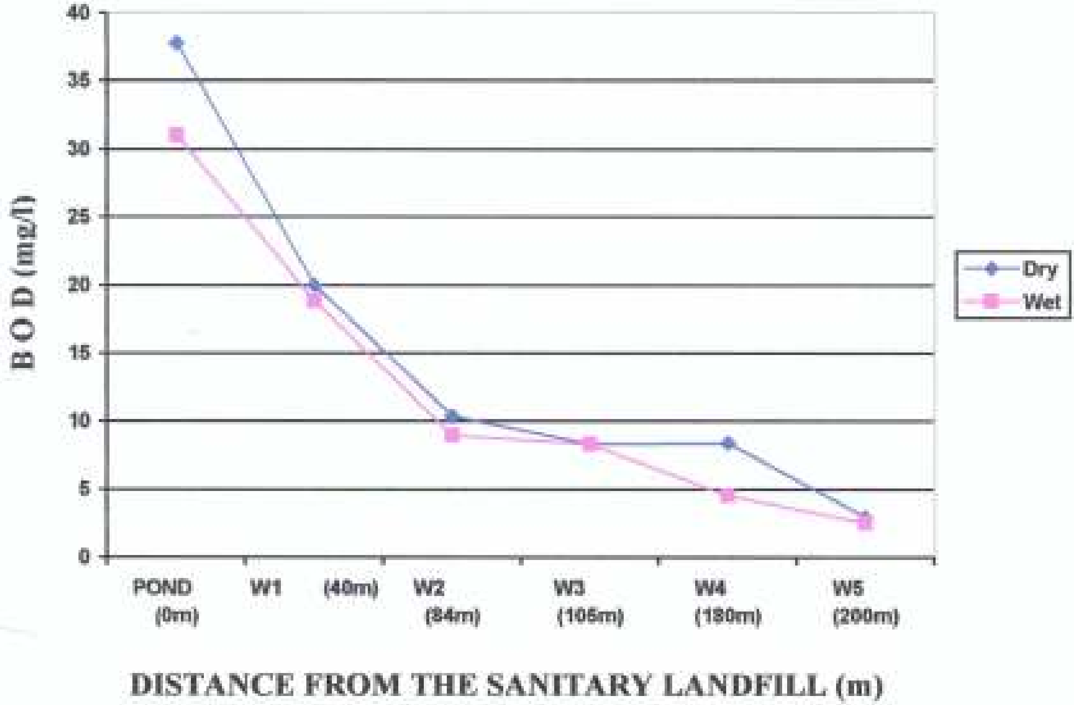


Fig 4.12 Wet And Dry Season Variation For BOD

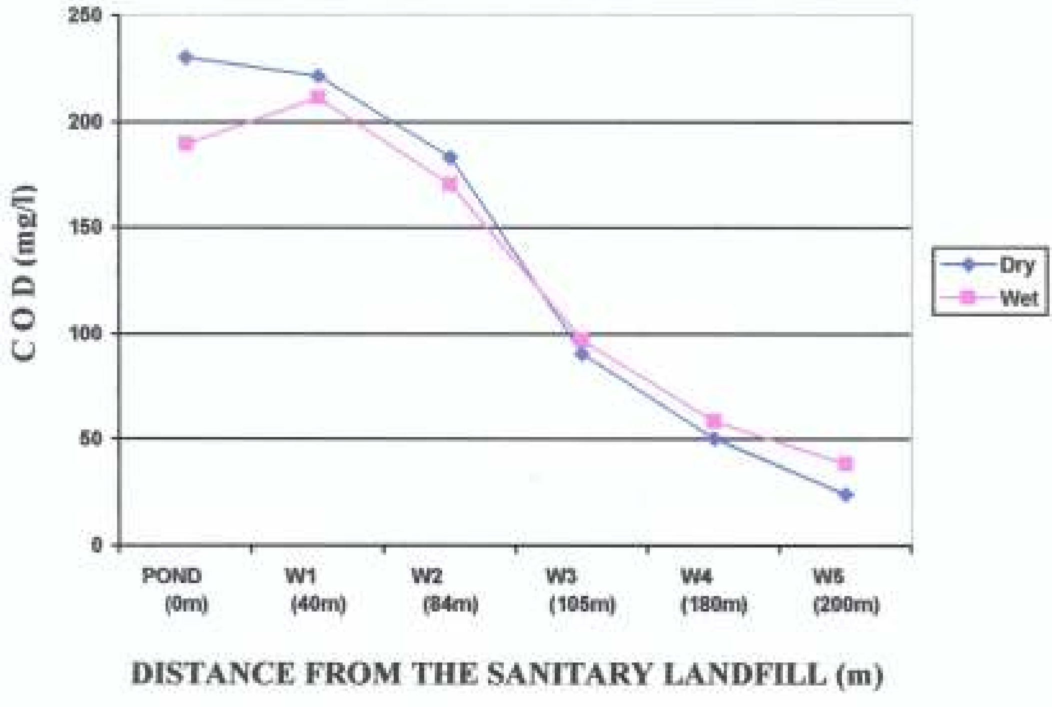


Fig 4.13 Wet And Dry Season Variation For COD

4.4 Discussion Of Results

4.4.1 Discussion On the results Of Sampled Wells

The results which were presented in the tables and graphically represented in the figures show the variation in the concentration of contaminants in the sampled wells.

4.4.1.1 Pond

The sampled pond parameters were compared with the WHO International Standard for drinking water and all the parameters concentrations exceeded the maximum recommended concentration limit as shown in the Tables A1- A8 in the appendix.

4.4.1.2 Well 1

Fig. 4.1 illustrate the monthly variation of colour in the well. It varies between 3.5 - 6.9 TCU. The monthly variation of temperature varies between 19^0C to 25^0C. The well is clear in appearance and odourless during the dry season i.e from the month of January to March, but very turbid in wet season (Apr.- Aug.) the remaining period of months observed as shown in Table 4.1. The BOD as given in d Fig. 4.5 varied between 13 mg/l – 2.6 mg/l.

Parameters in Fig. 4.1 – 4.6 reflect leachate pollution i.e PH, COD, BOD, Zn, and NO_3^- compared with WHO standard for drinking water as shown in tables A1 –A8 exceeded maximum concentration limits. Therefore the well 1 is polluted and unsuitable for drinking.

4.4.1.3 Well 2

This well is at a distance of 84m from the sanitary landfill and 7.5m deep. Fig. 4.1 illustrate that well 2 is not coloured during the month of January to April but very coloured in the remaining period of the months observed. Temperature is approximately uniform as shown in Tables A1- A8 with BOD variation of 5.8 mg/l – 11 mg/l as shown in Fig. 4.5.

Calcium hardness, iron concentration, phosphate, copper, manganese, zinc and lead concentrations in well 2 were compared with WHO standard for drinking water as given in Tables A.1 - A.8 exceeded maximum concentration limits. Therefore, the water in well 2 is polluted and unfit for drinking consumption.

4.4.1.4 Well 3

During the dry season the water in the well 3 is clear in appearance, colourless and odourless as shown in Table A.9 in the appendix. But during the wet season the watet is coloured, not clear in appearance as shown in Table A.10. Monthly turbidity as given in Table 4.1 varied between 8NTU – 89NTU with BOD variation of 8.0 mg/l – 8.7mg/l. Wet and dry season variation of Nitrate, Iron, COD and zinc as shown in Figs. 4.9 – 4.13 exceeded the maximum concentration limit when compared with WHO standard for drinking water. Therefore, the water in well 3 is unsuitable for consumption. There are no traces of fluoride and phosphate in the well (3).

4.4.1.5 Well 4

The concentration of the parameters that reflect leachate (chloride, nitrate, BOD, COD and zinc) in well 4 during the dry and wet season are lower than the concentration of parameters in well 1- well 3 as shown in Figs. 4.7 – 4.13. This is due to its distance from the sanitary landfill, it is sited at a distance of 180m from the sanitary landfill. The monthly variation of BOD as given in fig.4.5 varied between 4.0 mg/l – 4.7 mg/l. The monthly temperature of well 4 varied between 8^0C - 38^0C as given in Tables A1 – A8. The PH values for dry and wet season varied between 6.5 – 7.5 as shown in Fig. 4.8. The water in well 4 has an insipid taste, odourless, colourless, clear in appearance, with turbidity variation of 8 – 38 NTU as given in table 4.1. Calcium hardness, chloride concentration, sulphate, nitrate, iron and zinc concentrations fall below maximum concentration limit (MCL). Therefore the well is suitable for consumption and free from pollutant.

4.4.1.6 Well 5

It is colourless, odourless and clear in appearance during the dry and wet season as shown in Tables A9 and A10. Monthly turbidity varied between 4NTU – 18NTU as given in table 4.1. The BOD is relatively low and varied between 2.45 mg/l – 3.5 mg/l as shown in Fig. 4.12.

From table A.1 – A.8 the concentration of total dissolved solid (TDS), total hardness, and some of the parameters recommended by the WHO international standard for drinking water such as calcium hardness, chloride, sulphate, nitrate, phosphate, iron, copper, manganese and zinc concentrations compared with WHO standard for drinking water fall below the maximum concentration limit.

Well 5 is free from leachate pollution because it is farer and deeper than other sampled wells around the sanitary landfill, It is sited at a distance of 200m from the sanitary landfill and at depth of about 11m. The inhabitant make use of it all year round.

4.5 Geophysical Results showing alternation of sand band

Figs. 4.14, 4.15 and 4.16 respectively show the log data of the boreholes sunk around the site in Olusosun (Ojota) during mini-water works programme by Lagos State Ministry of Water Resources. The figures show the depth at which suitable or potable water can be obtained and also the alternation of sand band with clays and silt. Variation in the thickness of the sand bands is about 10 to 50m depending on the columnar strata and the aquifer is composed of sand sediments separated by less permeable silt and clay aquitard ranging thickness from 5 to 10m. The first level of fresh water accumulation was discovered at about 11m depth and the second aquifer was at 200-300m depth which was recommended for exploitation.

DEPTH (m)	LEGEND	LITHOLOGY DESCRIPTION
		TOP soil, laterite with grass brownish
10		**CLAY**, plastic, traces of quartz grains, reddish brown
20		**SAND**, fine grained mixed with reddish brown clay
30		**CLAY**; plastic, greyish colour
40		**SAND**, medium to coarse grained slightly pinkish to greyish
50		**SAND** medium grained/slightly coarse, poorly sorted, greyish colour.
60		**SAND**; fine to medium grained, traces of quartz grains light grey to whitish colour
70		**CLAY**; whitish colour
80		**SAND**; fine to medium grained, traces of hard black clay whitish colour
90		
100		**SAND**; medium to coarse grained traces of brownish quartz grain
110		
120		**CLAY**; plastic, slightly mixed with conglomerates quartz grains, whitish
130		
140		
150		**SAND**; medium grained whitish
160		**CLAY**; plastic, light brownish colour.
170		**SAND**; medium to coarse grained whitish
180		
190		
200		
210		**SAND**; coarse grained, whitish
220		
230		
240		
250		
		SAND; compacted fine grained mixed with whitish clay whitish colour

Figure 4.14: Log Data (1) of the Borehole sunk around the Site during Mini - Water Works Programme, 2000.
(Source: Lagos State Ministry of Water Resources)

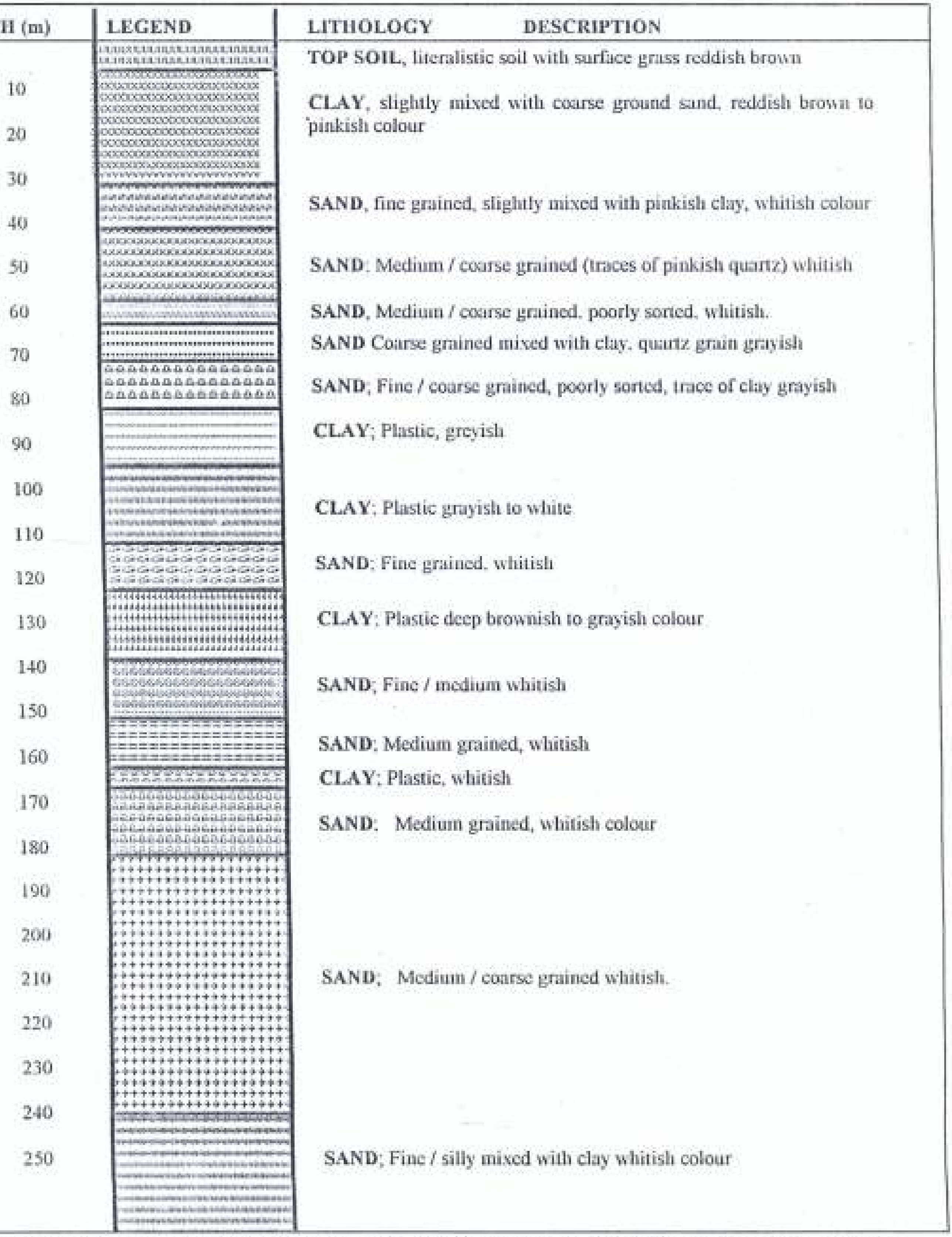


Figure 4.15: Log Data (2) of the Borehole sunk around the Site during Mini - Water Works Programme, 2000.
(Source: Lagos State Ministry of Water Resources)

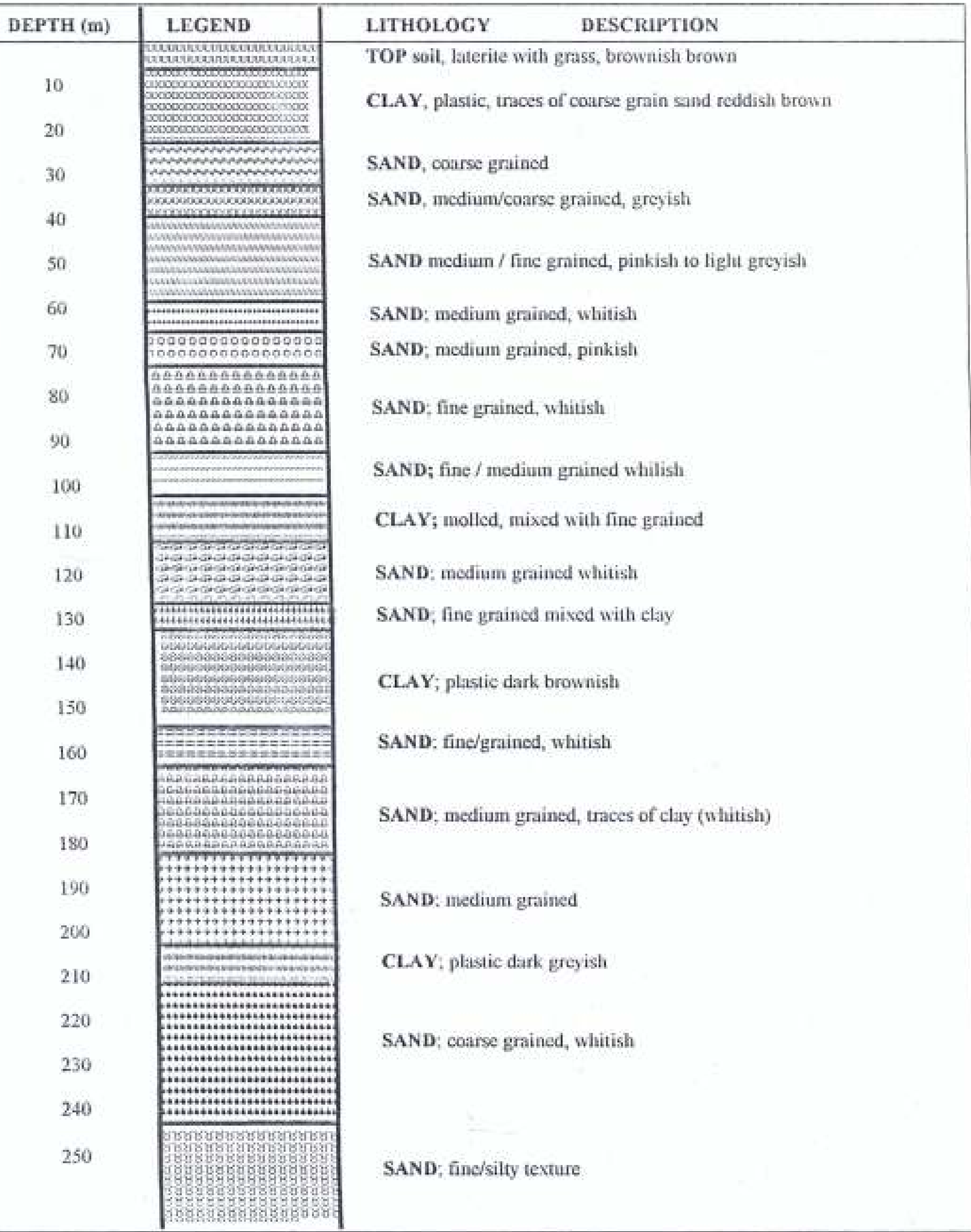


Figure 4.16: Log Data (3) of the Borehole sunk around the Site during Mini - Water Works Programme, 2000.
(Source: Lagos State Ministry of Water Resources)

Lagos State Minisry of Water Resources embarked on construction of borehole in Lagos State during mini- water works programme at the study area and the Log data of the boreholes obtained around the site were shown in figs.4.14 - 4.16 respectively. The area was underlain by clay to a depth of 11m and followed by the alternations of layers of sand bands with clays and silts where thicker layers are formed by the merging together of sand bands.

Four aquifer horizons were identified and that the bulk of groundwater resources in the state is exploited from coastal plain sands and recent alluvial deposit. The levels of freshwater accumulation was discovered at a depth of about 11m and the second aquifer which was recommended for exploitation was at a depth of 200m to 300m.

Reconnaissance survey also reveals that the sanitary landfill had already been dug to a depth of about 10m. Therefore, developed cracks at the base of the unlined (without protective goemembrane layers) landfill pit, serve as a passage for leachate to migrate to the lower aquifer, and cause serious damages and contamination to groundwater.

CHAPTER FIVE
DESIGN OF A MODERN SANITARY LANDFILL

5.1 Sanitary Landfill and Groundwater Pollution

The continuous generation of leachate without corresponding management of these leachate constitute a major threat to the quality of groundwater and public health in Olusosun (Ojota) in Lagos State. In response to the problems of groundwater pollution in Olusosun (Ojota) there is a need for design of a modern sanitary landfill. This is a positive step towards controlling, ameliorating and eliminating the problems of groundwater contamination in Olusosun (Ojota) environment. Good management techniques that can limit adverse impact of leachate on groundwater in Olusosun (Ojota) includes: control of leachate production discharge from the landfill, collection of the leachate with final treatment and or disposal. It is also imperative to formulate a policy on management strategies of municipal sanitary landfill, potting in place institutional and legal instruments for the management of the sanitary landfill and environment. Therefore, the minimization and containment of leachate within the landfill in Olusosun (Ojota) and elimination of groundwater contamination, ultimately depends on the design of modern sanitary landfill.

5.2 Design Information

Based on Technical manual UFC-3-240-10A, On the design of sanitary landfill, Unified Facilities Criteria (UFC), prepared by U.S. Army Corps of Engineers (USACE), the design of a modern sanitary landfill must meet the following criteria:

i **Access Road**: Paved all weather access roads to landfill site, temporary roads to unloading areas should be constructed.

ii **Cell Design and Construction**: Each day's wastes should form one cell with maximum depth of 3m, must be covered at the end of the day with 200mm thickness of earth.

iii Cover Material: Maximum use of on site earth materials approximately $1m^3$ of cover material will be required for every 4 to $6m^3$ of solid wastes; mix with sealants to control surface infiltration.

iv Drainage: Install drainage ditches to divert surface water run off. Maintain 1:2 gradient on finished fill to prevent ponding.

V Vent: gravel gas vent should be installed at every 18m to 60m.

vi Fire Protection: Water on site; if nonpotable, outlets must be marked clearly; proper cell separation prevents continuous burn through if combustion occurs.

vii Equipment Requirements: Scraper, compactor, road grader, water truck, tractor, crawler or rubber tyred, bulldozer.

viii Groundwater Protection: Install sealants for leachate control, install wells for gas and groundwater monitoring.

ix Sealant Classification: (See Table 5.1 below)

Table 5.1: **Sealant Classification**

Compacted Soil	Types	Remarks
Compacted clay	Bentonites, illites, kaolinites.	Should contain some clay or fine silt most commonly used sealant for landfills layers thickness varies from 150mm – 1200mm.
Asphalt	Modified asphalt, polypropylene fabric, asphalt concrete.	Layers must be thick enough.
Synthetic membrane liners	Polyvinyl chloride buty/rubber, polyethylene	Expensive.

i. **Litter Control**: Use movable fences at unloading areas, crews should pick up litter at least once per months or as required.

ii. **Spread and Compaction**: Waste should be spread and compacted in layers not less then 60cm thick.

iii. **Unloading Areas**: Operate separate unloading areas for automobiles and commercial trucks, generally under $30m^2$

iv. **Communication**: Telephone for emergencies

v. **Days and Hours of Operation**: Usual practice is 5 to 6 days per week and 8 to 10 hours per day.

vi. **Employee Facilities**: Rest rooms and drinking water should be provided.

vii. **Equipment Maintenance**: A covered shed should be provided for field maintenance of equipment.

viii. **Operation Records**: Tonnage, transaction and billing if a disposal fee is charged.

ix. **Salvage**: No scavenging, salvage should be allowed at the unloading area: no salvage storage site.

x. **Scales**: Essential for record keeping.

5.3 The Design Parameter

According to Bagchi and Amalendu (1990), the design parameter must be collated by the designer based on the data on topography,population of the environment, rate of waste generation, number of working hours per day or per week, volume of waste generated, Area of the landfill, Height lift and e.t.c. Therefore, from data collated from Olusosun (Ojota) landfill, the following parameter were deduced for design as stated below.

Population of Ikeja and Ojota (approximation)		4 million
Ratio of cover material to solid wastes	-	1:4
Area available	-	64.1ha

No. of truck/day:	*20*
Average volume per truck:	*$20m^3$*
Volume of waste generated by day:	*$400m^3$*
No of working days per week :	*6 days*
No. of working hours per day :	*8 hours*
Total lift height	*3m*

5.4 Determination of Waste Density

Wastes that were buried in Olusosun sanitary landfill were classified as residential and commercial – industrial wastes. According to Tchobanologlous, et al., (1985), the typical densities of municipal solid waste should be used for design analysis and are stated as:

i. Residential = $130.53 kg/m^3$

ii. Commercial – Individual = $534 kg/m^3$

The total densities shall be a proportion of residential to commercial/Individual waste. Say 70% - 30%.

Waste density = $0.7(130.53) + 0.3(534) kg/m^3$

= $251.54 kg/m^3$

Approximate waste density = $260 kg/m^3$

5.5 Determination of Rate of Waste Generation

The rate at which wastes are being generated shall be determined from the data on the volume of waste generated per day, per week and estimated population of Olusosun. The detailed calculation are stated below:

Volume of waste per/day - $20 \times 20 = 400 m^3$

Volume of waste per/week - $20 \times 20 \times 6 = 2400 m^3$

Weight / week = (Waste density) x (volume/week)

= $260 kg/m^3 \times 2400\ m^3$

= 624000kg

= 624 Tons

Overall solid waste generation rate =624 Tons/Week or $2400\ m^3$/Week

5.6 **Landfill Operation**

Guidelines for landfill operations shall be as follows:

a. **Site Preparation**: The decayed buried wastes at the landfill must be excavated and carted away as raw material to the Fertilizer Company or use as manure for farming. The undecayed wastes should be stockpiled and dumping of waste at the landfill should be stopped temporarily, until the site preparation is accomplished, meanwhile a temporary dumping site should be created for collection of waste.

b. **Permanent and Temporary Roads**: the next step in the preparation of the site is the construction of an entry road from the existing road that is parallel to Lagos – Ibadan expressway and an access road into the landfill. The road should be of permanent construction because it must be used for the useful life of the site. It should be at least 9m wide with the necessary side ditches for drainage. The temporary haul roads to the operation area of each lift can be constructed of a solid waste and soil mixture. The haul roads need not be permanent because they will be covered by successive lifts of solid wastes.

c. **Groundwater Protection**: The groundwater is to be protected by treating the bottom area and side of the trenches before placing of waste. The depth of excavation should be limited to less than 10m .

d. **Dept of Excavation**: Results obtained from log data on wells drilled at Olusosun environment, indicated that clay occupies average depth of 11m and underlain with coarse grained sand. Therefore, the depth of excavation should be limited to 10m..

e. **Filling Plan and Operation**: A layer of 150mm of cover material should be placed over the compacted fill at the end of each day to provide a surface for vehicle traffic and to eliminate rodent access to the compacted wastes.

f. **Unloading Area**: The width of the unloading area should be limited to a distance of 50m to prevent indiscriminate dumping and to maintain better operational control. Traffic at the unloading area will consist of the collection vehicles with experienced drivers, as well as vehicles from commercial and industrial establishments and private vehicles driven by residents who may not be familiar with a landfill operation.

g. **Erosion and Drainage Control**: A drainage ditch should be constructed around the operation area to carry away runoff water. The ditches should be located in such a way that it will carry water away from the landfill area.

h. **Wet Weather Operation**: Operations during the rainy period of the year, March to October, can continue if the haul roads are passable. The addition of a quick – draining gravel to the road surface should help keep it operational. Culverts under the road should transmit the water across the roadway to prevent flooding of the road.

Spreading and compacting equipment can operate in wet-weather conditions. If the haul roads become impassable, it may be necessary to develop a wet- weather unloading site near the paved entrance road.

i. **Water Supply and Fire Protection**: A supply of water is necessary for landfill operations. Wetting the solid wastes decreases the blowing and spreading of debris by the wind. Applying water to the face of the fill before covering greatly decreases the possibility of fire in the fill. The water supply should also be used for dust control in the operation area and on the roads. Potable water should also be provided at the gatehouse for operator consumption. Because of the poor quality of the on site water, potable water must be obtained from a bottled – water supplier.

j. **Operation Control**: An entrance scale and gatehouse are recommended. The gatehouse would be used by personnel who weigh trucks. If the weight of the solid wastes delivered is known, then the in-place density of the wastes can be determined and the weight records would also be used as a basis for charging participating agencies and private haulers for their contributions.

The gatehouse can be a relatively simple building since only a few people will be using it. A 3m x 6m office or prefabricated building should be adequate.

k. **Time of Operation**: The recommended time schedule for operation of the site is 8am to 5pm, 7 days week, as the site should be open for the convenience of the public.

5.7 Determination of Site Capacity of Waste:

The expected daily, yearly and cumulative yearly total waste quantities are given in table 5.2 below. The daily and yearly waste quantities were computed on the basis of the projected end-of-year population.

Approximated value of the density: 260kglm^3

Assumed population at Olusosun and Ikeja: 4×10^6

overall solid waste generation rate: 624 Tons/ Week or 400

Table 5.2: Summary of the Duration of Olusosun Sanitary Landfill

Year	Volume m^3 (Daily)	Yearly volume m^3	Cumulative Total m^3
2003	400	146,000	146,000
2004	430	156,950	302,950
2005	460	167,900	470,850
2006	490	178,850	649,700
2007	520	189,800	839,500
2008	550	200,750	1,040,250
2009	580	211,700	1,251,950
2010	610	222,650	1,474,600
2011	640	233,600	1,708,200
2012	670	244,550	1,952,750
2013	700	255,500	2,316,432
2014	730	266,450	2,474,700
2015	760	277,400	2,752,100
2016	790	288,350	3,040,450
2017	820	299,300	3,339,750
2018	850	310,250	3,650,000
2019	900	328,500	3,978,500
2020	950	346,750	4,325,250
2021	1150	419,750	4,745,000
2022	1350	492,750	5,237,750
2023	1550	565,750	5,803,500
2024	1750	638,750	6,442,250

This procedure is recommended even though it is on the conservative side. The volume was computed by using an evaluated value of 260kg/m^3 for the in-place compacted density of the solid wastes.

5.8 Determination of the total useful life of the Sanitary Landfill

The time that it would be necessary to develop another sanitary landfill can be determined from the site plan as shown in the figure 5.1 below:

The area of the landfill	=	640880sq.m
Assume 96% of the area will be		
use for excavation to receive fill	=	615,244.8
	$\simeq$	615,245 sq.m
Depth of Design	=	9m
Volume	=	615,245 x 9
	=	<u>5,537,2032m^3</u>

Therefore, the quantities given in table 5.2 are compared, the useful life of Olusosun sanitary landfill is found to be about 20years (2003 – 2023). At that time it would be necessary to develop another sanitary landfill.

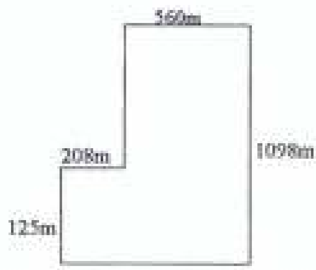


Figure 5.1: The site plan of Olusosun Sanitary Landfill

5.9 Equipment Requirements

The type of equipment that can be used at Olusosun (Ojota) sanitary landfill include both crawler and rubber – tyred tractors, scrapers, compactors, draglines and motorgraders.

Equipped tractors can be used to perform all the necessary operations at the sanitary landfill including spreading, compacting, covering trenching and even hauling cover materials.

5.10 Olusosun Sanitary Landfill Disposal Site Layout

The configuration of the landfill supporting buildings and access roads should be to facilitate effective storm water drainage, erosion control, leachate collection, and operation at a minimum cost.

Supporting building should be near the landfill. If the waste is to be weighed, a truck scale should be adjacent to the access road and situated where all vehicles entering and exiting the landfill. The site layout of Olusosun (Ojota) is shown in figure 5.2.

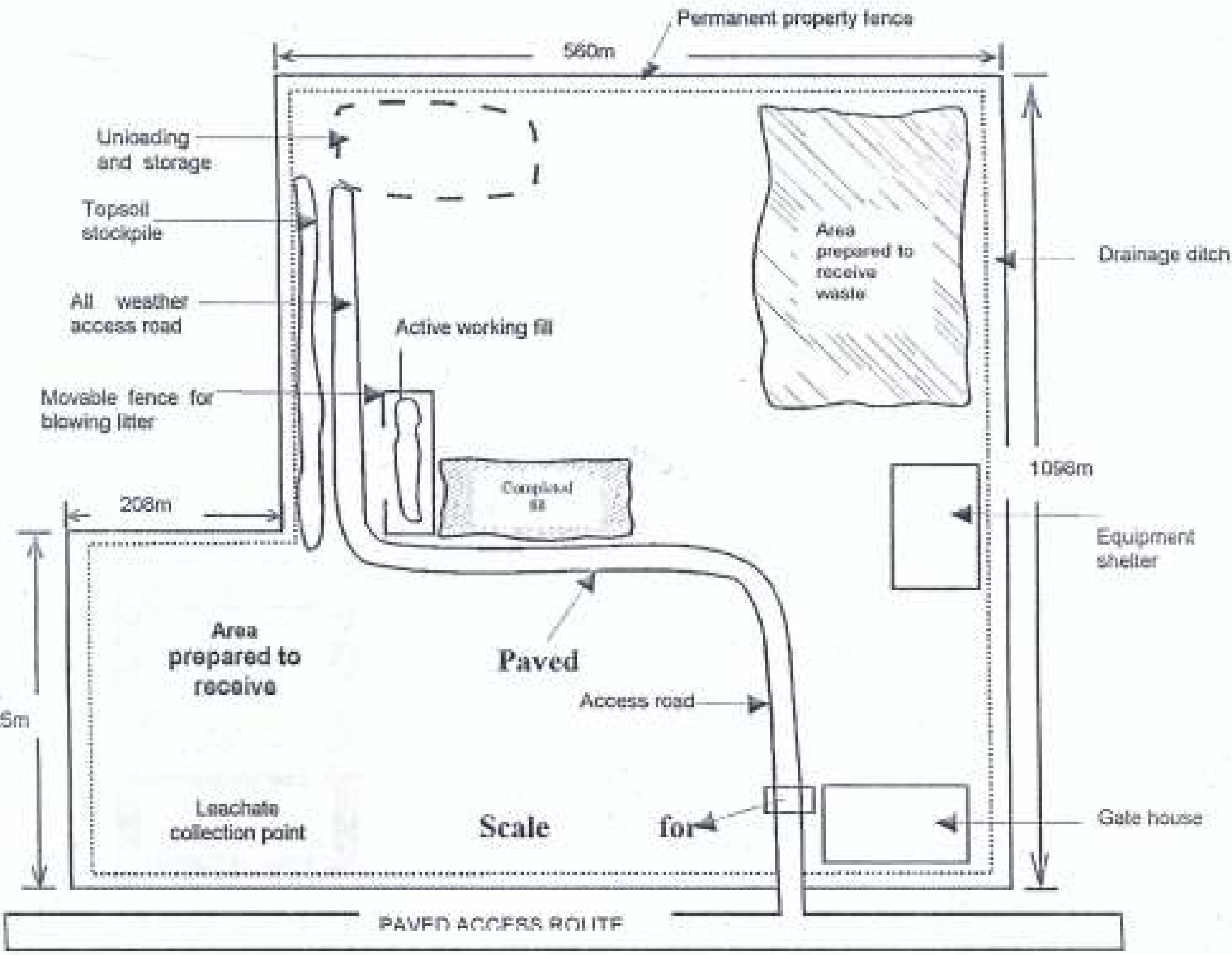


Figure 5.2 Olusosun Landfill Disposal Site Layout

5.11 Trench Design

A portion of the trench should be dug and the dirt should be stockpiled to form an embankment behind the first trench. Wastes are then placed in the trench, spread into layers usually 60cm to 90cm and compact. The operation continues until the desired height is reached. trenches vary from 30m to 120m in length and 6m to 9m width. Also, other considerations given to design of trenches are:

i. do not allow surface storm water to enter trenches;

ii. the floor of the landfill trench must have a 2 to 5 percent slope to drain leachate toward the collection system. Follow the slope of the original grade to minimize excavation, and keep the depth uniform to minimum leachate pumping:

iii. Provide side slopes of 90cm horizontal to 30cm vertical, and

iv. minimize the amount of storm water coming into contact with the waste, the trench can be constructed as a series of cells separated by berms or by alternating the direction of the bottom slope as shown in figures 5.3 and 5.4.

v. The entire trench is wrapped in a geotextile blanket as shown in figure 5.5

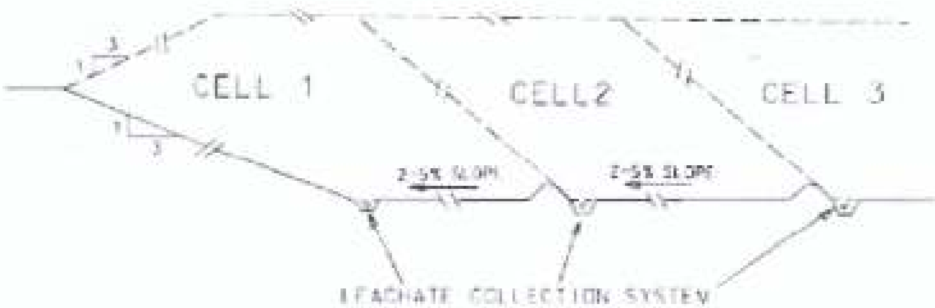


Figure 5.3: Trench Bottom Design

Figure 5.4: Alternate Trench Bottom Design.

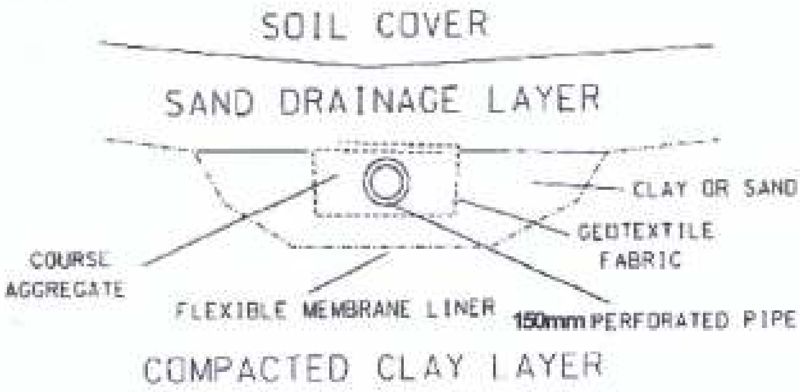


Figure 5.5: Collection Trench Detail.

5.12 Design Of Collection System

In the Technical manual UFC-3-240-10A, On the design of sanitary landfill, It is stated that for collection techniques to be successful an impermeable soil barrier or artificial liner must be in place to confine the leachate and to deliver it to the disposal site. The most common type of collection utilizes gravity drainage and consists of a layer of sand and or gravel underlain with perforated pipes that carry the leachate to a collection point as shown in figure 5.6

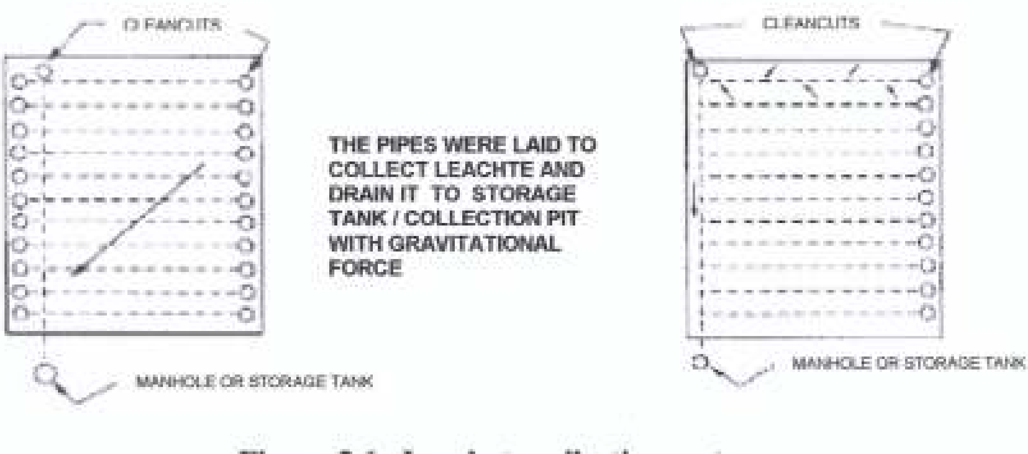


Figure 5.6 Leachate collection system

5.13 Design of Perforated Pipe

According to U.S Army Corps of Engineers (USACE) 2004; on guidelines for design of modern sanitary landfill. It is stated that the strength of the perforated pipe should withstand the weight of the compacted fill . Therefore, pipe manufacturers should be consulted to determine acceptable materials for the perforated pipe.

The minimum diameter of the pipe is 150mm and the maximum diameter is 300mm. Pipes are best protected when placed in a trench, with careful consideration given to proper bedding and to solid waste loading conditions over the pipe. The trench provides added protection for the pipe, especially during placement of the first lift of waste when the pipe is most susceptible to crushing.

5.14 Design of Liner System

Underlying the leachate collection system shall be a composite barrier consisting of a flexible membrane liner (FML) over a minimum depth of 60cm of compacted clay soil having hydraulic conductivity not greater than 1 x 10^{-7}cm/sec.

In most cases, a layer of clay with a minimum of 90cm depth should be specified as shown in figure 5.7. Liner manufacturer should be consulted to determine acceptable materials, the thickness recommended by U.S Army Corps of Engineers (USACE) for flexible membrane liner is 3mm to 5mm thickness.

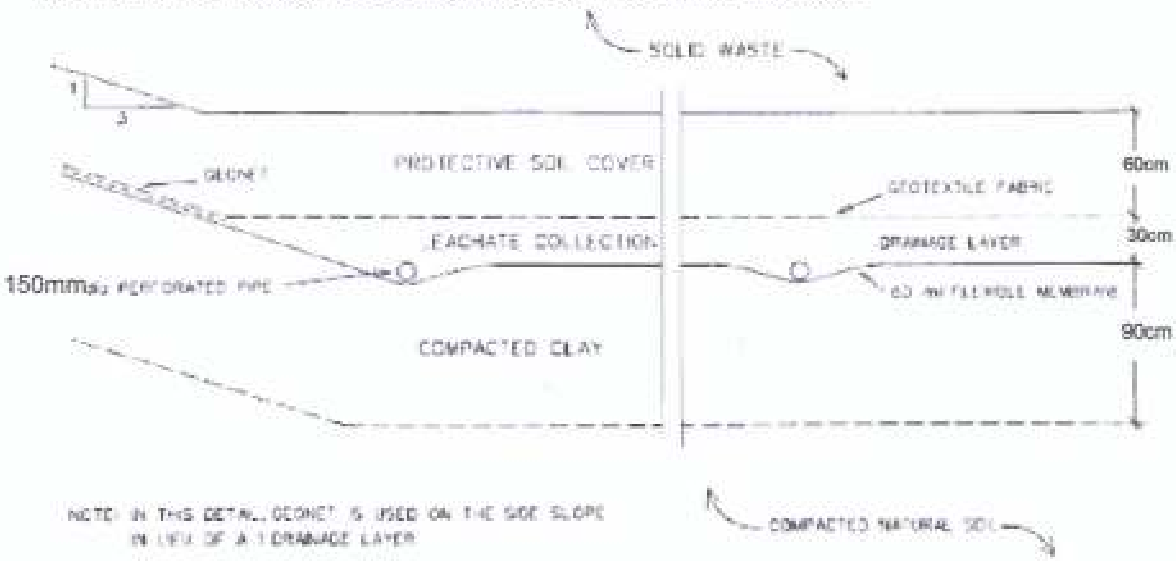


Figure 5.7: Liner System

5.15 Erosion Control Design

To minimize erosion, the top grade of the sanitary landfill must be sloped in accordance with the design standards, side slopes should be 3:1 as shown in figure 5.8. Drainage ditches around the perimeter of the landfill should carry stormwater away from the landfill quickly and should not cross over the landfill. Windbreakers at slopes facing prevailing winds can be used to minimize wind erosion.

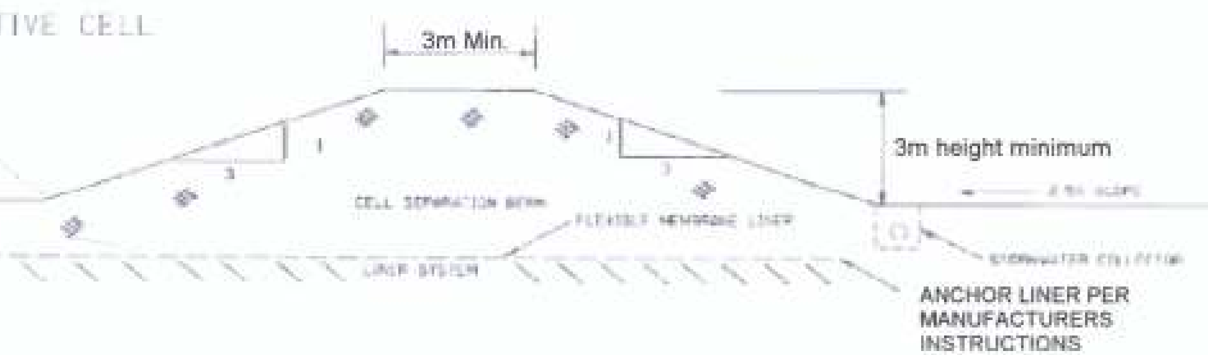


Figure 5.8 Berm Detail

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

A comparism of results obtained on the sampled wells with the WHO international standard on potable water couple with geophysical results on borehole mini water program embarked on by Lagos State Government shows that;

(a) Water in the well 1, 2 and 3 is contaminated, the quality concentrations exceeding the allowed maximum concentration limit. This is due to their proximity to the sanitary landfill. Leachate could easily migrate through such distance to contaminate the wells.

(b) These wells were sited on a reclaimed land formerly used for refuse dump. Therefore, the contamination could be easily traced down to a large percentage of the soil, being refuse dumps. This soil contains some contaminating elements apart from the leachate from the decomposed sanitary landfill.

(c) The lack of protection of the wells by well-plastered concrete rings enhanced the contamination of the water, by the landfill leachate.

(d) The quality of water from well 4 and 5 falls within the WHO recommended limit and these wells are suitable for drinking consumption. These are located at 180m and 200m respectively from sanitary landfill, on a non-reclaimed land.

(e) The sanitary trenches in the landfill were not lined with sealant.There were cracks within the walls and base of this trenches, enhancing the infiltration of the leachate into the groundwater.

(f) From hydrogeological study in the vicinity of the site indicate that clay occupies a layer of about 3-10m and underlain by graded sand with fine and alternations of layers of sand bands with soft clay. Cracks in the underlying wall of the sanitary landfill which had already been dug to a depth of about 10m, allowed the infiltration of leachate into the lower aquifer.

(g) Topography of the site permits excess rainfall to run off easily into the lagoon or swamps, as well as into the existing shallow wells that are not protected.

6.2 Recommendations

For better operations of the landfill and protection of the wells around the site and enhancement of cleaner environment, it is recommended that:

(i) An effective control of groundwater abstraction should be put in place. Wells locations with respect to the landfill should be properly sited on basis of available water quality information.

(ii) Sanitary landfill should be situated not less than 500m from the residential wells or borehole. This is necessary in order to avoid the aquifer being contaminated.

(iii) The sanitary trench should be treated with sealant before wastes are buried. These sealant could be compacted clay (Bentonite, Kaolinites), liner (polyethylene) and asphalt.

(iv) Construction of a water treatment plant to remove the contaminants before discharging into the receiving water bodies is a necessity.

(v) Boreholes for Olusosun inhabitants should be sunk up to a depth of 200m to 300m.

(vi) The Waste Management Board should recognize the geological features of the environment and apply latest technology of burying wastes at sanitary landfill, and use liners at sanitary trenches.

(vii) The State Government and Ikeja Local Government Council should embark on enlightenment campaign programmes to explain the dangers involved in building houses/sitting wells along the sanitary landfill.

(viii) Appropriate Town planning and environmental laws should be enacted for proper planning, design and operation of landfills.

(ix) A groundwater monitoring program should be established by Lagos State Government, through which the quality of every well and borehole water is monitored continuously.

(x) A recycling center is necessary to reduce the amount of wastes dumped at the sanitary landfill that cause excessive leachate. Recycled wastes are more valuable raw materials for the new products. Therefore, a fertilizer company established nearby can use the excavated degraded manure from landfill as raw materials.

(xi) Government should hasten up the implementation of mini water works in Olusosun (Ojota) so that people can have assess to potable water supply

(xii) Wells that contain high concentrations of contaminants should be closed with earth to refrain people from using them.

(xiii) Redesign and construction of modern sanitary landfill should be embarked upon by Lagos State Government so as to reduce or stop leachates from migrating from the landfill to the surrounding wells.

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APPENDIX

TABLE A1 **MONTH OF JANUARY 2003**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH DISTANCE FROM LANDFILL		1m 0m	6m 40m	7.5 84m	7.0 105m	10m 180m	11m 200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR		-	-
COLOUR	TCU	75	3.5	3.2	3.1	3.0	3.0		5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	140	20	16	18	9	8		5	25
TEMPERATURE	^0C	27	26	25	27	26	25		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	560	22	20	21	20	18		5	50
DISSOLVED SOLID	mg/l	1784	547	150	48	30	32		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	754	540	140	69	50	50		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	480	208	180	70	50	33		30	200
PH	-	5.5	6.5	7.8	8.2	7.2	7.0		6.5	9.2
CALCIUM HARDNESS	mg/l	320	280	240	58	74	68		75	200
CHLORIDE	mg/l	688	480	90	420	120	240		200	600
SULPHATE	mg/l	696	505	488	196	238	225		200	400
NITRATE	mg/l	38.65	32.8	15.69	30.4	3.6	4.0		5	30M
NH_3 (AMMONIA)	-	0.87	0.01	ND	ND	ND	ND		-	-
SILICA	-	ND	ND	ND	ND	ND	ND		-	-
PHOSPHATE	mg/l	5.2	1.23	1.16	-	-	-		-	0.03
IRON (Fe)	mg/l	1.50	1.20	1.18	1.08	0.9	0.05		0.1	1.0
COPPER	mg/l	2.1	1.85	1.66	1.58	0.4	0.67		0.5	1.5
MANGANESE	mg/l	3.12	0.68	0.65	0.58	0.3	0.2		0.05	0.5
ZINC	mg/l	20.24	16.88	15.85	15.62	9.40	7.35		5	15
LEAD (Pb)	mg/l	0.55	0.28	0.15	0.04	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DISSOLVED OXYGEN DO	-	10.5	8.5	6.0	5.0	3.8	4.5		-	-
BOD	mg/l	38.5	20.6	11	8.7	4.6	3.5		-	-
COD	mg/l	232	220	185	92	52	25		10	100
CONDUCTIVITY	Ohm	2.7×10^4	3.0×10^4	2.6×10^4	1.5×10^4	1.1×10^4	1.1×10^4		0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT 37^0C IN 24HRS	mg/l	25	11	5	6	3	2		0	10

TABLE A2 MONTH OF FEBRUARY 2003

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH DISTANCE FROM LANDFILL		1m 0m	6m 40m	7.5 84m	7.0 105m	10m 180m	11m 200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	S.C	CLEAR	CLEAR	CLEAR	CLEAR		-	-
COLOUR	TCU	74	32	3.3	3.2	3.1	3.0		5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	139.5	31	16.5	18.5	7.5	8.5		5	25
TEMPERATURE	°C	26.5	26	25	27	26.5	26		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	553	21.5	19	21	20	17		5	50
DISSOLVED SOLID	mg/l	1782	545	150	48	31	31.8		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	835	566.5	150	69	51	48.8		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	475	210	179	70	50	33		30	200
PH	-	5.6	6.2	7.6	8.0	7.1	7.2		6.5	9.2
CALCIUM HARDNESS	mg/l	318	278	238	58	74	67		75	200
CHLORIDE	mg/l	686	479	87	420	119	239		200	600
SULPHATE	mg/l	694	402	486	194	236	224		200	400
NITRATE	mg/l	38.4	32	15	30	3.4	3.8		5	30
NH_3 (AMMONIA)	-	0.87	0.01	ND	ND	ND	ND		-	-
SILICA	-	-	-	-	-	-	-		-	-
PHOSPHATE	mg/l	5.0	1.20	1.10	-	-	-		-	0.03
IRON (Fe)	mg/l	1.42	1.14	1.11	1.02	0.8	0.03		0.1	1.0
COPPER	mg/l	1.88	1.78	1.55	1.58	0.3	0.65		0.5	1.5
MANGANESE	mg/l	3.05	0.60	0.58	0.60	0.4	0.3		0.05	0.5
ZINC	mg/l	20.1	16.2	15.3	15.80	9.4	7.30		5	15
LEAD (Pb)	mg/l	0.55	0.25	0.10	0.03	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DO	-	10.10	8.30	5.80	4.90	3.60	1.32		-	-
BOD	mg/l	38.0	20.0	9.80	8.20	4.40	2.45		-	-
COD	mg/l	230	225	185	91	51	25		10	100
CONDUCTIVITY	Ohm	2.0×10^5	2.5×10^4	2.5×10^3	1.2×10^4	1.1×10^4	1.1×10^4		0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT 37°C IN 24HRS	mg/l	24.5	10	5	4	2	2		0	10

SC = Slightly Clear

TABLE A3 **MONTH OF MARCH 2003**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH DISTANCE FROM LANDFILL		1m 0m	6m 40m	7.5 84m	7.0 105m	10m 180m	11m 200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR		-	-
COLOUR	TCU	73.0	3.0	4.0	4.2	3.8	3.5		5	50
ODOUR	-	STINK	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	141	9	7	8	8	4		5	25
TEMPERATURE	^{0}C	28	27	26	28	25	26		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	555	21	22	19	21	18		5	50
DISSOLVED SOLID	mg/l	1780	540	147	45	28	30		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	733	568	169	64	49	48		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	478	200	177	72	58	32		30	200
PH	-	5.4	6.8	7.3	8.5	7.5	7.3		6.5	9.2
CALCIUM HARDNESS	mg/l	305	270	235	58.5	73	65		75	200
CHLORIDE	mg/l	680	475	84	415	115	236		200	600
SULPHATE	mg/l	195	406	487	192	230	223		200	400
NITRATE	mg/l	38.0	31	15.5	30	3.5	3.8		5	30
NH_3 (AMMONIA)	-	0.85	0.01	ND	ND	ND	ND		-	-
SILICA	-	-	-	-	-	-	-		-	-
PHOSPHATE	mg/l	5.0	1.10	0.95	-	-	-		-	0.03
IRON (Fe)	mg/l	1.45	1.15	1.10	0.95	0.8	0.04		0.1	1.0
COPPER	mg/l	1.90	1.75	1.48	1.58	0.4	0.60		0.5	1.5
MANGANESE	mg/l	3.08	0.65	0.60	0.59	0.10	0.5		0.05	0.5
ZINC	mg/l	19.86	16.50	15	15.85	9.0	7.0		5	15
LEAD (Pb)	mg/l	0.58	0.20	0.1	0.02	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DO	-	9.80	7.90	6.10	5.20	3.70	2.50		-	-
BOD	mg/l	37.0	19.5	10.5	8.0	4.0	3.0		-	-
COD	mg/l	229	220	180	89	48	23		10	100
CONDUCTIVITY	Ohm	2.0×10^{4}	2.5×10^{4}	2.4×10^{4}	1.2×10^{4}	0.96×10^{4}	0.9×10^{4}		0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT 37^{0}C IN 24HRS	mg/l	24.0	18.5	4.5	4	2.5	1.5		0	10

SC = Slightly Clear

TABLE A 4 **MONTH OF APRIL 2003**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m			
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	SC	CLEAR	CLEAR	CLEAR	CLEAR		-	-
COLOUR	TCU	74.0	58	5.3	5.2	5.2	5.3		5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	142	32	7.5	9	8	5		5	25
TEMPERATURE	°C	26	25	25	26	25.5	27		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	558	21	19	20.8	19.5	17.5		5	50
DISSOLVED SOLID	mg/l	1783	546	149.5	48	29.5	31.6		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	941	567	168.5	68.8	49	49		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	485	213	178	68	49	32.5		30	200
PH	-	5.4	6.0	7.5	8.0	7.0	7.2		6.5	9.2
CALCIUM HARDNESS	mg/l	315	275	238	57	72	66		75	200
CHLORIDE	mg/l	685	478	88	419	118	238		200	600
SULPHATE	mg/l	192	401	485	193	235	223		200	400
NITRATE	mg/l	38.6	32	15	29.5	3.0	3.5		5	30
NH_3 (AMMONIA)	-	0.84	0.01	ND	ND	ND	ND		-	-
SILICA	-	-	-	-	-	-	-		-	-
PHOSPHATE	mg/l	4.8	0.95	1.0	-	-	-		-	0.03
IRON (Fe)	mg/l	1.45	1.16	1.10	1.05	0.85	0.08		0.1	1.0
COPPER	mg/l	1.86	1.75	1.55	1.58	0.3	0.55		0.5	1.5
MANGANESE	mg/l	3.0	0.56	0.5	0.49	0.10	0.4		0.05	0.5
ZINC	mg/l	20.0	16	15	15.20	9.40	7.32		5	15
LEAD (Pb)	mg/l	0.50	0.2	0.2	0.02	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DO	-	10.2	8.10	5.80	4.80	3.60	1.30		-	-
BOD	mg/l	38.0	20.0	9.80	8.20	4.40	2.45		-	-
COD	mg/l	231	219	185	91	51	25		10	100
CONDUCTIVITY	Ohm	2.2×10^4	2.0×10^5	2.4×10^3	1.2×10^4	0.9×10^4	0.8×10^4		0.9×10^4	1.2×10^4
COLONIES GROWING ON NUTRIENT AGAR AT 37°C IN 2HHRS	mg/l	24.8	9.5	7	3.5	1.50	1.20		0	10

SC = Slightly Clear

TABLE A 5 MONTH OF MAY 2003

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m			
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	SC	SC	CLEAR	CLEAR	CLEAR		-	-
COLOUR	TCU	73.5	60	56	8.7	8.1	8.5		5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	138	29	29	15	12	8		5	25
TEMPERATURE	°C	25	21	25	33	25.0	19		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	447	90	19	18.8	21.7	11.4		5	50
DISSOLVED SOLID	mg/l	1700	251	149.5	39	37.5	31.9		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	888	612	408.5	48.8	61	51		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	498	220	185	128	66	44.5		30	200
PH	-	5.4	3.0	7.5	9.0	5.5	8.2		6.5	9.2
CALCIUM HARDNESS	mg/l	318	311	189	29	74	25		75	200
CHLORIDE	mg/l	605	219	128	267	826	281		200	600
SULPHATE	mg/l	185	121	229	221	281	513		200	400
NITRATE	mg/l	37.6	31	8	94.5	5.0	3.8		5	30
NH_3 (AMMONIA)	-	0.65	0.04	ND	ND	ND	ND		-	-
SILICA	-	-	-	-	-	-	-		-	-
PHOSPHATE	mg/l	4.2	0.87	5.0	-	-	-		-	0.03
IRON (Fe)	mg/l	1.04	1.21	1.50	1.03	0.45	0.04		0.1	1.0
COPPER	mg/l	1.70	1.91	1.25	1.65	0.61	0.81		0.5	1.5
MANGANESE	mg/l	2.5	0.33	0.3	0.29	0.71	0.45		0.05	0.5
ZINC	mg/l	20.5	21	7	11.20	9.01	8.31		5	15
LEAD (Pb)	mg/l	0.33	0.5	0.7	0.06	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DO	-	10.2	6.10	2.80	4.62	3.41	1.61		-	-
BOD	mg/l	38.0	21.0	5.80	8.45	4.71	2.52		-	-
COD	mg/l	231	169	112	45	89	92		10	100
CONDUCTIVITY	Ohm	2.2×10^{4}	2.0×10^{4}	2.4×10^{3}	1.2×10^{4}	0.9×10^{4}	0.8×10^{-4}		0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT 37°C IN 2HHRS	mg/l	24.8	9.3	5	5.6	1.54	1.76		0	10

SC = Slightly Clear

TABLE A6 MONTH OF JUNE 2003

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m			
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	NC	SC	SC	CLEAR	CLEAR		-	-
COLOUR	TCU	84	66	56	53.3	6.6	8.3		5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	160	44	37.55	25.8	8	4		5	25
TEMPERATURE	^oC	56	44	19	30	25	33		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	521	56	19	20.8	19.5	17.5		5	50
DISSOLVED SOLID	mg/l	1212	546	149.5	23	19.5	22.6		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	874	667	465.5	425.5	50	45		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	498	253	188	130	54	51.5		30	200
PH	-	5.2	8.0	7.5	6.0	5.0	6.8		6.5	9.2
CALCIUM HARDNESS	mg/l	375	568	268	47	62	56		75	200
CHLORIDE	mg/l	781	256	188	319	218	438		200	600
SULPHATE	mg/l	515	456	485	293	335	423		200	400
NITRATE	mg/l	76.6	25	15	79.4	5.0	8.5		5	30
NH_3 (AMMONIA)	-	0.78	0.03	ND	ND	ND	ND		-	-
SILICA	-	-	-	-	-	-	-		-	-
PHOSPHATE	mg/l	4.4	0.45	1.0	-	-	-		-	0.03
IRON (Fe)	mg/l	1.42	1.12	1.10	2.00	0.23	0.07		0.1	1.0
COPPER	mg/l	1.65	1.78	1.55	1.89	0.9	0.1		0.5	1.5
MANGANESE	mg/l	5.0	0.15	0.5	0.49	0.51	0.55		0.05	0.5
ZINC	mg/l	20.0	14	15	17.32	5.40	6.32		5	15
LEAD (Pb)	mg/l	0.10	0.7	0.2	0.06	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DO	-	10.5	3.70	5.80	4.91	3.63	1.20		-	-
BOD	mg/l	28.0	13.0	9.80	8.20	4.40	2.45		-	-
COD	mg/l	132	231	185	91	51	25		10	100
CONDUCTIVITY	Ohm	2.2×10^4	2.0×10^4	2.4×10^5	1.2×10^4	0.9×10^4	0.8×10^4		0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT 37^oC IN 2HHRS	mg/l	87.8	1.6	7	6.7	2.75	1.18		8	10

NC = Not Clear, SC = Slightly Clear

TABLE A7 **MONTH OF JULY 2003**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS								WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m		
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m		
PARAMETERS	**UNIT**	**POND**	**W1**	**W2**	**W3**	**W4**	**W5**	**MINIMUM LEVEL**	**MAXIMUM LEVEL**
APPEARANCE	-	CLOUDY	NC	NC	SC	CLEAR	CLEAR	-	-
COLOUR	TCU	94.0	68	63	52	4.2	73	5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	-	-
TURBIDITY	NTU	142	62	47.5	79	18	5	5	25
TEMPERATURE	^{0}C	58	25	25	26	25.5	27	-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	698	21	19	20.8	19.5	17.5	5	50
DISSOLVED SOLID	mg/l	1725	546	149.5	48	29.5	31.6	-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	899	567	468.5	468.8	49	49	100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND	30	500
TOTAL HARDNESS	mg/l	499	255	198	168	49	32.5	30	200
PH	-	5.4	6.0	7.5	8.0	7.0	12.7	6.5	9.2
CALCIUM HARDNESS	mg/l	672	375	288	57	72	11	75	200
CHLORIDE	mg/l	791	478	188	419	118	181	200	600
SULPHATE	mg/l	816	401	485	193	235	223	200	400
NITRATE	mg/l	81.6	32	15	29.5	3.0	3.5	5	30
NH_3 (AMMONIA)	-	0.59	0.01	ND	ND	ND	ND	-	-
SILICA	-	-	-	-	-	-	-	-	-
PHOSPHATE	mg/l	4.1	0.95	1.0	-	-	-	-	0.03
IRON (Fe)	mg/l	1.171	1.16	1.10	1.05	0.85	0.06	0.1	1.0
COPPER	mg/l	1.86	1.75	1.55	1.58	0.3	0.91	0.5	1.5
MANGANESE	mg/l	3.0	0.56	0.5	0.49	0.52	0.58	0.05	0.5
ZINC	mg/l	20.0	16	17	15.20	9.40	7.16	5	15
LEAD (Pb)	mg/l	0.50	0.2	0.2	0.02	-	-	-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-	-	-
DO	-	10.2	8.10	5.80	4.80	3.11	1.19	-	-
BOD	mg/l	38.0	20.0	9.80	8.20	4.46	2.45	-	-
COD	mg/l	231	219	185	167	51	25	10	100
CONDUCTIVITY	Ohm	2.2×10^{4}	2.0×10^{5}	2.4×10^{5}	1.2×10^{4}	0.9×10^{4}	0.8×10^{4}	0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT $37^{0}C$ IN 2HHRS	mg/l	14.6	1.8	18	8.9	1.78	1.51	0	10

NC = Not Clear, SC = Slightly Clear

TABLE A8 **MONTH OF AUGUST 2003**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m			
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	NC	NC	NC	SC	CLEAR		-	-
COLOUR	TCU	78	69	73	68	62	16		5	50
ODOUR	-	PUNGENT	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS	ODOUR-LESS		-	-
TURBIDITY	NTU	142	72	75	89	38	18		5	25
TEMPERATURE	^0C	26	25	25	26	25.5	39		-	-
TOTAL SUSPENDED SOLID (TSS)	mg/l	558	21	19	20.8	19.5	17.5		5	50
DISSOLVED SOLID	mg/l	262	8910	917	62	182.9	16.7		-	500
TOTAL DISSOLVED SOLID (TDS)	mg/l	927.7	913	512.5	481.9	171	91		100	500
TOTAL ALKALINITY	mg/l	ND	ND	ND	ND	ND	ND		30	500
TOTAL HARDNESS	mg/l	498	317	210	216	41	19.8		30	200
PH	-	58	6.0	5.7	5.0	9.0	6.8		6.5	9.2
CALCIUM HARDNESS	mg/l	695	391	308	57	75	86		75	200
CHLORIDE	mg/l	685	816	188	419	118	148		200	600
SULPHATE	mg/l	192	262	485	193	235	223		200	400
NITRATE	mg/l	38.6	12.9	15	29.5	3.0	3.5		5	30
NH_3 (AMMONIA)	-	0.84	0.67	ND	ND	ND	ND		-	-
SILICA	-	-	-	-	-	-	-		-	-
PHOSPHATE	mg/l	4.8	0.95	1.0	-	-	-		-	0.03
IRON (Fe)	mg/l	4.55	1.16	1.10	1.05	0.85	0.08		0.1	1.0
COPPER	mg/l	5.86	2.75	2.55	2.58	0.8	0.55		0.5	1.5
MANGANESE	mg/l	6.0	0.56	0.5	0.52	0.6	0.48		0.05	0.5
ZINC	mg/l	25.0	16	17.2	18.20	9.40	7.32		5	15
LEAD (Pb)	mg/l	13.5	0.2	0.2	0.02	-	-		-	0.05
MERCURY (Hg)	-	-	-	-	-	-	-		-	-
DO	-	9.2	8.10	5.80	4.80	3.60	1.30		-	-
BOD	mg/l	13.0	20.0	9.80	8.20	4.40	2.45		-	-
COD	mg/l	123	219	185	91	51	25		10	100
CONDUCTIVITY	Ohm	2.2×10^5	2.0×10^5	2.4×10^5	1.2×10^4	0.9×10^4	0.8×10^4		0.9×10^{-4}	1.2×10^{-4}
COLONIES GROWING ON NUTRIENT AGAR AT 37°C IN 2HHRS	mg/l	25.8	6.7	10	13.50	14.70	1.5		0	10

NC = Not Clear, SC = Slightly Clear

TABLE A9: **Average Value For The Parameters For Dry Season (January – March 2003)**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m			
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	SC	CLEAR	CLEAR	CLEAR	CLEAR		-	-
COLOUR	TCU	74	12.8	3.5	3.5	3.3	3.2		5	50
PH	-	5.5	6.5	7.6	8.2	7.3	7.2		6.5	9.2
CHLORIDE	mg/l	684.7	478	87	418.3	118	238		200	600
NITRATE	mg/l	38.4	31.9	15.4	30.1	3.5	3.9		5	30
ZINC	mg/l	20.1	16.5	15.4	15.8	9.3	7.2		5	15
BOD	mg/l	37.8	20	10.4	8.3	8.4	2.9		-	-
COD	mg/l	230.3	221.7	183.3	90.7	50.3	24.3		10	100

TABLE A10: **Average Value For The Parameters For Wet Season (April – August 2003)**

PHYSICAL CHEMICAL AND BACTERIOLOGICAL QUALITY OF SAMPLED WELLS									WHO RECOMMENDATION LIMIT	
DEPTH		1m	6m	7.5	7.0	10m	11m			
DISTANCE FROM LANDFILL		0m	40m	84m	105m	180m	200m			
PARAMETERS	UNIT	POND	W1	W2	W3	W4	W5		MINIMUM LEVEL	MAXIMUM LEVEL
APPEARANCE	-	CLOUDY	NC	NC	NC	SC	CLEAR		-	-
COLOUR	TCU	60.7	64.2	50.7	37.4	17.2	22.2		5	50
PH	-	15.9	5.8	7.1	7.2	6.7	6.7		6.5	9.2
CHLORIDE	mg/l	709.4	449.4	156	368.6	279.6	257.2		200	600
NITRATE	mg/l	54.6	26.58	13.6	52.48	3.8	4.56		5	30
ZINC	mg/l	21.1	16.6	14.2	15.2	8.5	7.3		5	15
BOD	mg/l	31	18.8	9	8.3	4.5	2.5		-	-
COD	mg/l	189.6	211.4	170.4	97	58.6	38.4		10	100