

**THE POTENTIAL OF SUBSURFACE INFILTRATION FOR THE
TREATMENT OF VERMIBED EFFLUENTS GENERATED BY THE BIOFIL
TOILET**

By
KNUST
Adane Sewhunegn Molla (MSc)

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

MASTER OF SCIENCE

in

Water Supply and Environmental Sanitation

Department of Civil Engineering

College of Engineering

July 2013

Abstract

In countries such as Ghana, where a significant proportion of the population depend upon ground water sources for domestic consumption, and where onsite sanitation is the predominant means of sanitation, the occurrence of water and sanitation related diseases due to contamination of groundwater remains the commonest public health problem. To safeguard groundwater from contamination a variety of treatment barriers have been practiced in various countries. The use of sub-soil infiltration in a form of soil aquifer treatment was one of such interventions that have long been practiced in this regard.

In this study, effluent from a biofil toilet has been studied under laboratory based soil columns simulating Ghana environmental conditions to see the performance of different soil types in removing potential contaminants. Four different soil columns were characterized and installed; namely-sandy soil, clay soil, loamy soil and red lateritic soil and a multi-layer sand filter (MLSF) was also used to see the possibility of developing compact treatment system. In every soil column, sampling ports were positioned at 0.3m, 0.8m and 1.5m depths and 0.45m depth for MLSF only one port at the bottom.

The results obtained showed that, the biofil digester was successful in reducing various contaminants. It achieved about 93% faecal coliform, 95% total coliform, 50% BOD, 54% COD and 88% TSS removals. Its performance for nutrient reduction was 25% total nitrogen with 79% $\text{NO}_3\text{-N}$ and 67% $\text{NO}_2\text{-N}$ removal, while Total phosphorous removal was 35% and 31% $\text{PO}_4\text{-P}$.

With respect to organic matter removal, sandy soil and red lateritic soil columns were able to produce quality effluent (TSS and BOD) well below the Ghana EPA guideline values (50mg/l). Superior performance up to 99% COD removal was observed in red lateritic soil column. Pathogen removal potentials of soil columns also show an average of 2 to 5 log removal of pathogen. Red lateritic soil specifically achieved 5 log removals at 1.5 m depth.

All soil columns with exception of MLSF fulfil the WHO guideline value for $\text{NO}_3\text{-N}$ in drinking water (<10mg/l) and very low concentrations of PO_4 .

Table of contents

Certification	i
Abstract	ii
Table of contents	iii
List of tables.....	vi
List of figures	vii
List of plates.....	ix
List of abbreviations	x
Definition of terms	xii
Acknowledgment	xiv
CHAPTER ONE	1
1. INTRODUCTION	1
1.1. Background	1
1.2. Problem statement.....	4
1.3. Research questions.....	5
1.4. Research objectives.....	6
1.4.1. Goal of the research	6
1.4.2. Specific objectives	6
1.5. Significance of the study.....	6
1.6. Scope of the study.....	7
1.7. Structure of the thesis.....	7
CHAPTER TWO	8
2. LITERATURE REVIEW	8
2.1. Faecal sludge management in developing countries.....	8
2.1.1. Problems associated with faecal sludge management in developing countries, constraints and opportunities	8
2.1.2. Centralized versus decentralized options.....	10
2.1.3. Resource oriented sanitation and the prospect for Africa	12
2.1.4. Overview of onsite sanitation systems and their challenges.....	13
2.2. Characteristics and composition of human excreta.....	14
2.2.1 Effect of diet and age on faecal composition.....	15
2.2.2 Daily excretion of urine and faeces.....	17
2.3. The biofil toilets: technical aspects and public health significance	18
2.3.1. Introduction.....	18

2.3.2. Historical development of the biofil concept and current application	18
2.3.3. The biofil toilet; genesis, types and engineering details	21
2.3.4. Operational processes and parameters of the biofil toilet	26
2.3.5. Resource orientation and public health aspects	29
2.4. Subsurface soil absorption	32
2.4.1. Types of subsurface soil absorption systems	32
2.4.2. Design, operation and maintenance of subsurface absorption systems	33
2.5. Subsoil characteristics and contaminant removal mechanisms	35
2.5.1. Subsoil characteristics	35
2.5.2. Background to Ghana subsoil	36
2.5.3. Key contaminants from onsite sanitation systems	38
2.5.3.1. Organics and suspended solids	38
2.5.3.2. Inorganic constituents and nutrients	38
2.5.3.3. Pathogens	39
2.5.4. Contaminant removal mechanisms in the subsoil	40
2.5.4.1. Physical factors and processes	40
2.5.4.2. Chemical factors and processes	42
2.5.4.3. Biological factors and processes	43
CHAPTER THREE	46
3. RESEARCH METHODOLOGY	46
3.1. Study site description	46
3.2. Soil characterization	46
3.3. General set and schematic diagram of the experiment	48
3.4. Soil column description and experimental setup	50
3.5. Column feeding regime and periodic sampling schedule	51
3.6. Parameters analysed and methods used	54
3.7. Data quality assurance	55
CHAPTER FOUR	56
4. RESULTS AND DISCUSSION	56
4.1. Effluent characteristics and performance of the biofil toilet	56
4.1.1. Black water characteristics	56
4.1.2. Performance of the biofil digester	60
4.2. Performance of experimental columns	63
4.2.1. Physico-chemical characteristics	64

List of tables

Table 2.1 Composition and characterization of human faeces and urine	15
Table 3.1 Particle size, bulk density and pH characteristics of column soils	47
Table 3.2 Summary of Sampling and analytical schedules	53
Table 3.3 Summary of materials, reagents and analytical methods.....	55
Table 4.1. Characteristics of fresh full flush blackwater and biofil effluent	57
Table 4.2 Characteristics of faecal sludge and sewage from tropical countries	59
Table 4.3. Temperature and pH measurements during various weeks of experimental run and at different soil types and corresponding sampling depths	103
Table 4.4. Conductivity and total dissolved solids concentrations during various weeks of experimental run and at different soil types and corresponding sampling depths	103
Table 4.5. TSS and BOD ₅ concentrations during various weeks of experimental run and at different soil types and corresponding sampling depths	104
Table 4.6. Concentration of COD at different soil types and corresponding sampling depths	104
Table 4.7 Faecal and Total coliform levels during various weeks of experimental run and at different soil types and corresponding sampling depths	105
Table 4.8 Faecal and total coliform log removal achieved at different soil types and corresponding sampling depths.....	105
Table 4.9 Nutrient levels during the 2 nd week of experimental run.....	106
Table 4.10 Nutrient levels during the 5 th week of experimental run	106

List of figures

Figure 2-1 Biofil septic tank and biofil toilet of the Indonesians version (Source: PT.Biofil International, 2012).....	21
Figure 2-2 Malaysian versions BioFil tank used to treat high strength palm oil effluent (POME) and the attachment 'Cosmo-balls' (Source: PMT, 2012) ...	23
Figure 2-3 Cross section of the Biofil digester system (Source: Biofilcom, 2012).....	25
Figure 2-4 Illustration of an on-site wastewater soil infiltration system (a) and the hydraulic and purification processes (b) (Ausland, 1998).	32
Figure 2-5 Subsurface soil absorption systems; a) trench system and b) bed system (Ausland, 1998).....	33
Figure 3-1. Conceptual schemes of the experimental soil column arrangements and general set; (RLS-Red Lateritic Soil, SS-Sandy Soil, CS-Clay Soil, LS-Loamy Soil and MLSF-Multi Layer Sand Filter)	49
Figure 4-1. Physico-chemical and nutrient levels of raw blackwater and biofil effluent (actual values of total nitrogen are indicated on the diagram)	60
Figure 4-2. Physico-chemical and nutrient removal potential of the biofil toilet	62
Figure 4-3. Average temperature and pH levels at various weeks of experimental run ..	64
Figure 4-4. Conductivity and TDS levels at 2 nd , 5 th and 8 th weeks of experimental run ..	66
Figure 4-5. Performance of soil types and corresponding depths for dissolved solids removal at 2 nd , 5 th and 8 th weeks of experimental run	67
Figure 4-6. Concentration of COD in the feed wastewater and treated effluent compared to Ghana EPA guideline values (250 mg/l).....	69
Figure 4-7. TSS, and BOD ₅ levels of the feed wastewater and treated effluent.	70
Figure 4-8 Boxplot of soil column effluent BOD at various filter depths during the two months experimental run.....	71
Figure 4-9. TSS, BOD and COD removal at different infiltration depths of soil columns	73
Figure 4-10. TSS, BOD and COD removal profiles of the different soil columns under different weeks of experimental run	74
Figure 4-11. Pathogen levels observed from influent and treated wastewater.	78
Figure 4-12. Faecal coliform log removal rates of experimental soil columns	79

Figure 4-13. Total coliform log removal rates of experimental soil columns.	79
Figure 4-14. Percentage distribution of helminth ova obtained during 2 nd and 5 th week experimental run.	81
Figure 4-15. Helminth ova count during second and fifth week experimental run.	81
Figure 4.16. Nutrient content of effluents taken from various depths of soil columns during two weeks experimental run	82
Figure 4.17. Nitrate and orthophosphate levels during the fifth week experimental run	84

KNUST



List of plates

Plate 3-1 Soil characterization and preparation for use as column filling material. (a) Soil preparation, (b) hydrometric analysis set-up and (c) permeability apparatus	48
Plate 3-2 Experimental soil column set up representing feeding and sampling ports	51
Plate 3-3 Site work for sampling arrangement.....	54
Plate 4-1. Visual comparison of the raw biofil effluents and column treated effluent	68

KNUST



List of abbreviations



ANOVA-----	Analysis of variance
BOD-----	Biochemical Oxygen Demand
COD-----	Chemical Oxygen Demand
DeSaR-----	Decentralized Sanitation and Reuse
EcoSan-----	Ecological Sanitation
US EPA-----	United States of America Environmental Protection Agency
Ghana EPA-----	Ghana Environmental Protection Agency
GSAP -----	Ghana Sustainable Aid Project
GSS-----	Ghana Statistical Services
GSI -----	Geological survey of Ireland
IETC-----	International Environmental Technology Centre
JMP-----	WHO/UNICEF Joint Monitoring Program
KVIP-----	Kumasi Ventilated Improved Pit latrine
OSS-----	Onsite Sanitation Systems
PMT-----	Pakar Management Technology
PGR-----	Plant Growth Regulating Hormone
POME-----	Palm Oil Mill Effluent
ROS-----	Resource Oriented Sanitation
SANDEC/EAWAG-	Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute of Aquatic Science and Technology
SuSanA-----	Sustainable Sanitation Alliance
TDS-----	Total Dissolved Solids
TSS-----	Total Suspended Solids

UDDT----- Urine Diversion Dry Toilets

UNEP-----United Nations Environment Programme

UN-HABITAT-----United Nations Human Settlements Programme

UPM-----University Putra Malaysia

WASH-----Water Sanitation and Hygiene

WHO-----World Health Organization

WSSCC-----Water Supply and Sanitation Collaborative Council



Definition of terms

- **Biomat:** A biologically active layer that covers the bottom and sides of percolation trenches and penetrates a short distance into the percolation soil. It includes complex bacterial polysaccharides and accumulated organic substances as well as micro-organisms
- **Blackwater:** A mixture of urine, faeces and flush water along with anal cleansing material (e.g. toilet paper and anal cleansing material).
- **Conductivity:** A measure of the capacity of water and wastewater to carry an electrical charge due to the concentration of dissolved substances in it.
- **Faecal sludge:** Sludge of variable consistency collected from on-site sanitation systems, such as latrines, non-sewered public toilets, septic tanks and aqua privies. Septage, the faecal sludge collected from septic tanks, is included in this term.
- **Full flush system:** a biofil toilet that uses as much as 7-12 liters of water per flush
- **gdry:** grams dry sample
- **gpe¹:** grams per population equivalence
- **gwet:** grams wet sample
- **Improved sanitation facilities:** Facilities that ensure hygienic separation of human excreta from human contact. They include:- flush or pour-flush toilet/latrine connected to piped sewer system, septic tank, ventilated improved pit latrine (VIP), and composting toilets. *Source: WHO/UNICEF joint Monitoring Platform (JMP).*
- **Log removal:** Pathogen removal efficiencies of a treatment unit: 1 log unit =90%; 2 log units = 99%; 3 log units = 99.9%; and so on.
- **Mega City:** A metropolitan area with a total population of more than 10 million.

- **Micro flush system:** a biofil toilet that uses as low as 150ml of water per each flush
- **On-site Sanitation:** A System of sanitation where the means of storage are contained within the plot occupied by the dwelling and its immediate surroundings. It may be disposed of on site or removed manually for safe disposal.
- **Oocyst:** A thick-walled structure in which sporozoan protozoan zygotes develop into an infective stage and that serves to transfer them to new hosts.
- **Organic bulking agent:** dry and fibrous materials such as sawdust, leave moulds, finely chopped straw, peat moss, rice hulls or grass clippings, mixed in the biofil digester in order to prevent odour, absorb urine, and eliminate any fly nuisance
- **Slum:** An area of a city characterized by substandard housing and squalor and lacking in tenure security.
- **Unimproved sanitation facilities:** Facilities that do not ensure hygienic separation of human excreta from human contact. Unimproved facilities include: flush or pour flush toilets that are not connected to piped sewer system, pit latrines without slab or platform, hanging latrines and bucket latrines.
- **Vermicomposting:** is the process by which worms are used to convert organic materials (usually wastes) into a humus-like material known as vermicompost. The goal is to process the material as quickly and efficiently as possible.

Acknowledgment

I am tremendously grateful to my supervisors Dr Richard Buamah, Dr Mrs. Helen Essandoh, Prof. Mrs. Esi Awuah and my mentor Mr Peter Owusu Antwi for their earnest guidance and careful coaching in the course of the research undertaking. I pray for the blessings of God Almighty unto the lives of my supervisors. Peter, your careful advice, inspiration and approach has got a great place within my heart.

I am highly indebted to all lecturers in the Water Resources and Environmental Sanitation Programme who made constructive suggestions and critics that lead to a successful execution of this study. I highly appreciate the unreserved contribution of Mr Emmanuel Botwe during all aspects of the laboratory undertakings. I thank Mr Kingslay Osei Bonsu and Mr Fredrick Antwi for all your assistance. I am also grateful to all the staff of Civil Engineering soils laboratory who unreservedly contributed to my work. My special gratitude also goes to Mr Sarkodie Mensah who permitted his premises as a starting point for my study. I salute him for his unreserved support throughout the study.

My special gratitude goes to UNESCO-IHE Institute for water education for offering this wonderful chance to experience the worldwide prestigious institution and International experience. My sincere thanks extend to the Bill and Melinda Gates foundation for their full financial support throughout my study without whom it wouldn't have been realised. My heartfelt thanks also goes to KNUST-WRESP office especially to Dr G.K. Anornu for facilitating essential support from beginning to end especially in times of critical ventures. Sir, I wholeheartedly say God bless you.

I sincerely thank my family, who brought me the way I am. My wife Ayinye, my son Dagimawi and my little daughter Efratye, you all are my source of inspiration; I thank you and love you so much. Last but not least, I would like to extend my earnest thanks to my classmates, friends and colleagues who put a drop of contribution in one way or another.

CHAPTER ONE

1. INTRODUCTION

1.1. Background

In many poor countries in Africa where economic and financial growth are not balanced with the fast growth of urbanization, provision of water and sanitation continues to be one of the main challenges that leads to untimely deaths from frequent epidemics and severe deterioration of urban settings.

An estimated 2.6 billion people lack access to improved sanitation-defined as facilities that hygienically separate human excreta from human contact (WHO/UNICEF JMP, 2010). Improved sanitation includes toilets connected to sewers, septic systems, water-based toilets that flush into pits, simple pit latrines, and ventilated improved pit latrines.

In Ghana approximately 85% of inhabitants are served by on-site sanitation facilities (OSS) with only 7% coverage for sewer systems (Strauss et al, 2006) in Accra, Kumasi and Akosombo in the Greater Accra, Ashanti and Eastern regions respectively. OSS facilities comprise non-sewered household and public toilets, aqua privies and septic tanks. As of 2010, 58% of Ghanaians use shared public sanitation facilities, 14% use improved sanitation and the remaining 9% and 19% use unimproved facilities and open defecation respectively (WHO/UNICEF JMP, 2012). This shows that OSS systems predominate over water-borne sewerage sanitation systems, essentially due to limited sewerage lines as a result of inadequate capital investment on sanitation.

Most OSS facilities such as pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil and/or groundwater (vanRyneveld and Fourie,

1997). Accordingly, contaminants from pit-latrines may potentially leach into groundwater, thereby threatening human health through groundwater contamination. On the other hand, faecal sludge from such OSS facilities has to be disposed-of frequently to final disposal site for further treatment when they are full. Open spaces around the outskirts of towns and cities, stream draining catchments, and oceans are the common disposal areas for faecal sludge (Monney, 2011).

Pathogenic bacteria, infectious viruses, protozoa, organic matter, ammoniacal compounds and a variety of toxic chemicals are all found in significant amounts in faecally contaminated wastewater from OSS facilities (Belen, 2010). In spite of this, a significant proportion of the peri-urban dwellers and surrounding rural communities rely on untreated groundwater sources such as boreholes and protected wells for domestic purposes. Owing to poor maintenance conditions and improper settings of OSS facilities in the majority of urban areas, they are frequently the commonest causes of contamination to the sources of water apart from creating nuisance to the environment (Odai and Dugbantey, 2003). Hence a careful and systematic investigation of their impact with regard to groundwater contamination potential is a palpable undertaking.

Outbreak of water and sanitation related diseases such as Cholera, diarrhoeal diseases due to bacterial infections, viral infections such as Hepatitis B, Helminth infections such as Ascariasis Schistosomiasis etc. are common in areas where improper disposal and management of faecally contaminated wastewater in communities prevails. Provision of environmentally friendly and sustainable sanitation system is therefore essential for solving the commonest peri-urban sanitation problems.

In the drive to achieve sustainable sanitation under the emerging approaches to sustainable development, preferred sanitation systems must be; ecologically friendly, affordable and safe, improve health by minimizing the introduction of pathogens from human excrements into the water cycle, promote safe recovery and use of nutrients, organics, trace elements, water and energy, conserve resources, preserve soil fertility and improve agricultural productivity (Mema and Gyampo, 2011).

In an effort to promote sustainable sanitation, a new onsite sanitation technology, named "The Biofil toilet technology" has recently been introduced and implemented over the last five years in Ghana. Biological Filter Company (BIOFILCOM), the brain behind the technology has over 3000 units of the systems installed all over the country in resettlement camps, refugee camps, schools, mining communities, slum communities and individual middle and high income residences (Biofilcom, 2012).

In the Biofil toilet technology faeces together with flush water are discharged onto the digester where there is a rapid solid-liquid separation through a filter membrane made of pervious coarse gravel. Solid faecal matter undergoes composting by worms and other microorganisms within the digester whereas the flush water goes through a sand bed filter media and further through the subsurface soil where it percolates into the subsoil or applied to backyard gardening. The toilet technology operates as a full flush toilet system (7-12 litres per flush) or as a micro flush system that uses as little as 150ml of water per flush.

The technology is a simple compact on-site sanitation facility that combines the benefits of the flush toilet system (septic tanks) and those of the composting toilets (UDDT,

KVIP and Pit latrine) ([Biofilcom, 2012](#)) while reducing the disadvantages and drawbacks such as odour, frequent desludging etc. For example odour problems of the composting toilets can be reduced by the use of biofil toilet technology due to their fully aerobic composting process. On the other hand desludging and further treatment is required for septic tanks and pit latrines whereas biofil toilet technology is reported not to require further disposal. In addition, the biofil toilet technology requires small installation space compared to other traditional on-site sanitation facilities typically the septic tank. However there is little literature on its operational processes, performance, and environmental and public health impacts. In order to resolve the ground water concerns and associated presumed limitations of the technology which are central to its promotion and widespread acceptance, further research needs to be done principally on the effluent from the Biofil toilet technology.

1.2. Problem statement

Even though a significant proportion of the population relies on private and shared onsite sanitation systems, there is an issue of limited space in towns of the present that leaves a number of households without space for installation of onsite sanitation facilities. In addition to this, the requirement for long distance hauling of filled toilet contents to disposal facilities, inaccessible septic tanks and toilets and an even escalating cost of transport and disposal leads to frequent toilet spillages and discharge of faecal matter into nearby water bodies, open spaces, bushes etc. making the sanitation conditions of cities deteriorate from time to time ([Charles, 2007](#)).

The advent of the Biofil toilet technology is therefore a promising solution to the urban sanitation problems of the country. However, the effluent of such systems especially for

those connected to a full flush system usually infiltrate to the underground soil formation. Infiltration of faecally contaminated wastewater into the underground structure might become a threat to the underground water systems whereby some urban dwellers in Ghana and many other cities in Africa as well use it as domestic supplies.

While the biofil toilet technology is essential in solving the inherent urban sanitation problems, the technology being relatively young and presumed limitations (such as pathogen and nutrient contamination of the underground water and soils as well as associated ecological impacts) remaining unexplored might potentially hinder the advancement of the technology. To this effect a closer look to the technology aiming at further improvement geared towards providing viable solution to some of the potential drawbacks is therefore imperative. A study on the effluent quality of the biofil toilet technology and the potential of subsurface soil in removing potential contaminants to the underground water system is therefore one of such efforts.

1.3. Research questions

In this study, the filtered effluent from the biofil digester have been collected, characterized and applied onto soil columns to see the percentage removal of contaminants within the subsurface soil. With this in mind the following were the list of questions that the research aims to investigate:

- What are the characteristics of the filtered effluent from the bio-digester?
- What will be the performance of the subsoil in further treating the effluent from the Biofil toilet technology?
- Will there be significant removal of dissolved components within the bio-digester?

1.4. Research objectives

1.4.1. Goal of the research

The goal of the study is to assess the potential of natural infiltration systems for the treatment of vermibed effluent generated by the biofil toilet.

1.4.2. Specific objectives

The specific objectives are:

1. Characterization of the raw blackwater and biofil toilet effluent using selected biofil toilets from Kumasi installations
2. Determination of the effects of subsurface infiltration on the physico-chemical and microbial quality of the effluent at various infiltration depths
3. Investigation of the infiltration potential of different subsurface soil types and a modified intermittent sand filter.

1.5. Significance of the study

Undertaking this study can provide basic data about the characteristics of biofil toilet effluent which is the essential step for assessing the impacts on groundwater.

1. To the rapidly urbanizing Africa, complementing such newly developed technologies can help solve the inherent problems of onsite sanitation systems as substantial public health benefits would emanate from its successful implementation.
2. To the technology developer, the findings of this study could be used to improve the technology and speed up its widespread acceptance. Besides this the outcomes of this research might indicate the suitable soil types in Ghana for effective removal of contaminants from this system. Once suitable soil types are known, the technology

could be disseminated with or without supplementary packages aiming at further improvement of the system for those areas where the soil formation is not performing well. On the other hand, the development of a multi-layer sand filter could serve as the lasting solution for areas where the prevailing soil types may be inappropriate and/or insufficient to purify the effluent as it passes through.

1.6. Scope of the study

This study is limited to the effluent of the existing biofil toilets installations in Kumasi. Because of the limited amount of effluent that can be collected from the micro-flush installations (that operate with as low as 150 ml flush water) over the research period, emphasis has been given to the full flush toilet installations only. Moreover further investigation on the bio-digester performance of various biofil toilets have not be covered at large scale except giving a bird's eye view of limited installation assessed in this study; however detailed analysis on the impact of the effluent to the underlying sub-surface with special emphasis to groundwater contamination has been thoroughly investigated with the help of a lab scale soil column and a multi-layer sand filter.

1.7. Structure of the thesis

The thesis consists of five chapters. The first chapter begins with introduction which provides the background of the study followed by problem statement, research questions, objectives and significance and scope of the study. Chapter two deals with review of related literatures. Chapter three presents the methodological framework of the study which details how the experimental procedures were performed. Chapter four is dedicated to the results of the study and discussion of the findings. Chapter five deals with the conclusions and recommendations drawn based on the findings of the study.

CHAPTER TWO

2. LITERATURE REVIEW

In this chapter the status of faecal sludge management, associated problems and the various treatment options have been reviewed to present the processes and efforts put in place towards addressing faecal sludge management in Africa with special emphasis on Ghana. The scientific basis and historical development of the biofil technology, its operation, engineering details and the associated subsurface infiltration systems have also been thoroughly reviewed. In addition to these, key contaminants of onsite sanitation technologies, their removal mechanisms and public health and environmental concerns have been addressed as well.

2.1. Faecal sludge management in developing countries

With ever increasing population growth rates, unmatching infrastructure development and increasing urban poverty, sanitation provision continues to be a major challenge especially for developing countries. Given the fact that a large proportion of urban dwellers depend on OSS, faecal sludge management is one of the issues that needs a concerted effort. This section presents the various options for faecal sludge management, its related problems, effluent reuse plans and state of the art inventions and efforts made worldwide to solve the problems with special emphasis to developing countries.

2.1.1. Problems associated with faecal sludge management in developing countries, constraints and opportunities

In urban areas of developing countries, excreta disposal remains a major challenge. Every day, around the world, several hundred thousand tons of faecal matter from either

open defecation or the use of an overhang toilet and those collected from OSS installations such as unsewered family and public toilets, aqua privies and septic tanks are disposed of into the urban and peri-urban environment (Klingel et al., 2002). In some areas faecal sludge are either used in agriculture or aquaculture or discharged indiscriminately into open spaces, drainage ditches, into inland waters, estuaries and the sea. Unregulated disposal of faecal matter can cause nuisance, and serious health impacts due to water pollution where a significant proportion of the population in these countries depend on untreated water sources (Odai and Dugbantey, 2003).

Today the world is on the brink of “sanitation revolution” in which everyone must widen its horizons about the way excreta is managed in order to make sure that cities are running properly and the health of people are protected. The shortage of finite resources becomes more apparent and the prices for water, fertilizer and energy continue to rise (Christoph et al, 2011). In addition to maintaining a sanitary environment in which to live, sustainable sanitation systems will need to promote water, nutrient and energy recovery and reuse. In this respect today round the world, a number of concepts and practices towards sustainable sanitation such as ROSA, DeSaR, SuSanA, EcoSan, Biofil etc., have emerged that consider waste as a resource.

ROSA, abbreviated as Resource Oriented Sanitation, is one of the emerging sanitation systems and technologies that uses faecal sludge to produce compost for agricultural reuse. DeSaR (Decentralized Sanitation and Reuse) uses greywater and blackwater to produce fertilizer and biogas for electricity using an advanced wastewater treatment system. SuSanA (the Sustainable Sanitation Alliance) is an informal network of organisations who share a common vision on sustainable sanitation. It works as a

coordination platform, working platform, contributor and "catalyst" to the policy dialogue on sustainable sanitation. EcoSan (ecological sanitation) also sees human waste and wastewater as an opportunity. The primary application for EcoSan systems has been in rural areas where connection to a sanitary sewer system is not possible, or where water supplies are very limited. Both EcoSan and SuSanA are based on sustainable sanitation concepts with a wide range of activities ranging from technology innovation to promotion and social mobilization. The Biofil toilet technology uses vermicomposting for the production of organic fertilizer and polishing of wastewater for gardening applications. It is one version of sustainable sanitation specifically looking at the toilet technology which seeks to produce valuable compost while protecting groundwater (Lens et al., 2008, Müllegger et al., 2010 and Biofilcom, 2012).

2.1.2. Centralized versus decentralized options

For those urban dwellers having access to a sanitary facility, private and public OSS systems are the predominant type of installation in Latin America, Africa and Asia. Particularly in Africa and Asia where the proportion of sewered sanitation is considerably very low OSS are exceptionally dominant (Strauss et al., 2000). A study by UNEP also asserts that in Kumasi, more than 50% of households prefer a ventilated pit latrine to a water-flushed toilet, because the former does not depend on water, is simple and does not break (UNEP-IETC, 2002). This situation is therefore likely to last for decades to come, since city-wide sewered sanitation is neither affordable nor feasible for the majority of urban areas in developing countries.

The problems and challenges in faecal sludge management involves all the components of the faecal matter stream - viz. pit/vault emptying, haulage, storage or treatment, and

use or disposal with institutional/managerial, financial/economic, socio-cultural, and technical aspects of the overall management system. Pit emptying constitutes a major problem in many places, both technically and managerially. In many cities in different countries, both mechanized and manual pit emptying services are being offered (Montangero and Strauss, 2002).

Collection of faecal matter and its transport to disposal sites are particularly challenging in urban centres with often large and very densely built-up, low-income districts of developing countries. Vacuum trucks may not have access to pits or suction hoses must be laid through neighbours' yards and homes. The fact that squatter settlements and urban slums are stretched out and unplanned causes the haulage routes to be rather long. Traffic congestion further aggravates the problem and renders haulage to designated disposal sites too costly and financially unpleasant, leading to illegal dumping of collected faecal sludge at shortest possible distance from the area of collection close to squatter or formally inhabited low-income areas where they threaten the health of this ever-growing segment of population (Klingel et al., 2002). Children, in particular, are at greatest risk of getting into contact with indiscriminately disposed excreta. This circumstance dictates that faecal sludge management problem may, in most situations, be solved through decentralized schemes and institutional set-ups, only. In fact in many regional capitals of the sub Saharan Africa, treatment facilities are few and even non-existent (Montangero and Strauss, 2002). A study by Maxwell and Romi (2006) reaffirmed that small scale or decentralized wastewater treatments are popularly seen as an alternative solution to faecal sludge related problems both in the big cities and small villages in the West African sub-region as a whole and Ghana in particular.

2.1.3. Resource oriented sanitation and the prospect for Africa

In ancient Roman and Greek cultures, the use of excreta in agriculture was widely practiced. Traditional forms of sanitation and excreta reuse have continued in various parts of the world for centuries and were still common practice at the advent of the Industrial Revolution. Even as the world became increasingly more urbanised, the nutrients in excreta from urban sanitation systems were still used in many societies to maintain soil fertility, despite rising population densities ([Christoph et al., 2011](#)).

The continued depletion of limited available mineral resources is increasingly recognized to be an impending crisis. On the other hand, modern agricultural farming practices depend upon the continual application of synthetic fertilizer to support improved crop production. Consequently, these situations have led to increasing concerns about the sustainability of current agricultural practices and a focus of attention on strategies to mitigate associated environmental problems ([Gilbert, 2009](#)).

In developing countries in Africa where the proportion of the urban poor is high and characterized with unplanned and overcrowded settlements, sewer based sanitation and advanced wastewater treatment systems are largely unaffordable by the society. With unreliable power supply, expensive chemicals and the need for high calibre professionals to operate them especially for nutrient removal purposes, such systems remain impractical. On the other hand most of the common OSS systems are also complicated by a number of limitations with their final disposal (such as shortage of disposal area, surface and groundwater contamination risks etc. to mention few). Therefore, with the need for sustainable agricultural practices and the search for suitable sanitation technologies, nutrient recovery is now one of the highest agenda in the

scientific invention of wastewater treatment (Verstraete et al., 2009 and Graaff, 2010). Vinneras and Jonsson (2002) asserted that, using urine-diverting toilets where all the urine is diverted and collected and 70% of the faecal nutrients separated locally, the potential for local nutrient recovery from the household wastewater is 88% for nitrogen, 75% for phosphorus and 55% for potassium, mainly in the form of directly plant available nutrients.

Over the years various researchers have invented different technologies such as EcoSan, Urine Diversion dry toilets, composting toilets and others as resource oriented sanitation systems with different arrangements and settings. The recent invention of biofil toilets also as a resource oriented sanitation system will have a fundamental contribution to the development of sustainable sanitation system especially suited for poor settlements in Africa.

2.1.4. Overview of onsite sanitation systems and their challenges

The most common types of onsite sanitation technologies in developing countries are a "drop and store" type which include traditional pit latrines, ventilated improved pit latrines, aqua privy, pour flush toilets, bucket latrines and water closets connected to a septic tank. Septic tanks are either directly connected to sewerage facilities or are connected to a soak away system or just function as mere storage. Most of these "drop and store" systems require final disposal every two to five years. This final disposal step is frequently challenging and is the most common cause of environmental pollution and public health problems of the developing world.

2.2. Characteristics and composition of human excreta

There is relatively little information available in the scientific literature concerning the composition of human faeces. Studies by [Belen \(2010\)](#) suggested that human stools consisted of roughly 70-80% water and around 20-30% solid matter, though the water content of faeces is dependent on dietary intake and digestive function. Other studies ([Stephen & Cummin, 1980](#) and [Janson et al., 1993](#)) also confirm similar characterization of human faeces as 75% water and 25% solid matter. About 30% of the solid matter consists of dead bacteria; about 30% consists of indigestible food matter such as cellulose; 10 to 20% is cholesterol and other fats; 10 to 20% is inorganic substances such as calcium phosphate and iron phosphate; and 2 to 3% protein. Cell debris shed from the mucous membrane of the intestinal tract also passes in the waste material, as do bile pigments (bilirubin) and dead leukocytes (white blood cells). The brown colour of faeces is due to the action of bacteria on bilirubin, which is the end product of the breakdown of haemoglobin (red blood cells). The odour of faeces is caused by the chemicals indole, skatole, hydrogen sulphide, and mercaptans, which are produced by bacterial action (www.healthhype.com). Faecal bacteria composition had been studied by [Macneal et al. \(1909\)](#); who also reported a figure of 30% for the bacterial component of faecal solids.

Modelling studies carried out by [Zavala \(2002\)](#) to characterise faeces and to describe its biodegradability showed that 80% of the chemical oxygen demand (COD) of human faeces are made up of slowly biodegradable organic matter and the other 20% is biologically inert material. Urine is rather a dilute aqueous solution of metabolic wastes such as urea, salts, and organic compounds. In total the dissolved material amounts to about 5% by weight ([Zavala, 2002](#)).

The composition of human excreta shows a wide range of variability from person to person and from country to country. Table 2.1 presents a summary of different parameters characterizing human faeces and urine (Source: [Belen, 2010](#)).

Table 2.1 Composition and characterization of human faeces and urine

Composition	Faeces	Urine
Quantity(wet) per person per day(g)	70-520	1000-1500
Quantity(dry solids) per person per day(g)	30-70	50-70
Moisture content (%/gwet sample)	66-85	93-99
Total solids (%/gwet sample)	14-22	1.3-4
Volatile solids (%/gdry sample)	79-84	0.4
COD _{total} (g/l)	46.2-78.3	12.8
COD _{soluble} (g/l)	-	11.3
COD _{particulate} (g/l)	-	1.5
Nitrogen (gpe ⁻¹ day ⁻¹)	5.0-7.0	15-19
Total Phosphorus (gpe ⁻¹ day ⁻¹)	0.7-2.5	1.1-2.2
pH	-	7.1-9
Protein (g)	4-12	0.3
Total lipids (g)	4-6	-
Polysaccharides (g)	4-10	0.7

Source: adapted from Belen, 2010

2.2.1 Effect of diet and age on faecal composition

Changes in diet result in both quantitative and qualitative changes in the supply of substrates to the large intestinal microbiota and therefore are reflected in the faeces as a result of the ease and extent of microbial conversion. Diet, especially fiber content, can also affect the transit time through the gut which will have a major effect on the final faecal matter composition ([Belen, 2010](#)). Many secondary plant metabolites ingested, such as polyphenolic substances, a proportion of undigested food, such as: elastin, tendons, uncooked starch, various phosphates and salts of the alkaline earths, and neutral

fats may also reach the large intestine and are subject to bacterial transformations (Louis et al., 2007).

Diet can alter the microflora in the gut and thus have an impact on faeces. For example, insulin and fructo-oligosaccharides stimulate the growth of *Bifidobacteria* and *Lactobacilli* and there is evidence from *in-vivo* studies with prebiotics that changes in the supply of non-digestible carbohydrate can lead to shifts in the species composition of the colonic bacterial community (Louis et al., 2007). The microbial ecosystem is highly complex and science is in the early stages of understanding the effect of diet on the composition and activity of the gut microbiota (Belen, 2010). It has also been suggested by Louis et al. (2007), that adaptation to varying substrates and environmental conditions might result in more prominent changes of activity rather than of bacterial populations.

The bacterial composition of human faeces can vary greatly with factors such as age and disease too. In some groups of bacteria, species diversity was found to change with age despite the overall numbers of organisms being similar at genus level. Species such as *Bifidobacteria*, which are regarded as being protective, are thought to decline in numbers with age, whereas *Clostridia* and *Enterobacterial* populations, which are viewed as being detrimental to health, increase (Hopkins and Macfarlane, 2002). Diarrhoea is a common cause of mortality and morbidity of the under-five in the developing world. There are many pathogens associated with infectious diarrhoea, which include: many viruses, bacteria, protozoa and helminths. Diarrhoea results in an increased frequency or decreased consistency of bowel movements which significantly affects its composition (loss of fluid or electrolyte imbalances). In a study carried out by

Krogius-Kurikka et al. (2009) on the microbial community changes between patients with diarrhoea and healthy individuals, it was shown that microbial communities of patients were enriched in Proteobacteria and Firmicutes, but reduced in the number of Actinobacteria and Bacteroidetes compared with control.

2.2.2 Daily excretion of urine and faeces

The amount of faeces and urine excreted by individuals varies considerably depending on water consumption, climate, diet and occupation. Even in comparatively homogeneous groups there may be a wide variation in the amount of excreta produced per person (Franceys et al., 1992). For example, Egbunwe (1980) reported a range of 500-900g of faeces per person per day in eastern Nigeria. A study in Southern Thailand also found that an average person excretes from 730 to 1530 g wet matter/cap/day with a dry matter content of 50 to 87 g dry matter/cap/day (Schouw et al., 2001). Generally, active adults eating a high-fibre diet and living in a rural area produce more faeces than children or elderly people living in urban areas eating a low-fibre diet (Louis et al., 2007). The amount of urine is greatly dependent on temperature and humidity, commonly ranging from 0.6 to 1.1 litres per person per day. In the absence of local information, Franceys et al. (1992) suggested the following figures as reasonable averages: An individual with high protein diet in a temperate climate will excrete faeces of 120g, and 1.2 litre/person/day of urine. On the other hand a vegetarian diet in a tropical climate will excrete faeces of 400g, and urine 1.0 litre/person/day.

2.3. The biofil toilets: technical aspects and public health significance

2.3.1. Introduction

A revolution is unfolding in vermiculture studies (rearing of earthworms) for total and sustainable waste management virtually creating wealth from filth or waste. The Greek philosopher Aristotle called them 'intestine of the earth', meaning they digest a wide variety of organic materials from earth (Sinha et al., 2009). Sinha also claimed that earthworms have over 600 million years of experience as waste and environmental managers of bio-waste, including human waste. In this sub topic the essence and development of the concept of vermiculture and biofil technology has been analysed to lay down the grounds from which biofil technology has its root.

2.3.2. Historical development of the biofil concept and current application

The science and 'art' of wastewater engineering stretches only slightly beyond one hundred years. Within this period, the applied technology has certainly made significant strides in promoting disease control and environmental protection (Alleman, 1982). In earlier times, sewage was collected and spread out over land as a fertilizer. However, water-logging became a major problem, and the continuous expansion of cities made it more difficult to find sufficient land nearby. The idea that there might be better ways of treating wastes with a significant reduction of disposable mass, using 'organisms', gradually begun to emerge (Cooper, 2001).

In the United States and the United Kingdom, organisms already found their way as applied water cleaners in the so-called biological filters: biofilms on rocks in the river bed. One of the earliest biological filters near Manchester in the UK stems from 1893. In the US the first filter was installed in 1901, in Madison, Wisconsin. Between 1895 and

1920 many were installed to treat sewage from towns and cities in the UK (Henze et al., 2008). Biofilm based treatment technology unquestionably plays an important role in this history, particularly since it represented the original biological mechanism. Beginning with options like the trickling filter, intermittent filter, contact bed systems, and subsequently to a more popular application of the suspended growth process, biofilm systems dominated the technology of wastewater treatment for several decades (Alleman, 1982).

The fertilizer value of human excreta however has been recognized in early days in ancient Greeks (300 BC to 500 AD) (Henze et al., 2008). During those times, used public latrines were being drained into sewers conveying the sewage and stormwater to collection basin outside the city and subsequently into agricultural fields for irrigation to fertilize crops and orchards. Along with the fertilizer value of sewage, the importance of specific organisms such as earthworms has also been recognized in those ancient days of Greeks and Egyptian civilizations, the concept of which combined with the biological based waste treatment gave rise to what is now known as vermicomposting and vermiculture technology

Vermicomposting, as an industrial process, was originally developed to remove unwanted organic materials from the agricultural and industrial waste streams. The derived product: earthworm castings, is now recognized as a high value material which, when blended with soil, can restore soil tilth by correcting the imbalances caused by the over-utilization of petro-chemical based fertilizers. Restoration of soil tilth will enable crops and plants to naturally combat pests and diseases, consequently resulting in an increased crop production and general plant health (OSC, 2012).

With the escalating socio-economic and environmental cost of dealing with current and future generation of mounting municipal and industrial wastewater, the use of waste eater earthworms what is now known as vermifiltration is a newly conceived novel technology with several advantages over the conventional systems. A research done on the role of earthworms body work as a biofilter asserted that, earthworms were able to remove BOD by over 90%, COD by 80-90%, TDS by 90-92% and TSS by 90-95% from wastewater by the general mechanism of ingestion and biodegradation of organic wastes and also by their absorption through body walls (Sinha et al., 2010). Suspended solids are trapped on top of the vermifilter and processed by earthworms and fed to the soil microbes immobilized in the vermifilter. Worms also remove chemicals including heavy metals and pathogens from wastewater (Bajsa, et al., 2003) and the treated water becomes conducive and nutritive for 'reuse' in irrigation of parks.

Though not much has been said about the concept of biofil systems, it seems that the concept stems from the use of composting that aims at maintaining optimal performance of modern biosolids composting and vermicomposting systems by blending with organic bulking agents such as; dry and fibrous materials such as sawdust, leaf moulds, finely chopped straw, peat moss, rice hulls or grass clippings. Basically the aim of such blending was to prevent odour, absorb urine, and eliminate any fly nuisance. On the other hand, the use of such bulking agents in collaboration with microbial and other live organisms such as bacteria, earthworms, fly larvae and etc. filled within a wastewater treatment unit to maximize system performances, might gave rise to the name biofil (filled or blended with biological organisms and bulking agents) and or Vermifiltration technology.

In Malaysia, BioFil technology is a proprietary system developed by the Waste Technology Centre, University Putra Malaysia (UPM). It is a simple and innovative Biofilter process which is capable of treating high strength organic effluent (exceeding 1000 mg/l to 150,000 mg/l of BOD) at a minimum operating cost. The technology also requires less space, use less power and is more environmentally friendly. It is a product of 8 years of research works carried out at UPM in particular related to treatment of the palm oil mill effluent (PMT, 2012). The Waste treatment technology uses specially designed proprietary plastic media called Cosmo-balls developed by UPM Waste Technology Centre which are used as filter media that provide a very large surface needed for microbial attachment in the BioFil tank of an effluent treatment system. Currently Pakar Management Technology (PMT), an integrated engineering and technology specialist company established in 1991 owns the marketing of the technology. PMT claims that, full scale and pilot studies confirm the suitability of BioFil technology to treat large variety of effluent such as paper mill, hospital wastewater, laboratory wastewater, poultry processing and palm oil mill and etc. with a proven good results in achieving compliance to Indonesian Standard 'A' effluent discharge limits. There are two versions (Aerobic and Anaerobic BioFil) developed to treat specific waste streams, enabling plants to be built to individual industrial requirement and to whatever capacity requirement to cope with the anticipated level of effluent.

2.3.4. Operational processes and parameters of the biofil toilet

According to Biofilcom (2012), the Biofil toilet system operates on the principle of aerobic decomposition (vermicomposting), as a 'living filter' where a habitat is created for natural organisms to break down the waste product. The key difference between the system and the traditional septic tank system is the rapid drainage of water from the waste stream so that the liquid undergoes infiltration into the underlying soil formation while the solid matter retained within the digester undergo aerobic composting. As there are no detailed studies on the operational parameters of a particular biofil toilet a good approach to establish process performance would be the review of studies on the application of vermicomposting techniques that has nearly similar operating principles of the biofil toilet.

Different varieties of earthworms; such as deep burrowing, shallow burrowing, and surface dwellers have been recommended by Bhawalkar (1995), Ismail (1997), and Tripathi & Bhardwaj (2004) in vermicomposting applications. The researchers have also established that surface dwellers and shallow burrowing earthworms are the most suitable species for vermicomposting. The potential utilization of epigeic worms (*Perionyx excavatus*), a shallow burrowing tropical Asian species, in organic waste degradation has been reported by various authors (Hallatt et al., 1990, Hallatt, 1992, and Ismail, 1997, Edwards et al., 1998). Aira et al. (2007) also asserted that microbial population and its activity; especially fungi are generally enhanced by earthworms during vermicomposting processes rendering enhanced biodegradation of organic matter.

Vermicompost worms need five basic things for their optimal performance:

1. A hospitable living environment usually called “bedding”; a material that provides the worms with a relatively stable habitat having the following characteristics: high absorbency to be able to absorb and retain water, good bulking potential, low protein and/or nitrogen content (high C:N ratio) to avoid excessive heating which may result in an inhospitable environment often fatal to the worm. Generally good bedding must provide protection from extremes in temperature and pH, the necessary levels and consistency of moisture, and an adequate supply of oxygen.

2. pH; Earthworms are very sensitive to either acidic or alkaline extremes, thus pH of soil or waste is sometimes a factor that limits the distribution, numbers and species of earthworms. Little information is available on effect of substrate pH during vermicomposting. Several researchers have stated that most species of earthworms prefer a pH near neutrality (Arrhenius, 1921, Allee et al., 1930 and Petrov, 1946). However, some species such as *Lumbricus terrestris* have been found to occur in soils with pH 5.4 in Ohio, U.S.A. (Olson, 1928). Satchell (1955) reported that *Bimastos eiseni*, *Dendrobaena octaedra* and *Dendrobaena rubida* were acid tolerant species, and *Allolobophora caliginosa*, *Allolobophora nocturna*, *Allolobophora longa* were acid intolerant. He also reported that *Lumbricus terrestris* was not very sensitive to pH. Edwards (1995) and Singh et al. (2005), reported a wide range of 5.0 to 9.0 for maximizing the productivity of earthworms in waste management. Bhawalkar (1995) however, has suggested for neutral substrate pH to be used in vermicomposting for optimal performance of the system in general.

3. A food source; Compost worms are voracious eaters. Under ideal conditions, they are able to consume in excess of their body weight each day, although the general rule-of-thumb is $\frac{1}{2}$ of their body weight per day. Though a wide variety of organic wastes can be used as sources of food for worms, partially decomposed organic materials such as manure are more rapidly consumed than fresh food (Gaddie & Douglas, 1975).

4. Adequate moisture (greater than 50% water content by weight). The ideal moisture-content range for vermicomposting or vermiculture processes is 70-90% (Munroe, 2007). Within this broad range however, researchers have found slightly different optimums: Dominguez and Edwards (1997) found 80-90% range to be best, with 85% optimum, while Nova Scotia researchers found that 75-80% moisture contents produced the best growth and reproductive response (GEORG, 2004). Both of these studies found that average worm weight increased with moisture content (among other variables), which suggests that vermiculture operations designed to produce live poultry feed or bait worms (where individual worm size matters) might want to keep moisture contents above 80%, while vermicomposting operations could operate in the less mucky 70-80% range.

5. Adequate aeration; Worms are oxygen breathers and cannot survive anaerobic conditions. They are also sensitive to toxic substances (e.g., ammonia) created by different sets of microbes that bloom under such oxygen deficient conditions. Although composting worms' oxygen requirements are essential, they are rather relatively modest (Munroe, 2007). Worms survive harsh winters inside windrows thriving on the oxygen available in the water trapped inside the windrow. Nevertheless, they operate best when

ventilation is good and the material they are living in is relatively porous and well aerated. In fact, they help themselves in this area by aerating their bedding by their movement through it.

6. Protection from temperature extremes. Controlling temperature to within the worms' tolerance is vital to vermicomposting processes. This does not mean, however, that heating or cooling systems are required. Compost worms can redistribute themselves within piles according to temperature gradients and can maintain optimum conditions. Some species of worms (e.g. *Eisenia*) can survive in temperatures as low as 0°C, even though they don't reproduce below 10 °C and they don't consume as much food. Temperature ranges of 20°C - 30°C are optimum ranges for most composting worms. Extreme temperature higher than 35°C is highly fatal to vermicomposting worms (GEORG, 2004 and Munroe, 2007).

In conclusion according to the technology developer K.A. Anno Engineering Limited, the parameters indicated so far applicable for vermicomposting operations are the working principles of the Ghana Biofil toilet. So far no studies done on the operating parameters and their likely effects for their particular application have been found that can help document specific operational conditions of the system.

2.3.5. Resource orientation and public health aspects

Vermicompost, like conventional compost, provides many benefits to agricultural soil, including increased ability to retain moisture, better nutrient-holding capacity, better soil structure, and higher levels of microbial activity (Munroe, 2007). Moreover, literatures claim that vermicompost has superior benefits over conventional aerobic compost.

Atiyeh et al. (2000) and Hammermeister et al. (2004) argued that the process of vermicomposting can promote plant-availability of most nutrients essential for plant growth (N, P, K, S, Mg and others) than does the conventional composting process.

It is also widely believed that vermicompost greatly exceeds conventional compost with respect to levels of beneficial microbial activity. Work by Dr Clive Edwards at Ohio State University (Subler et al., 1998) stated that, vermicompost may be as much as 1000 times as microbially active as conventional compost for a plant-growth medium. Atiyeh et al. (2002) further stated that, since the process of vermicomposting increases microbial diversity and activity dramatically, vermicompost can therefore be taken as a definitive source of plant growth regulators produced by interactions between microorganisms and earthworms.

There has also been considerable anecdotal evidence in recent years regarding the ability of vermicompost to protect plants against various diseases (Munroe, 2007). The theory behind this claim states that the high levels of beneficial microorganisms in vermicompost protect plants by out-competing pathogens for available resources (starving them, so to speak), while also blocking their access to plant roots by occupying all the available sites. Arancon and Edwards (2004) reported that vermicompost applications suppressed the incidence of plant disease significantly.

Modern agricultural farming practices depend upon the continual application of synthetic fertilizer to support crop production. However with the continued depletion of limited available mineral resources the sustainable supply of fertilizers is increasingly recognized to be an impending crisis. From these arguments, it is clearly evident that

vermicomposts can have substantial contribution in promoting agricultural productivity and conserve the depleting mineral resources.

Lack of sanitation is a serious health risk and an affront to human dignity. It affects billions of people around the world, particularly the poor and disadvantaged. Severe diarrhoea due to poor sanitation for example, kills 1.5 million children each year, where 90% are children under five, mostly in developing countries ([UNICEF/WHO/WSSCC, 2008](#)). [Gaggero \(2011\)](#) also stated that, in Africa 115 people die every hour from diseases linked to poor sanitation, poor hygiene and contaminated water. Access to basic sanitation is therefore a means to reduce disease, promote good health, increase family incomes and keep girls in school.

Improved access to sanitation can also bring substantial economic benefits. According to WHO, every \$1 invested in improved sanitation can deliver up to \$9 return in social and economic benefits, as a result of its contribution to increased productivity, reduction in healthcare costs, and preventing illness, disability, and early deaths ([Carlos, 2011](#)). In Sub-Saharan Africa, treating diarrhoea consumes 12 % of the health budget. On a typical day for example, more than half of hospital beds are occupied by patients suffering from diseases due to faecal contamination ([WSSCC, 2012](#)). Infectious agents however, are not the only health concerns associated with wastewater and excreta. Heavy metals, toxic organic and inorganic substances too can pose serious threats to human health and the environment if they are not managed properly. In the wake of disasters as much as in everyday life, public health interventions that secure adequate sanitation in communities can prevent the spread of disease and save lives. Successful application of the Biofil technology therefore could play a significant role in raising the general access of

through a combination of processes such as: pollutant retention by sieving, adsorption, straining, interception and sedimentation (WHO, 2004). Continuous application however causes a clogging mat to form at the infiltrative surface which slows down the movement of water into the soil. Fortunately, the clogging mat seldom seals the soil completely. Therefore, if a subsurface soil absorption system is to have a long life, the design must be based on the infiltration rate through the clogging mat that ultimately forms (Van Cuyk et al., 2000).

The mean hydraulic load of infiltration cannot exceed about $0.25 \text{ m}^3/\text{day}/\text{m}^2$ of sand-bed area for systems receiving primary effluents and $0.65 \text{ m}^3/\text{day}/\text{m}^2$ for those receiving secondary effluents (Blanca et al., 2009). The use of infiltration-percolation systems is therefore restricted to small works serving only a few thousand people, although they can be used to serve populations up to approximately 25,000 when treating secondary effluents. Larger plants would require too much filter surface and sand volume.

A key component impacting design and long term performance of onsite wastewater infiltration systems is the comprehensive site and soil evaluation phase (Powell et al., 2002). A thorough site and soil evaluation include soil conditions, slope, zoning restrictions, wetlands, and separation distances from structures, wells, and property lines, easements, and rights-of-way. According to Powell et al. (2002), sites characterized by low permeability soils, shallow soil over rock, high groundwater, poor drainage, or steep slopes are unsuitable for conventional soil absorption systems and may require more elaborate and expensive alternative methods for treatment of wastewater. If design considerations are not comprehensive, the system life is often substantially shortened and the total annual cost rises dramatically. Generally a thorough site evaluation must

locate the area to be used for the onsite wastewater system. It also helps to assess the suitability of an area and is used to determine the effluent loading rate for the required absorption field area.

2.5. Subsoil characteristics and contaminant removal mechanisms

2.5.1. Subsoil characteristics

The word 'soil' is the general term used by engineers to describe all 'Quaternary deposits', 'drift' and 'overburden'. However, it is useful to distinguish between the topsoil (the upper a meter deep or so affected by biological and weathering processes) and the underlying subsoil as the latter is of most relevance in attenuating contaminants from on-site wastewater systems (Gill et al., 2004). Sub-soils are the 'loose' unlithified sediments that are found between topsoil and bedrock which act as a protecting filter layer over groundwater. The effectiveness of this layer towards groundwater protection depends on soil type, permeability and thickness of the subsoil. In this regard, the extent of groundwater pollution from waste disposal facilities is therefore most importantly influenced by sub-soils features of the surrounding area.

According to the British Standard Code of Practice, BS5930; sub-soils are described primarily on the basis of their material characteristics (which give the subsoil name) such as particle size distribution (including texture), plasticity and dilatancy; and the mass characteristics such as density/compactness, bedding and discontinuities (Daly and Swartz, 1999). The material and mass characteristics are features of relevance to the permeability and attenuation capacity of subsoil and thus to groundwater or surface water vulnerability.

2.5.2. Background to Ghana subsoil

Most of the soils in Ghana are developed on thoroughly weathered parent materials. They are old and have been leached over a long period of time (Benneh et al., 1990); as a result they are low in organic matter content and inherent fertility. Their buffering capacity as well as cation exchange capacity is also low since their predominant clay mineral is kaolin (Gyapong and Asiamah, 2002).

According to the interim Ghana soil classification system, major groups of Ghana soil are classified in the order of *Climatophytic* earths and *Topohydric* earths (Gyapong and Asiamah, 2002). The order of *Climatophytic* earths represent well drained soils whose genesis is considered to have been predominantly influenced by climate and vegetation of the areas in which they occur. Its suborders are differentiated by the intensity of leaching as: *Hygropeds*: thoroughly leached soils, where percolating water reaches the water table without much accumulation of basic cations in the profile; and *Xeropeds*: not thoroughly leached, this suborder however is doubtfully represented in Ghana. The *Hygropeds* are common in the country. Two groups have been defined at the subgroup family level of *Hygropeds*. These are: *Latosols*: highly weathered soils with the clay fraction dominated by 1:1 clays (kaolinitic clays), iron and aluminium oxides and; *Basisols* representing soils with considerable amounts of weatherable minerals in parts of the soil profile. The weatherable minerals are rich in basic cations and the clay fraction contains appreciable amounts of 2:1 clays (montmorillonitic clays).

The morphological and physico-chemical characteristics of *Topohydric* earth soils are primarily influenced by the relief and drainage conditions. Five suborders are recognized under this order (Brammer, 1962): The *Planopeds*: poorly or imperfectly drained soils as

induced by flat topography e.g. peneplains and river terraces; the *Clinopeds*: soils occurring on slopes that are influenced by lateral seepage of water from upslope following a recharge-discharge phenomenon which consequently leads to the precipitation of chemical substances in the profile; the *Depressiopeds*: soils developed in depressions, and are poorly drained externally in parts of the year; the *Hydropeds*: soils developed in open water, for example shallow lagoons and permanent swamps and lakes and the *Cumulopeds*: these are soils developed in depressions where peat has accumulated.

According to the nature and reaction of the groundwater that influences the soil, the suborders of the Topohydric earths, except the Depressiopeds, are recognised as: very acid, acid, neutral, calcium and sodium group families. The Depressiopeds are grouped into Gleisols (very acid, acid and neutral) and Vleisols (calcium and sodium).

The major soil family groups in Ghana are the Oxysols, Ochrosols, Tropical Black and Grey earths, Groundwater laterites, and Sodium Vleisols (Brammer, 1962). Generally the soils of Ghana are composed of predominantly light textured surface horizons in which sandy loams and loams are common. Lower soil horizons have slightly heavier textures varying from coarse sandy loams to clays. Heavier textured soils occur in many valley bottoms and in parts of the Accra Plains. Many soils contain abundant coarse material either gravel and stone, or concretionary materials which affect their physical properties, particularly their water holding capacity (Ghana-EPA, 2005).

2.5.3. Key contaminants from onsite sanitation systems

2.5.3.1. Organics and suspended solids

Biodegradable organics in either dissolved or suspended form characterised by biochemical oxygen demand (BOD) or chemical oxygen demand (COD) which measure the amount of oxygen required for biochemical and chemical oxidation respectively are the main contaminant forms from onsite wastewater systems. Suspended solids, including organic and mineral matter are other forms of contaminants responsible for pressing oxygen demand of the waste stream and turbidity to the receiving water and or to the underground subsoil micro environment (Gill et al., 2004). The large specific surface of individual soil particles and subsoil organic matter provide high potential for biofilm development which is of great importance in the breakdown of organics in the percolating wastewater stream (Brady and Weil, 2002).

2.5.3.2. Inorganic constituents and nutrients

(i) Nitrogen

The two forms of nitrogen that are of concern to the pollution of groundwater and surface water (ammonium and nitrate) are contaminants of concern from onsite sanitation systems. Ammonium is toxic when present in high concentrations while nitrate presence in drinking water has been linked to methaemoglobinaemia (blue baby syndrome) in infants and it also promotes eutrophication in estuarine environments receiving such wastes (Harman et al., 1996). Ammonium ions can be discharged directly from domestic wastewater systems to the percolation trench or they can be formed by the mineralization process of organic nitrogen, contained in the wastewater itself, in the upper layers of the soil system (Fox et al., 2001).

(ii) Phosphorous

Phosphorous, considered as the limiting nutrient for algal growth in many aquatic ecosystems is one of the contaminants of concern in domestic wastewater systems. The main source of phosphorous is household detergents. Phosphorous is mainly present in onsite sanitation systems as orthophosphate, dehydrated orthophosphate and organic phosphorous (Siegrist et al., 2000). Bouma (1979) reported on studies that more than 85% of total phosphorous from onsite sanitation systems was in the soluble orthophosphate form.

2.5.3.3. Pathogens

Quite significant number of communities in Africa depend on wells and springs as their main source of water for drinking (WHO/UNICEF JMP, 2012). The survival of pathogens under unsaturated and saturated conditions is therefore a major concern in the protection of groundwater resources. Pathogens commonly found from onsite sanitation facilities include enteric bacteria, at sustained concentrations, and viruses and protozoa, at highly variable and episodically released levels (Cliver, 2000). The most important pathogenic bacteria and viruses that might be transported to groundwater include *Salmonella* sp., *Shigella* sp., *Escherichia coli* and *Vibrio* sp., and hepatitis virus, Norwalk virus, echovirus and coxsackievirus (Abu-Ashour et al., 1994). Viruses and protozoa are not continuously present at high densities, but rather are shed during disease events and thus are of concern for this study.

Although little has been written on their persistence in the subsoil or the threat they present to contamination of groundwater resources, protozoa and helminths are an issue of concern in relation to the use and treatment of surface water for human consumption.

They are however of lesser concern than bacteria and viruses since they are relatively large and therefore are removed more efficiently by subsoil filtration (Reneau et al., 1989). Certain protozoa such as; cryptosporidium and Giardia lamblia, most frequently reported to be found in surface drinking water sources, however, form protective “oocysts” which allow them to survive for long periods (generally several months) in damp cool situations (Gray, 1994).

2.5.4. Contaminant removal mechanisms in the subsoil

When a contaminant infiltrates into the underlying subsoil, different physicochemical reactions and processes can occur all the way through. Some of such processes include: physical straining, hydrolysis, oxidation–reduction reactions, biodegradation by microorganisms, adsorption, and volatilization of the contaminant to the air present in the unsaturated zone and etc. The relative importance of each of these processes however depends on the physical and chemical characteristics of the contaminant and on the specific conditions of the subsurface environment, the ultimate impact of which might potentially alter the groundwater characteristics (Gill et al., 2004).

2.5.4.1. Physical factors and processes

(i) Permeability

Even though it is not considered as a contaminant removal mechanism by its own, for effective treatment of wastewater by the subsoil to happen, permeability of the porous medium is critical. Permeability controls flow of the percolating effluent and thus contact-time between the contaminant and soil particles and associated biofilms. The ease with which liquid flows through a given medium; measured as hydraulic conductivity is dependent both upon the physical properties of the flowing liquid (such

as viscosity, density and specific weight) and the characteristics of the transmitting medium (i.e., permeability of the medium which in turn depends on its degree of saturation and subsoil geometry) (Domenico and Schwartz, 1998). When a soil is saturated, all of the pores are water-filled, pressure head is positive and conductivity is maximal. When the soil dries out however, some of the pores become air-filled and thus the conductive portion of the soil's cross-sectional area diminishes. These air-filled pores are assumed to act like solid particles inhibiting fluid flow (Hillel, 1998). As unsaturation develops, the first pores to empty are the largest ones, thus confining flow to the smaller less conductive pores. These large empty pores will then be circumvented by the percolating fluid, increasing flow path tortuosity, thereby increasing the overall residence time and keeping the contaminant in closer proximity to the solid phase. This phenomenon can enhance the removal of pathogens and chemicals from the percolating fluid (Gill et al., 2004).

Permeability depends on grain size, orientation of the particles, degree of sorting within the particles and preferential flow paths. Research has shown that permeability generally decreases for poorly sorted sediments and finer particles (Krumbein and Monk, 1942; and Beard and Weyl, 1973). Various studies proved that contaminants appeared faster at a given soil depth than would be predicted if the water flowed through the entire volume of soil due to the prominence of preferential flow paths (Williams et al., 2000). It should be noted, however, that not all large voids are preferential flow paths as some are hydrologically effective in channelling flow through the soil while other are not. Such channelling for instance increases the tortuosity of macro-pores thereby reducing the effect of preferential flow paths.

(ii) Filtration

Particle size distribution also plays an important role in the removal of suspended solids, including bacteria by acting as an effluent filter. There are three filtration mechanisms (McDowell-Boyer et al., 1986): *Surface Filtration* – occurs at soil surface when particles are too large to penetrate the soil resulting in biomat formation; *Straining* – particles small enough to enter the soil pores are removed by mechanical straining as the effluent percolates through the subsoil, and *Physico-Chemical Filtration* - this occurs when very small particles, i.e. where the ratio of soil grain diameter to that of the particulate is greater than twenty, are retained if the attractive forces predominate when the particles collide with the soil.

2.5.4.2. Chemical factors and processes

(i) Adsorption

Adsorption is a factor in the removal of phosphates, ammonium, organic compounds, bacteria and viruses from wastewater streams infiltrating in to subsoil. It is an important phenomenon in soils that contain clay as the very small size of clay particles, their generally platy shapes and the occurrence of large surface area per given volume make them ideal adsorption sites (Gill et al., 2004).

Adsorption is a physical and/or chemical process in which a substance accumulates at a solid-liquid interface (Mihelcic, 1999). It results from the differential forces of attraction or repulsion occurring among molecules or ions of different phases at their exposed surfaces. During the process of adsorption a chemical species passes from one bulk phase to the surface of another where it accumulates without penetrating the structure of this second phase (Hillel, 1998).

Chemical adsorption (*chemisorption*), involves valence forces of the type which bind atoms to form chemical compounds of definite shapes and energies (Burchill et al., 1981). It tends to occur at specific adsorption sites, and does not proceed past the monolayer stage, i.e. all of the adsorbed molecules are in contact with the surface layer of the adsorbent. Physical adsorption on the other hand is a rapid, non-activated process which occurs at all interfaces (Gill et al., 2004).

(ii) Precipitation

Precipitation is the separation of an insoluble product when two solutions are mixed together. It occurs in soils for example when the soluble orthophosphate ions (PO_4^{3-}) present in percolating wastewater, or sorbed onto soil colloids, react with ions in the soil solution. The nature of the product and the efficiency of this precipitation process, described as phosphate fixation, depends on the cations present and the pH of the soil (Gill et al., 2004). In strongly acidic soils there are sufficient aluminium, iron and manganese ions in solution to cause the precipitation of all dissolved phosphate ions. Zanini et al. (1998) reported that constant nitrification also generates acidity which can increase the number of cations present.

2.5.4.3. *Biological factors and processes*

As wastewater flows through sub-soils both aerobic and anaerobic biological transformations such as organic matter decomposition, nitrification and denitrification can occur.

(i) Microbial decomposition of organic matter

Microbial decomposition of organic matter proceeds most rapidly in the aerobic zones where microorganisms in the subsoil use the oxygen present as an electron acceptor

during the decomposition of the substrate (McCarty et al., 1984). Inside the localized anaerobic zones within the subsoil treatment system, anaerobic or facultative organisms, such as methanogenic bacteria, become dominant (Henze et al., 2008).

Since anaerobic decomposition is a slower process, pockets of partially decomposed organic matter such as organic acids, alcohols and methane gas can often accumulate in the subsoil (Brady and Weil, 2002). Some of these by-products may have a detrimental effect on the subsoil “micro-environment” by inhibiting flora and fauna growth.

(ii) Mineralization, nitrification and denitrification

The nitrogen content of faecal sludge and domestic wastewater with minor contribution from industrial wastewater on an average is about 60-75% ammonium and 25 to 40% organic nitrogen (Eawag/Sandec, 2008, Henze et al., 2008). Organic nitrogen contains amine groups which are broken down by soil micro-organisms, a process called mineralization, into simple amino compounds which are then hydrolysed releasing nitrogen in the form of ammonium (NH_4^+). The reduction in ammonium concentration in the wastewater as it percolates through the unsaturated subsoil is accompanied by an increase in nitrate (NO_3^-) concentration brought about by the process of nitrification (Brady and Weil, 2002). Nitrification can be limited by low temperatures, insufficient oxygen or by lack of alkalinity (Henze et al., 2008).

As the wastewater infiltrates down, the nitrified effluent enters into an anaerobic pocket, or zone of reduced oxygen concentration. In the presence of appropriate bacteria and a supply of readily available carbon source in the form of organic substrate, it further undergoes denitrification which reduces the nitrate to gaseous nitrogen (NO , N_2O or N_2)

(Brady and Weil, 2002). Under anaerobic conditions, where nitrification is inhibited, prolonged adsorption of $\text{NH}_4\text{-N}$ appears most effective. Canter and Knox (1985) reported that under anaerobic conditions normally prevailing directly below the percolation trench, ammonium ions are readily adsorbed onto negatively charged soil particles where it temporarily gets immobilized. Several studies demonstrated that approximately 50 to 85% of fixed $\text{NH}_4\text{-N}$ may be unavailable or only slowly available to nitrifying micro-organisms (Nommik and Vahtras, 1982). Jenssen and Siegrist (1988) also claimed that $\text{NH}_4\text{-N}$ ions are adsorbed by organic colloids in the soil. After the adsorption capacity of the first few inches of soil is exhausted, the ions in the percolating wastewater will travel further to find unoccupied sites if anaerobic conditions persist.

Phosphorous removal in the subsurface is controlled by soil adsorption and mineral precipitation reactions which can be considered in two general categories: initial adsorption reactions and much slower precipitation reactions that regenerate additional adsorptive surfaces occurring both from phosphate in solution and from phosphate previously sorbed (Lance, 1984). The types of reaction that fix phosphorous in relatively immobilized forms differ from soil to soil and are closely related to soil pH. In acid soils these reactions involve mostly Al, Fe or Mn, either as dissolved ions, as oxides, or as hydrous oxides. In alkaline and calcareous soils, the reactions primarily involve precipitation as various calcium phosphate minerals or adsorption to the iron impurities on the surfaces of carbonates and clays (Brady and Weil, 2002).

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Study site description

The research was undertaken on the existing biofil toilet installations in Kumasi city where about 15 private houses currently use the technology. Installed capacity of these individual biofil toilets are designed to serve 10 people for a full-flush system and 20 people for a micro-flush system.

Biofil effluent samples were collected from selected households of the existing installations. Soil columns were installed and operated under laboratory conditions at the Environmental Quality lab of the college of Engineering, KNUST, simulating the natural soil formation of the existing installations. A multi-layer sand filter was also set up.

3.2. Soil characterization

Four different soil types were manually collected from different areas at about 20 to 30 cm below ground surface. Red lateritic soil was taken from Maxima installation, loamy soil at KNUST College of Agriculture research farm site located around Kumasi Soil Research Institute, clay soil was purchased from KNUST art school and sand soil was acquired from soils laboratory of the college of Engineering. The various soil types used in the development of soil columns were scientifically classified with their respective particle size ranges using hydrometric and sieve analysis. The results were then interpreted based on soil classification chart and procedures as recommended by ASTM (1981). Finally the four different soil types fall into three classes of soils as: clay loamy soil, sandy soil, and silty loam soils. See Table 3.1 for further details. See also charts used for the classification purpose (Appendix-III).

Table 3.1 Particle size, bulk density and pH characteristics of column soils

Column Soil types	Constituent Particle size percentages				Soil Class	Bulk density - as filled* (kg/m ³)	pH
	Clay <0.002mm	Silt, 0.002 - 0.06mm	Sand, 0.06-2mm	Aggregate, >2mm			
RLS [†]	38.20	21.50	40.30	0	Clay Loamy	1,367.94 (wet) [‡]	5.55
Sandy Soil	0	0	99.71	0.29	Sandy Soil	1,592.43 (wet)	5.66
Clay Soil	23.5	65.68	10.82	0	Silty Loam	1,272.82 (dry)	4.07
Loamy Soil	10.5	78.75	10.75	0	Silty Loam	1,336.38 (wet)	6.02

The column soils were then dried and crushed into convenient uniform size (Plate 3.1). For the red lateritic soil, undisturbed soil bulk density of 1,874.39 kg/m³ was measured. However, for the rest of column filling soils including the red lateritic soil, as filled bulk density was considered on a wet basis. Wet basis was chosen because water was used during column filling for the purpose of avoiding air entrainment that might affect permeability of the finished columns. Results show that sandy soil had the heavier bulk density of 1,592.43kg/m³ followed by red lateritic soil (1,367.93kg/m³), and Loamy soil 1,336.38kg/m³. Clay soil column was filled dry with a bulk density of 1,272.82kg/m³, as saturating from the beginning might result in complete clogging of soil pores considering that clay is impermeable soil.

The pH of clay soil was 4.07, 5.55 for red lateritic soil, 5.66 for sandy soil and 6.02 for loamy soil (see also Table 4.1).

A constant head permeability test was performed for the various soils to determine permeability coefficients. Results showed that clay soil has the lowest permeability

* The dimension and weight of empty columns were taken first and after filling them with the respective soils, the finished columns were weighed again and finally as filled bulk density computed.

[†] RLS- Red Lateritic Soil

[‡] Undisturbed bulk density for this soil was 1,874.39 kg/m³

3.4. Soil column description and experimental setup

PVC tubes of 110mm internal diameter and 180cm long were used for soil column set up as presented in the general schematic diagram (Figure 3.1). Each of the PVC pipes were sealed at the bottom to make it watertight and it was then drilled at 60cm, 110cm and 177.5cm from top to bottom to be used as sampling ports. The first 30cm from top of each pipe was allowed as a freeboard to permit constant feeding regime to the column; the next 30 cm from the freeboard (60cm from top) was taken as the uppermost sampling port. About 50cm below this sampling port was the middle sampling port which represents 80cm soil depth and the last sampling port located at the bottom had a total of 1.5m soil depth which is 177.5cm including the free board. UNEP suggested a depth of 2m as an optimal clearance to the groundwater table for soil aquifer treatment studies (UNEP, 2002). However for this particular study to be on the conservative side, a depth of 1.5m is specified as the clearance between a typical toilet installation and groundwater table. At the bottom of each soil column 2.5 cm pea gravel was used as a bedding of soil columns to prevent soil incrustation and further wash away of finer particles.

A separate multilayer sand filter adopted from Baig et al. (2011) was also installed to compare with the soil columns for the purpose of developing a more compact filtration system. The multilayer sand filter was composed of a bottom 5cm gravel of 15mm diameter and another 5cm gravel of 6mm diameter followed by a 45cm washed filter sand. The sand filter is composed of sand media with an effective size range of 0.25-0.65 mm; uniformity coefficient 3-4, as described by Cagle and Johnson (1994). On top

according to the [GSS \(2008\)](#) report, considering an average of 4 persons in a family; about 128 litres of flush water daily in a family drained off from full flush biofil toilets that needs further treatment and handling. According to the design guidelines for onsite sanitation ([US EPA, 1980](#)); the recommended hydraulic loading rate for intermittent sand filtration ranges from 0.3 to 0.6 m³/m²/day depending on the effective size of the filter sand and type of wastewater applied. For subsurface infiltration systems, with soil type ranging from fine sand to loamy and very fine sand, a wastewater BOD of ≥ 150 mg/l, a hydraulic loading rate of 0.105m³/m²/day is recommended ([US EPA, 2002](#)).

Biofil effluent was collected every morning between 6.00am and 7.00am based on the peak toilet utilization time for two consecutive months (see plate 3.3 for sampling arrangement). Two months was selected on the basis of biomat formation as suggested by researchers, [John et al. \(1989\)](#) and [Essandoh et al. \(2011\)](#). Both researchers recommend a minimum 50 days to 100 days for a biomat to fully mature and achieve better contaminant removal capacities.

Fresh toilet effluent (blackwater) into and out of the biofil digester was first thoroughly characterized to see the strength of toilet effluents and the performance of the biofil digester (Table 3-2). Samples from the two selected installations in Kumasi were considered for this initial characterization.

For the leachate from soil columns a three round sampling season was used ranging from the first two weeks of experimental run to fifth and eighth weeks run. The first sampling time two weeks was chosen based on optimal initiation of biofilm as suggested by [Jantrainia and Gross \(2006\)](#) which suggested 14 to 21 days for biomat formation to

begin. On the other hand the fifth and eighth weeks of sampling was employed to see the removal efficiency as a function of time.

Table 3.2 Summary of sampling and analytical schedules

R. No	Parameters	Raw flush Toilet eff.	Biofil effluent	Column Effluent				
				MLSF	Red Lateritic soil	Sandy Soil	Loamy Soil	Clay Soil
1	NH ₃ -N	2*3	2*3	--	--	--	--	--
2	NO ₃ -N	2*3	2*3	3*3	3*3	3*3	3*3	3*3
3	NO ₂ -N	2*3	2*3	--	--	--	--	--
4	TKN	2*3	2*3	--	--	--	--	--
5	PO ₄ ³⁻	2*3	2*3	3*3	3*3	3*3	3*3	3*3
6	Total-P	2*3	2*3	--	--	--	--	--
7	Helminth Egg	2*3	2*3	3*3	3*3	3*3	3*3	3*3
8	Total Coliform	2*3	2*3	3*3	3*3	3*3	3*3	3*3
9	Faecal Coliform	2*3	2*3	3*3	3*3	3*3	3*3	3*3
10	COD	2*3	2*3	3*3	3*3	3*3	3*3	3*3
11	BOD ₅	2*3	2*3	3*3	3*3	3*3	3*3	3*3
12	Temp	2*3	2*3	3*3	3*3	3*3	3*3	3*3
13	TDS	2*3	2*3	3*3	3*3	3*3	3*3	3*3
14	Conductivity	2*3	2*3	3*3	3*3	3*3	3*3	3*3
15	pH	2*3	2*3	3*3	3*3	3*3	3*3	3*3
16	TSS	2*3	2*3	3*3	3*3	3*3	3*3	3*3
Total		96	96	108	108	108	108	108
Total number of samples and analysis performed						732		

*NB: 2*3 refers two sampling times and triplicate analysis considered and 3*3 refers three sampling times in triplicate analysis.*

Blackwater was sampled two times from the selected installation during the 5th and 8th week of experimental run to determine the strength using a range of parameters listed in table 3.2. The outgoing biofil digester effluent then collected for two months was also characterized using similar parameters before being fed into the columns. Characterization of the biofil effluent was envisioned for two purposes. The first was to determine the contaminant removal performance of the biofil digester and secondly to establish the load applied to the receiving soil column which serves as basis for evaluating the performance of the subsoil. Once a known wastewater fed into the

Table 3.3 Summary of materials, reagents and analytical methods

S.N	Parameters	Methods/ Equipments	Chemical reagents
A) Physical parameters			
1	Temp, pH, TDS, Conductivity	Hand held digital Temp/Cond/TDS/pH meter	N/A
2	TSS	Gravimetric	N/A
B) Chemical parameters			
3	NH ₃ -N, NO ₃ ⁻ -N, NO ₂ -N, TKN	Spectrophotometric (DR/2400 Spectrophotometer)	Ammonia Cyanurate Powder Pillow, NitraVer 5 Nitrate Reagent Pillow
4	PO ₄ ³⁻ , TP	Spectrophotometric (DR/2400 Spectrophotometer)	PhosVer 3 Phosphate Powder Pillow
C. Biological parameters			
6	BOD ₅ , COD	Winkeler's titration method and open reflux method respectively	K ₂ Cr ₂ O ₇ , H ₂ SO ₄ , AgSO ₄ , FeCl ₂ , KOH, HgSO ₄ , Sulfamic acid, KHP etc. ...
7	Total Coliform and E-coli	Multiple Tube Fermentation technique	Lauryl sulfate tryptose lactose broth
8	Helminth egg	Microscopic examination and counting	Aceto-acetic buffer, Ether or ethyl acetate, Saturated zinc sulfate solution, etc....

3.7. Data quality assurance

For reliability purposes, analyses were performed in triplicate and an average of the results computed. Besides this, standard analytical procedures according to the procedures described by Standard methods for the Examination of water and wastewater analysis (Clesceri et al., 1998) were followed. For quality assurance purpose, sampling bottles were washed thoroughly with clean tap water, rinsed with non-ionized water and finally exposed to UV sterilization prior to usage for next sampling. Statistical package for social scientists version 16 (SPSS-16) was used to make scientifically sound judgments for analysis.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In this chapter the findings of the study are presented with sufficient discussion and/comparison with works from similar studies. It is presented in two main sub sections. The first section presents analytical results for the raw blackwater characteristics and established the performance of the biofil toilet in removing main contaminants as it passes through the biofil digester. The second section presents the findings from the column analysis. The performance of the different soil types is established from the perspectives of physico-chemical parameters, biodegradable organics, pathogen removal and nutrient removal behaviours.

4.1. Effluent characteristics and performance of the biofil toilet

4.1.1. Black water characteristics

An acidic or alkaline wastewater can damage the wastewater collection and treatment facilities (especially those of concrete and metallic structures) as well as affects/influences biological treatment processes. In the same manner extremes of temperature may have favourable or unfavourable aspects. Other wastewater parameters such as BOD, COD etc. too can indicate the strength of the waste and possible wastewater treatment phenomenon/scheme. This sub-section presents the analytical results of the black water in light of physicochemical, biological, microbiological and nutrient characteristics.

According to the results obtained, the average pH value measured for the fresh toilet effluent (raw blackwater) was 8.48. Average temperature of 29.25°C, conductivity and TDS of 4,240 $\mu\text{S}/\text{cm}$ and 2,120 mg/l respectively were measured for the raw blackwater.

In order to see the load to the biofil digester various physicochemical and biological parameters were also measured from the raw blackwater and the biofil effluent. Table 4.1 below, shows characteristics of fresh toilet effluent (raw blackwater) and filtered wastewater from the biofil digester (biofil effluent that was used as the experimental column feed). A maximum concentration as high as 8,000 mg/l of COD, 1,590 mg/l of BOD₅, a COD/BOD ratio of 4:1, 492.93 mg/l of total nitrogen and 86.02 total phosphate were measured from the raw blackwater. An average of 1.3E+09 cfu/100ml faecal coliform and 3.15E +09 cfu/100ml total coliform was also measured.

Table 4.1. Characteristics of fresh full flush blackwater and biofil effluent

Wastewater characterization parameters	Wastewater concentration		Percentage removal
	Raw blackwater	Biofil effluent	
Temperature (°C)	29.25	29.50	-
pH	8.48	8.88	-
Cond (µS/cm)	4,240.00	3,225.00	24%
TDS (mg/l)	2,120.00	1,615.00	24%
TSS (mg/L)	3,740.00	584.58	84%
BOD ₅ (mg/L)	1,245.00	382.50	69%
COD (mg/L)	5,160.00	988.00	81%
COD/BOD	4:1	3:1	31%
Faecal Coliform	1.3E+09	8.50E+07	93%
Total Coliform	3.15E+09	1.66E+08	95%
NH ₄ -N (mg/L)	34.78	54.91	-58%
NO ₃ -N (mg/L)	1.25	0.26	79%
NO ₂ -N (mg/L)	0.03	0.01	67%
Total-N (mg/L)	492.93	371.46	25%
PO ₄ -P (mg/L)	69.29	47.71	31%
Total-P (mg/L)	86.02	56.30	35%

Even though literature on the characteristics of fresh black water hardly exist in Ghana and in Africa in general, different researches done round the world however showed quite variable qualities. A study done in the Netherlands for example showed a COD value of 9,500 to 12,300 mg/l (Kujawa-Roeleveld et al., 2006). Another study on a blackwater from vacuum toilets in *Flintenbreite*-Lübeck, Germany reported an average COD of 8,060 mg/l, TSS 6,530 mg/l, total nitrogen as high as 1,495 mg/l, and total phosphate 175 mg/l (Wendland, 2008). A study by Coquin (2005) in Sweden, also documented a COD value of 1,900 mg/l, BOD 740 mg/l, TSS 2,100 mg/l, total nitrogen 170 mg/l and total phosphorous of 22 mg/l. Indeed various researchers argued that the composition of blackwater varies from society to society and from country to country depending on the type of diet and prevailing environmental conditions (Louis et al., 2007; Belen, 2010). According to studies by Mara (1978) and Strauss et al. (1997) (Table 4.2), however the average concentrations of the raw blackwater characteristics in this particular study was found to be higher than a domestic wastewater considered to be strong for tropical countries and considerably lower than latrine sludge and septage faecal sludge. Release of high strength wastewater related to organic matter would result in clogging of drain fields. On the other hand, strength of wastewater due to physical and chemical components can interfere with the biological treatment process and hence may affect the overall treatment in particular and the receiving environment in general.

Table 4.2 Characteristics of faecal sludge and sewage from tropical countries [§]

	Faecal Sludge		Sewage
	High strength	Low strength	
Source	Public toilets or bucket latrine sludge	Septage	Tropical countries
Characterization	Highly concentrated, mostly fresh; stored for days or weeks only	Low concentration, usually stored for several years; more stabilized	
COD (mg/l)	20,000 - 50,000	< 15,000	500 -2,500
COD/BOD*	5:1 - 10:1	5:1 - 10:1	2:1
NH ₃ -N (mg/l)	2,000 - 5,000	< 1,000	30 -70
Total Solids (%)	≥ 3.5	< 3	< 1
Suspended solids (mg/l)	≥ 30,000	≈ 7,000	200 - 700
Helminth eggs (no/l)	20,000 - 60,000	≈ 4,000	300 - 2,000

Source: www.ruaf.org/sites/default/files/Chap6-Sanitation.pdf. Mara (1978) and Strauss et al. (1997)

The ratio of COD/BOD is a useful tool to decide treatment system and environmental monitoring strategies of receiving environment (Samudro1 and Mangkoedihardjo, 2010). In connection with the actual concentration of BOD and COD, the COD/BOD ratio can be used to evaluate the biodegradability characteristics of a particular wastewater, acceptability criteria for disposal into the environment and toxicity to microbial consortium responsible for biodegradation in biological treatment works (Quano et al., 1978; Asia and Akporhonor, 2007). It is one of the basic design and operational criteria that must be considered.

From the present study, the COD/BOD ratio of 4:1 dictates that the blackwater is biodegradable but largely composed of slowly biodegradable and/or resistant organic contaminants (Quano et al., 1978)). Different researches agreed that COD/BOD ratios

[§] **NB:** The table is based on FS studies in Argentina, Ghana, Philippines and Thailand. The characteristics of typical municipal wastewater in tropical countries are also included for comparison purposes.

not have sufficient retention time within the bio-digester especially for dissolved substances to interact with the adsorbent surface, not so much removal is expected from the system. In the same manner its nutrient removal potential would be limited. As can be seen from Figure 4.2, ammonia nitrogen was rather increased. It is true that due to microbial action on the degradation of organic nitrogen, formation of ammonia through nitrification increases for some time with the net removal in total nitrogen. On the other hand as the contact time of the wastewater stream in the biofil unit is so short, the likelihood of ammonia to be adsorbed to the system is very low or negligible. [Sato et al. \(2010\)](#) also agreed with this argument. He argued that the concentration of ammonia nitrogen increased with an increase in the flow rate of wastewater into the multi-soil-layering system due to the decreased contact time of the wastewater as it passes through the underlying packing material. Moreover as the wastewater passes through the biofil digester, organic nitrogen undergoes rapid ammonification reaction and hence a rise in ammonia nitrogen can be observed. Various researchers also agree with this observation that under aerobic conditions heterotrophic bacteria convert organic nitrogen into $\text{NH}_4\text{-N}$ ([Cheremisinoff, 1996](#), [Sawyer et al., 2003](#); [WEF, 2005](#) and [Henze et al., 2008](#)).

The removal of $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$ was relatively better (79.2% and 66.7% respectively). This good achievement could be attributed to the high performance attained on TSS removal (88%) whereby nitrite and nitrate might be embodied within the retained solid matter. Probably these forms of nitrogen might have been adsorbed onto the TSS and remained within the digester in a form of ion exchange process that might have occurred in the system. Studies also argued that nitrates can be removed from solution phase through adsorptive ion exchange in the presence of strong anionic

As much of the contaminants in faecal wastewater are attached to the solid content of the blackwater, the TSS removal achieved can potentially reduce the load to the receiving subsoil. Generally the contaminant removal performance of the biofil system is better as compared to performance of conventional settling tanks (Heinss and Larmie, 1998). From a four years performance monitoring study at Achimota Faecal Sludge treatment plant, Heinss and Larmie observed that the sedimentation tank achieved 45% SS removal, 55% removal of COD and 25% BOD removal. The biofil system, with just an instant rapid filtration process, performs better as opposed to the several hours of retention in sedimentation tanks.

Observation of the COD/BOD ratio of the biofil effluent dictates that, much of the degradation resistant (slowly biodegradable) components of the COD were retained within the digester along with the solid matter and hence the leftover organic matter (COD and BOD) is on the higher zone of biodegradation (COD/BOD ratio of $< 2:1$) (Samudro1 & Mangkoedihardjo, 2010). This means that under natural conditions the receiving environment can successfully take care of the effluent without causing toxicity to microorganisms or environmental upset.

4.2. Performance of experimental columns

In order to establish the removal efficiency of the different subsoil for the various pollutants, a strategic sampling was done at three sampling ports of each of the five soil columns for two months at three weeks intervals. Analyses of influent fed into the column and effluents of the columns have been done for physico chemical parameters vis-à-vis; temperature, pH, conductivity, TDS and TSS; biodegradable organic matter (COD and BOD); nutrients (nitrogen and phosphorous) and microbiological quality

Wastewater with very low or very high pH (below 6 or above 9) is not desirable as it interferes with the biological reactions that could act upon it. As a result, pH adjustment might be necessary before discharge for the receiving system to function well (Metcalf and Eddy, 2003). Moreover pH adjustments might be expensive due to the need for chemical additives and additional processes and manpower. Soil columns in this experiment have shown a tendency of reducing the pH of the applied wastewater, even though its reduction is not so high. As presented on the soil characterization results and literature reviewed on major soil characteristics of Ghana, most of the soils used in this experiment are relatively acidic (pH 4.07 to 6.02).

Literature indicated that most plants like soil pH close to neutral or just a little on the acid side. As very high or very low pH can be toxic to the plants, the use of wastewater in such types of soils has been used to ameliorate soil acidity (Angus, 2001). Sandy soil and MLSF show a relatively narrower influence on the pH of the incoming wastewater compared to loamy soil and red lateritic soil. According to McCauley et al. (2009), soils with high amounts of clay and/or organic matter will typically have higher cation exchange capacity (CEC) and buffering capacities than more silty or sandy soils.

Conductivity and total dissolved solids levels also do not show appreciable variations during the various weeks of experimental run. A minimum average conductivity and TDS measured were 417 $\mu\text{S}/\text{cm}$ and 209 mg/l respectively at 1.5m depth of red lateritic soil during the first 2 weeks run of the experiment. The maximum average observed was from influent wastewater fed into the filter columns, conductivity of 2,870 $\mu\text{S}/\text{cm}$ and TDS of 1,437 ppm both observed at the 8th week of experimental run. Details are presented in Figures 4.4 and 4.5.

As can be seen from the plot, loamy soil shows greater variability along the experimental durations particularly at 0.8m and 1.5 m depths. This variation at these specific depths could be due to the incremental infiltration and leaching of contaminants at lower depths specifically for the first two weeks experimental run. Moreover, the missed data at the 1.5 m depth during the 5th week experimental run would also contribute for its variation. On the other hand sandy soil and red lateritic soil show approximately uniform performances particularly the red lateritic soil. Boxplots for COD, TSS, Conductivity, TDS, Faecal coliform and Total coliform removal as a function of weeks of experimental run are presented in Appendix III, showing approximately similar variability with the plot observed for BOD.

Figures 4-9 to 4-10 show the percentage removal profiles of TSS, BOD and COD of various soil columns at the 0.3m, 0.8m and 1.5m infiltration depths throughout the two months experimental duration. As is evident from figure 4-9, all the soil columns perform comparatively the highest removal capabilities at the 0.3m depths. The rest of infiltration depths could otherwise play just a polishing role. [Amador et al. \(2008\)](#) studied the effect of sand depth on contaminant removal capacities. They conclude that wastewater renovation in intermittently aerated leach-field mesocosms appears to take place in a narrow zone ($\leq 7.5\text{cm}$) below the infiltrative surface with the medium below contributing little to renovation.

The sharp fall in contaminant removal observed across depths especially for BOD removal of loamy soil column during the first two weeks and 5th week experimental run and COD removal of the sandy soil during 5th and 8th week run (Figure 4-9) could probably be an error due to limited number of analysis performed.

In all the soil columns relatively limited contaminant removal performance has been observed for the first two weeks. This may be attributed to the acclimatization period required for the columns to develop an active biomass that will help remove BOD and COD from the system. Soil microorganisms adjust themselves when they encounter or are exposed to a new environment. According to John et al. (1989) a minimum of 50 days to over 100 days may be required at 10°C - 30°C for soil microorganisms to adapt and degrade organic matter optimally. Essandoh et al. (2011) also suggested three months for acclimation of bacteria in the soil to occur and a steady state conditions to be established. Even though the formation of biomat is believed to begin immediately, researchers argue that three to eight years are required for it to form completely (<http://ehs.ncpublichealth.com/oet/docs/cit/oswpmmod/Chapter4-Section1.pdf>).

A Multivariate statistical analysis (Appendix-II-1 to II-3) showed that there are significant performance differences across the various soil columns in terms of TSS and BOD removal; loamy soil vs sandy soil ($\alpha=0.021$), loamy soil vs red lateritic soil ($\alpha=0.001$), red lateritic soil vs multilayer sand filter (MLSF) ($\alpha=0.044$). From this analysis it follows that red lateritic soil performed extremely better than loamy soil and an MLSF column with respect to BOD and TSS removal ($\alpha=0.001$ and 0.044 for BOD and $\alpha=0.000$ and 0.032 for TSS respectively, which is < 0.05). On the other hand loamy soil and MLSF perform the same ($\alpha=0.843 > 0.05$) meaning that both performed poorly compared to the better performance achieved by Red lateritic soil which in practice was 97.5% BOD and 98% TSS at 0.3m depth, 98.8% BOD and 98% TSS at 0.8m depth and 99% BOD and 99% TSS at 1.5m depth during the 8th week of experimental run while loamy soil and MLSF performed from 80-86% in the same duration.

As stated by Ireland EPA (2009); filtration, micro-straining, and aerobic biological decomposition processes in the biomat and infiltration zone remove more than 90% of BOD and suspended solids (SS) and 99% of the bacteria. Similar results were also found by the Colorado School of Mines in 2005. These findings are supported by Irish EPA funded research projects (Gill, 2005).

Statistical tests had also been employed to confirm whether experimental durations had significant influences on the contaminant removal ability of the system as presented by a multivariate analysis annexed at Appendix II-1-3. The test confirmed that the first two weeks of experimental run had demonstrated lower rates of contaminant removals as compared to the fifth and eighth weeks run, meanwhile there was no significant difference observed between the fifth and eighth weeks of experimental run. These confirmatory tests agreed with justifications presented by various researchers that argue a minimum of 50 to 100 days to be required for the development of biomat and for soil microorganisms to optimally degrade organic matter (John et al., 1989, Essandoh et al., 2011, and <http://ehs.ncpublichealth.com/oet/docs/cit/oswpmmod/Chapter4-Section1.pdf>).

Generally red lateritic soil exhibited an exceptionally superior potential in terms of TSS, BOD and COD removals. Moreover, the eighth week experimental run was the time for which better performance of the system has been achieved.

4.2.3. Pathogens

Bacteria, virus, protozoa and helminthic parasites are major groups of pathogens that are frequently associated with an access of human excreta into fresh water resources for drinking and/or agricultural. Water sources in direct or indirect contact to such

contaminant therefore require treatment before drinking or such uses of direct public health importance, and thus needs continuous monitoring of their existence and their load. Microorganisms are adsorbed, strained out, or die because of competition with other soil microorganisms as they pass through soil columns. In this study the levels of indicator bacteria in terms of total and faecal coliform, and helminths of public health importance have been analysed and the potential of subsurface contaminant attenuation has been presented below.

4.2.3.1. Faecal and total coliforms

The highest coliform level measured was 1.63×10^8 and 8.47×10^7 cfu/100ml of Total and Faecal coliform respectively for the influent fed into the columns and the lowest level observed was at the 1.5 m depth of the red lateritic soil; 1,600 and 820 cfu/100ml of total and faecal coliform (Figure 4.11 and Table 4.7 in Appendix-I).

Sufficient samples were not obtained at certain sampling ports of the various soil columns due to pore clogging. These were; loamy soil column at 1.5m depth during the 5th week experimental run; sandy soil at 0.8m depth during the first two weeks and last 8 weeks run and red lateritic soil at 0.3m depth during the first two weeks experimental run. Because of this results for total and faecal coliform are not presented.

Observation on the durations of experimental run for faecal coliforms appears to have variations (Figures 4.12 and 4.13), however it was not statistically significant ($\alpha=0.151>>0.05$). The difference therefore may be due to chance or error or there is real difference but at lower level of confidence at 90% or less. In a similar manner one way ANOVA test for soil depth does not appear to have statistically significant impact on pathogen reduction for this particular experiment. The main reason for this result might be due to the continuous application of wastewater onto the soil columns for the duration of the experiment. The fact that there is no alternate drying and wetting interchange for this particular study, which would have made the environment hard for pathogens to survive, may lead to their proliferation and continuous presence (Ronald et al., 2006). This can be seen from the performance observed for total coliform that show significant removal differences by various soil types; however faecal coliforms being relatively naturally resistant and living longer compared to other coliform groups persisted for longer times and accumulated therein (Gabriel, 2005). In addition to this the occurrence of background growth in total coliform might lead to their relatively elevated level in the biofil effluent. Study by Park et al. (2006) argued that the use of total coliform as indicator to faecal contamination had been influenced by the presence of background contaminants that are mostly present in larger proportions in shallow tributaries. From this study it may be concluded that such background causes in the influent (could be of bacteria relatively larger in size and/or stay very short) were not detected in the effluent collected after passing through soil columns as a result of their large sized or short life nature.

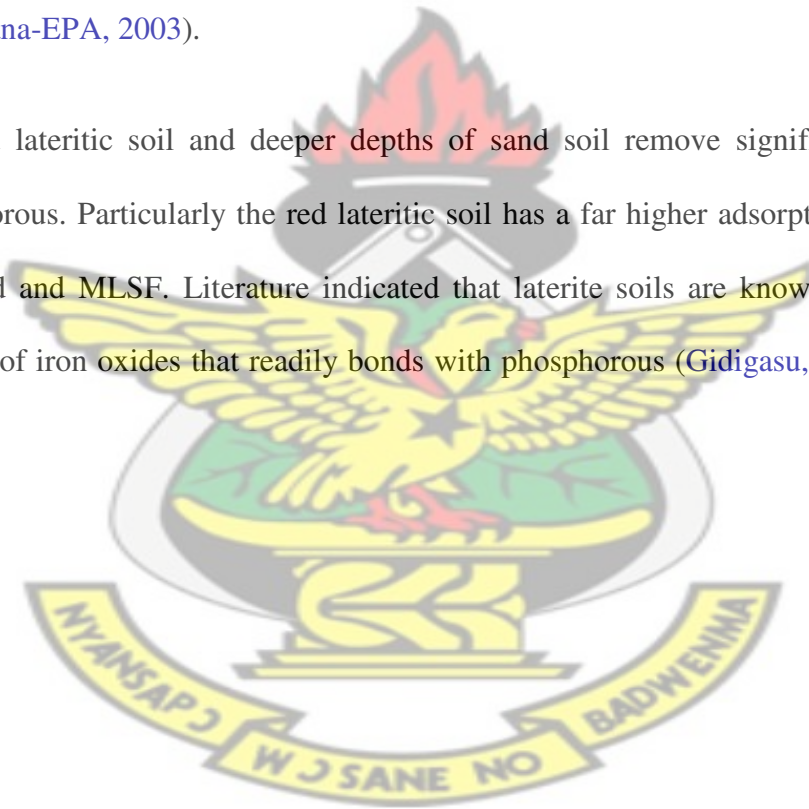
The unusually high total nitrogen observed during the first two weeks could be due to residues of organic nitrogen present in the virgin sand. Moreover the high ammonia concentration in the MLSF and 0.3m depth of sand soil might be due to a continuous wetting process where ammonia oxidation has been hindered (Figure 4.16). Ronald et al. (2006) argued that the wet-dry ratio of application of wastewater in an overland treatment system such as soil aquifer treatment, has a significant impact on ammonia removal, the higher the wet-dry ratio the lower ammonia removal (conversion of ammonia into successive forms of nitrogen, i.e., $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ that could then be removed through denitrification process in the next anoxic zone). The main reason for this reduced ammonia removal is the reduced oxygen concentration beneath the waste feed whereby alternate drying would have replenished this oxygen. Ronald et al. (2006) also suggested that effective ammonia removal through nitrification can be achieved with a wet-dry ratio of 0.5 or less. As ammonia might be retained through adsorption onto soil particles, the level of ammonia in the lower sampling ports was not very high.

The total phosphorous load into the columns was about 126 mg/l. As discussed in section 4.1.1, this concentration is generally strong. In this study, over 50% of this load was removed by red lateritic soil and 46% by sandy soil. Only minimal removal of total phosphorous was achieved from the MLSF (14%) and even a higher concentration of total phosphorous was obtained from the top 0.3 m depth of sand soil. The poor phosphorous removal trend observed at the top layer of sand soil and the MLSF could be attributed to the exhaustion of the adsorption capacity of the layer for phosphorous. Eventually the phosphorous passes through without being removed from the system.

with literature that argues that the majority of nitrogen in fresh wastewater is in the organic nitrogen form which gets converted in to ammonia by the action of heterotrophic bacteria (Cheremisinoff, 1996; Sawyer et al., 2003; WEF, 2005 and Henze et al., 2008).

In the loamy soil column, the highest concentration of $\text{NO}_3\text{-N}$ (2.04 mg/l) was recorded at 0.3 m depth, dropping down to 0.47mg/l at 0.8m depth of the same column. In all of the soil columns in this experiment, the $\text{NO}_3\text{-N}$ concentration was below EPA general effluent guideline values for discharge into natural water bodies in Ghana (10 mg/l $\text{NO}_3\text{-N}$) (Ghana-EPA, 2003).

The red lateritic soil and deeper depths of sand soil remove significant amounts of phosphorous. Particularly the red lateritic soil has a far higher adsorption capacity than the sand and MLSF. Literature indicated that laterite soils are known to have a high content of iron oxides that readily bonds with phosphorous (Gidigas, 1976 and David, 1983).



CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

This chapter of the thesis presents the conclusions drawn from the study and the recommendations proposed.

5.1. Conclusion

The raw black water and biofil effluent in this study were found to be strong (COD of 3,750 mg/l, BOD 988mg/l and COD/BOD of 4:1 & 3:1).

From the experiments conducted it can also be concluded that biofil toilet technology has a remarkable performance as pre-treatment for various wastewater parameters, with a capacity of over 69% BOD, 81% COD and 84% suspended solids removals and one log to 5 log removal of coliform organisms.

Most soil columns achieved sufficient contaminant removal at various depths (65% to 80% removal) and up to 98% removal at 1.5 m depth; however the lion share occurred in the first 30 centimetres of the soil columns. Among the different soil types used in this study, clay soil was not suitable as an infiltration surface for such wastewater due to the compact nature of its particles. The red lateritic soil, followed by sandy soil and the MLSF however performed better in all aspects of contaminant removal. Their performance with respect to various water quality parameters for ground water, with exception of helminth ova, were within the guideline values recommended by both WHO guidelines for drinking water quality and Ghana-EPA general effluent quality guideline values for discharge to natural water bodies.

Observation and site visits confirmed that clogging of infiltration surface was the main problem in areas where there is no sufficient land area to spread out the effluent.

Pore clogging due to biomat formation in soil columns was also found to be the main hindrance to efficient contaminant removal especially in cases where a faster loading rate to be applied.

5.2. Recommendations

- One of the main challenges of this column infiltration experiment was pore clogging due to fast biofilm growths. Application of alternate wetting and drying conditions can solve the problem of pore clogging. An alternate wetting and drying cycles can also improve the general contaminant removal process with better loading rates. In addition to this a better nutrient removal can be achieved by such alternate wetting and drying process as it creates an alternate aerobic/anoxic condition, which is an essential mechanism for nitrification and denitrification reaction that are essential for complete removal of nitrogen.
- The poor performance observed by the multi-layer sand filter (MLSF) can be improved by introducing a better adsorbent material such as the red lateritic soil that has been used in this study. Complementing these two soil types can greatly enhance the wastewater reclamation potential with much improved loading rates and possibly in a compact space.
- In areas with limited permeability, pre-treatment of the biofil effluent aiming to greatly reduce organic matter responsible for increased biomat layer could contribute to an improved performance of the system.
- It is recommended that further work be done to improve helminth ova and phosphorous removal capacities of soil columns.

REFERENCES

- Abu-Ashour J, Joy DM, Lee H, Whiteley HR and Zelin S (1994). Transport of micro-organisms through soil. *Water, Air and Soil Pollution*, 75: 141-158, 1994.
- Aira Manuel, Monroy Fernando and Domínguez Jorge (2007). *Eisenia fetida* (Oligochaeta: Lumbricidae) Modifies the Structure and Physiological Capabilities of Microbial Communities Improving Carbon Mineralization during Vermicomposting of Pig Manure. *Microbial Ecology* Volume 54, 662-671(2007)
- Allee WC, Torvik MM, Lahr JP and Hollister PL (1930). Influence of soil reaction on earthworms. – *Physiol. Zoology* 3(2): 164–200.
- Amador J, Potts D, Patenaude E and Görres J (2008). "Effects of Sand Depth on Domestic Wastewater Renovation in Intermittently Aerated Leachfield Mesocosms." *J. Hydrol. Eng.* (13) 729–734.
- Angus Judge (2001). The effects of surface-applied poultry manure on top-and sub-soil acidity and selected soil fertility characteristics. *MSc thesis, School of Applied Environmental Sciences, University of Natal, Pietermaritzburg, KwaZulu-Natal, SA*
- McCauley Ann, Jones Clain and Jacobsen Jeff (2009). Soil pH and Organic Matter, In: Nutrient Management Module No. 8, unpublished document; Montana State University Extension Continuing Education Series. Bozeman, Mt 59717, USA.
- Arancon NQ, Edwards CA, Atiyeh RM and Metzger JD (2004). Effects of vermicomposts produced from food waste on greenhouse peppers. *Bioresource Technology*, 93: 139-144
- Arrhenius O (1921). Influence of soil reaction on earthworms. In: Aira Manuel, Monroy Fernando and Domínguez Jorge, 2007. *Eisenia fetida* (Oligochaeta: Lumbricidae) Modifies the Structure and Physiological Capabilities of Microbial Communities Improving Carbon Mineralization during Vermicomposting of Pig Manure. *Microbial Ecology* Volume 54, 662-671(2007)
- Asia IO and Akporhonor EE, (2007). Characterization and physicochemical treatment of wastewater from rubber processing factory. *International Journal of Physical Sciences* Vol. 2 (3), pp. 061-067, March, 2007
- ASTM (1981). Annual Book of ASTM Standards. American Society for Testing and Materials, Philadelphia, PA.

- Atiyeh RM, Lee S, Edwards CA, Arancon NQ and Metzger JD (2002). The influence of humic acids derived from earthworms-processed organic wastes on plant growth. *Bioresource Technology*, 84, 7-14.
- Atiyeh RM, Subler S, Edwards CA, Bachman G, Metzger JD and Shuster W (2000). “*Effects of vermicompost and composts on plant growth in horticultural container media and soil*”. In: *Pedo biologia*, 44, pp. 579-590.
- Ausland GA (1998). Hydraulics and Purification in wastewater filters. PhD Dissertation. Agricultural University of Norway. In: S. Van Cuyk, R. Siegrist, A. Logan, S. Masson, E. Fischer and L. Figueroa (2000) Hydraulic and purification behaviors and their interactions during wastewater treatment in soil infiltration systems. *Wat. Res. Vol. 35, No. 4*, pp. 953-964, 2001, Elsevier Science Ltd.
- Baig S.A., Mahmood Q., Nawab B., Shafqat M.N. and Pervez A. (2011). Improvement of drinking water quality by using plant biomass through household Biosand filter – A decentralized approach. *Journal of Ecological Engineering* 37 (2011) 1842–1848
- Bajsa O, Nair J, Mathew K and Ho GE (2003). Vermiculture as a tool for domestic wastewater management; *Water Science and Technology*; IWA Publishing; Vol. 48: No 11-12; pp.125-132.
- Beard DC and Weyl P (1973). Influence of texture on porosity and permeability of unconsolidated sand: *American Association of Petroleum Geologists Bulletin*, v. 57, pp. 349-369.
- Belen Torondel (2010). Sanitation Ventures-Literature Review: on-site sanitation waste characteristics. London School of Hygiene & Tropical Medicine
- Benneh G, Agyepong GT and Allotey JA (1990). Land Degradation in Ghana. Commonwealth Secretariat and University of Ghana.
- Bhawalkar US (1995). Vermiculture bioconversion of organic residues. – Ph.D. Thesis, I.I.T. Mumbai, India
- Blanca J, Duncan M, Richard C and François B (2009). Wastewater Treatment for Pathogen Removal and Nutrient Conservation for Developing Countries. In: *Wastewater Irrigation and Health; Assessing and Mitigating Risks in Low-Income Countries, Chapter-8, WHO, 2009*.

- Bouma J (1979). Subsurface applications of Sewage Effluent, In: *Planning the Uses and Management of Land*, ASA-CSSA-SSSA, Madison, Wisconsin, pp. 665-703.
- Brady NC, and Weil RR (2002). *The Nature and Properties of Soils* (11th ed.)
- Brammer H (1962). Soils: In *Agriculture and Landuse in Ghana*. J.B Wills ed., Oxford University Press London, Accra, New York. Pp 88-126.
- Burchill S, Greenland DJ and Hayes MHD (1981). Adsorption of Organic Molecules. In: *The Chemistry of Soil Processes*, Greenland, D.J. and Hayes, M.H.B. (eds.). John Wiley & Sons Inc. New York. pp. 221-401
- Cagle WA and Johnson LA (1994). On-site Intermittent Sand Filter Systems, a Regulatory/ Scientific Approach to Their Study in Placer County, California. In *On-Site Wastewater systems manual*
- Canter L and Knox R (1985). *Septic Tank System Effects on Groundwater Quality*. Lewis Publishers, Inc.
- Chabani M, Akhrib K, Ait OY, Amrane A and Bensmaili A (2010). Removal of nitrate from drinking water by adsorption using ion exchange resin. *Desalination and Water Treatment* 24 (2010) 109–116
- Charles Thrift (2007). *Sanitation Policy in Ghana: Key Factors and the Potential for Ecological Sanitation Solutions*. Stockholm Environment Institute, Kräftriket 2B, 10691 Stockholm, Sweden
- Cheremisinoff Nicholas P (1996). *Biotechnology for waste and wastewater treatment*. Noyes Publications, Fairview Avenue, Westwood, New Jersey. ISBN-0-8155-1409-3, Pp 151-156
- Christoph L, Arne P, Thorsten S, Anna N, Jennifer McC, Jonathan P, Darren S and Rahul I (2011). *Sustainable Sanitation in Cities: A Framework for Action*. First Edition 2011: Papiroz Publishing House, Rijswijk, The Netherlands.
- Wendland Claudia (2008). *Anerobic Digestion of Blackwater and Kitchen Refuse*. PhD Thesis, Technische Universität Hamburg-Harburg, Germany. Pp 30, ISBN 978-3-930400-43-0. Eißendorfer Str. 42, 21073 Hamburg
- Clements Ernest V and Otis Richard J (1980); *Design Manual: Onsite Wastewater Treatment and Disposal Systems*. US EPA Office of Water Program Operations, Municipal Environmental Research Laboratory, Washington DC 20 460.

- Clesceri LS, Greenberg AE and Eaton AD (Eds.), (1998). *Standard Methods for the Examination of Water and Wastewater*, APHA 20th Ed.
- Cliver DO (2000). Fate and Transport of Pathogens. In: *Proceedings of Decentralized Wastewater Management Research Needs Conference*, Washington University, St. Louis, MO. May 19-20, 2000. USEPA, Cincinnati, OH.
- Cooper PE (2001). Historical aspects of wastewater treatment. In: *Biological wastewater treatment: Principles, Modelling and Design*. Edited by Henze et al. (2008). ISBN: 9781843391883, IWA Publishing, London, UK.
- Daly D and Swartz M (1999). Using BS5930 to Describe Subsoils. *Notes for Groundwater Section Staff*, Geological Survey of Ireland
- David A Alao (1983). Geology and Engineering Properties of Laterites from Ilorin, Nigeria. *Engineering Geology*, 19 (111-118)
- Domenico PA and Schwartz FW (1998). *Physical and Chemical Hydrogeology*. John Wiley & Sons, Inc., New York.
- Dominguez J and Edwards CA (1997). “*Effects of Socking Rate and Moisture Content on the Growth and Maturation of Eisenia andrei (Oligochaeta) in Pig Manure*”. In: *Soil Biology Biochemistry* Vol 29, #3,4, pp 743-6.
- Eales Kathy (2008). “Partnerships for sanitation for the urban poor: Is it time to shift paradigm?” Essay for Symposium on Urban Sanitation. IRC International Water and Sanitation Centre. Delft, The Netherlands, 2008.
- Eawag/Sandec (2008). *Faecal Sludge Management (FSM); Sandec Training Tool 1.0 – Module 5*
- Edwards CA (1995). Earthworm. *McGraw-Hill Encyclopedia*, pp. 81–83.
- Edwards CA, Dominguez J & Neuhauser EF (1998): Growth and reproduction of *Perionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management. *Biology and Fertility of Soils* 27: 155–161.
- Egbunwe N (1980). Alternative excreta disposal systems in Eastern Nigeria: Engineering and Development Centre. In: Belen Torondel, 2010. *Sanitation Ventures Literature Review: on-site sanitation waste characteristics*. London School of Hygiene & Tropical Medicine.

- Elke Müllegger, Günter Langergraber, Markus Lechner (2010) Sustainable Sanitation Practice: The Rosa Project, Issue 4.7 EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria.
- Essandoh HMK, Tizaoui C, Mohamed MHA, Amy G and Brdjanovic D (2011). Soil aquifer treatment of artificial wastewater under saturated conditions. *Water research* 45 (2011) 4211-4226
- Fox P, Houston S, Westerhoff P, Drewes JE, Nellor M, Yanko W, Baird R, Rincon M, Arnold R, Lansey K, Bassett R, Gerba C, Karpiscak M, Quanrud D, Amy G and Reinhard M (2001). An investigation of soil-aquifer treatment for sustainable water reuse. A tailored collaborative research project. National Center for Sustainable Water Supply (NCSWS), Arizona State University, Tempe, Arizona 85287-5306, U.S.A.
- Franceys R, Pickford J and Reed R (1992). *A Guide to the Development of on-site Sanitation*. World Health Organization; Geneva.
- Gabriel Bitton (2005). Wastewater microbiology, 3rd ed. John Wiley & Sons, Inc., Hoboken, New Jersey, USA. ISBN 0-471-65071-4
- Gaddie RE (Sr.) and Douglas DE (1975). Earthworms for Ecology and Profit. Volume1: *Scientific Earthworm Farming*. Bookworm Publishing Company, Cal.
- Gaggero Carlos (2011). 10 facts on sanitation, WHO/PAHO fact files on sanitation. www.who.int/features/factfiles/sanitation/en/index.html, Retrieved on December 09, 2012.
- GEORG (2004). Feasibility of Developing the Organic and Transitional Farm Market for Processing Municipal and Farm Organic Wastes Using Large-Scale Vermicomposting.
- Ghana-EPA (2003); Sector specific effluent guidelines for discharge into natural water bodies (Maximum permissible levels)
- Ghana-EPA (2005); Ghana State of Environment Report 2004
- Gidigas MD (1976) Laterite Soil Engineering: Pedogenesis and Engineering Principles. Developments in Geotechnical Engineering, Vol 9, Pp 219; ISBN 0-444-41283-2.
- Gilbert N (2009). The disappearing nutrient. News Feature. Nature, Vol 461, 716-718.

- Gill L, Johnston P, Misstear B and ÓSúilleabháin C (2004). An investigation into the performance of sub-soils and stratified sand filters for the treatment of wastewater from on-site systems: *A literature review*, Trinity College, Dublin.
- Gill L, O'Súilleabháin C, Misstear B and Johnston P (2005). An Investigation into the Performance of Subsoils and Stratified Sand Filters for the Treatment of On-Site Wastewater: Synthesis Report, EPA, Johnstown Castle Estate, Wexford, Ireland.
- Graaff MSD (2010). Resource recovery from black water. PhD Thesis Wageningen University, Wageningen, NL.
- Gray NF (1994). *Drinking Water Quality: Problems and Solutions*. John Wiley & sons, Chichester.
- GSS (2008). Ghana Living Standard Survey report of the fifth round. Ghana Statistical Service, Accra, Ghana
- Gyapong T Adjei and Asiamah RD (2002). Brief overview of the interim Ghana Soil classification system; Brammer, 1962; Soil Research Institute, Kwadaso, Kumasi. retrived on 8th January 2013: <ftp://ftp.fao.org/docrep/fao/005/y3948f/y3948f02.pdf>.
- Hallatt L (1992): Moisture requirements in life cycle of *Perionyx excavatus*. In: *Soil Biology and Biochemistry* 24(12): 1333–1340.
- Hallatt L, Reinecke AJ & Viljoen SA (1990): The life cycle of the oriental compost worm *Perionyx excavatus* (Oligochaeta). In: *South African Journal of Zoology* 25: 41-45.
- Hammermeister AM, Warman PR, Jeliaskova EA, and Martin RC (2004). Nutrient supply and lettuce growth in response to vermicompost and composted cattle manure. *Bioresource Technology*, Dec, 2004.
- Harman J, Robertson WD, Cherry JA and Zanini L (1996). Impacts on a Sand Aquifer from an Old Septic System: Nitrate and Phosphate. In: *Ground Water*, Vol. 34, No. 6, pp.1105-1114.
- Heinss U and Larmie SA (1998). Four Years Field Monitoring of Achimota Faecal Sludge Treatment Plant. EAWAG/SANDEC, P.O. Box 611, CH-8600 Duebendorf, Switzerland.

- Henze Mogens, van Loosdrecht Mark CM, Ekama George A, and Brdjanovic Damir eds. (2008). *Biological Wastewater Treatment: Principles, Modelling and Design*. IWA Publishing, ISBN: 9781843391883, London, UK.
- Hillel D (1998). *Environmental Soil Physics: Fundamentals, Applications, and Environmental Considerations*, 1st Edition. Academic Press, New York.
- Holden Richard (2008). *Urban Sanitation Technologies: The Challenges of Reaching the Urban Poor*. Essay for Symposium on Urban Sanitation. IRC, International Water and Sanitation Centre. Delft, The Netherlands.
- Hopkins MJ and Macfarlane GT (2002). Changes in predominant bacterial populations in human faeces with age and with *Clostridium difficile* infection. *Journal of Medical Microbiology*. May 2002; 51(5):448-454.
- Ireland EPA (2000). *Wastewater treatment manuals: Treatment systems for single houses*; Johnstown Castle Estate, Co. Wexford, Ireland
- Ireland EPA (2009). *Code of Practice: Wastewater Treatment and Disposal Systems Serving Single Houses*. Environmental Protection Agency, Ireland, ISBN: 978-1-84095-196-7
- Ismail SA (1997). *Vermiculture – The biology of earthworms*. Orient Longman Limited, Hyderabad (A.P.), India.
- Jansen GJ, Wilkinson MHF, Deddens B and Waaij D van der (1993). Characterization of human faecal flora by means of an improved fluoro-morphological method. *Epidemiology of infectious diseases* (111) 265-272
- Jantrainia Anish R, and Gross Mark A (2006). *Advanced onsite wastewater systems technologies*. CRC Press, Taylor & Francis Group-Boca Raton, USA; ISBN 0-8493-3029-7. Pp 76.
- Jenssen PD and Siegrist RL (1988). Nitrogen Removal from Wastewater In *Soil Infiltration Systems*. Avløpsvann. Redigert av Hallvard Ødegaard, Tapir Forlag, 1988. pp 114-128.
- John T Novak, Gary T Hickman, Mark A Morris and Robert E Benoit (1989). *An Investigation of the Biodegradation Potential of Groundwater Contaminants*. Virginia Water Resources Research Center, Bulletin 165, Virginia Polytechnic Institute and State University, Blacksbur, USA.

- Klingel Florian, Montangero Agnès, Koné Doulaye and Strauss Martin (2002). *Faecal Sludge Management in Developing Countries: A planning manual*. Swiss Federal Institute for Environmental Science and Technology EAWAG/SANDEC, 1st edition, 8600 Duebendorf, Switzerland.
- Krogius-Kurikka L, Lyra A, Malinen E, Aarnikunnas J, Tuimala J, Paulin L, Mäki vuokko H, Kajander K and Palva A (2009). Microbial community analysis reveals high level phylogenetic alterations in the overall gastrointestinal microbiota of diarrhoea-predominant irritable bowel syndrome sufferers. *BMC* (9)95.
- Krumbein WC and Monk GD (1942). Permeability as a function of the size parameters of unconsolidated sands. *Petroleum Tech.*, AIME Tech. Publ., pp. 1-11.
- Kujawa-Roeleveld K, Elmitwalli TA, and Zeeman G (2006). Enhanced primary treatment of concentrated blackwater and kitchen residues within DESAR concept using two types of anaerobic digesters. *Wat Sci Tech* 53(9), pp 159-168
- Laak R (1976). Pollutant Loads from Plumbing Fixtures and Pretreatment to Control Soil Clogging. *J. Environ. Health*, 39:48-50(1976).
- Lance JC (1972). Nitrogen Removal by Soil Mechanisms. *J. Water Poll. Control Fed.* 44(7): 1352-1361
- Lance JC (1984). Land Disposal of Sewage Effluents and Residues. In: *Groundwater Pollution Microbiology*. Bitton, G and Germa, C.P. (eds.). John Wiley and Sons, Toronto, Ont.
- Louis P, Scott KP, Duncan SH and Flint HJ (2007). Understanding the effects of diet on bacterial metabolism in the large intestine. *Journal of Applied Microbiology*. May 2007; 102(5):1197-1208.
- Macneal W, Latzer L and Kerr J (1909). The Faecal bacteria of healthy men. Introduction and direct quantitative observations. *Journal of Infectious Disease*. 1909; 6: 123.
- Mara D D (1978). Sewage Treatment in Hot Climates. Chichester: *John Wiley & Sons*. In: www.ruaf.org/sites/default/files/Chap6-Sanitation.pdf
- Coquin Marie-Catherine (2005). Black Water recycling at Skogaberg, Msc Thesis, CHALMERS department of civil and environmental engineering, Water Environment Technology Gothenburg, Sweden.

- Maxwell Adu-Ahyiah and Romi Ernest Anku (2006). *Small Scale Wastewater Treatment in Ghana (a Scenerio)*. Lund University, Sweden; Retrieved on Nov. 22, 2012. From: www.vateknik.lth.se/exjobb/E314.pdf.
- McCarty PL, Rittmann BE and Bouwer EJ (1984). Microbiological Processes Affecting Chemical Transformations in Groundwater. In: *Groundwater Pollution Microbiology*. Bitton, G and Germa, C.P. (eds.). John Wiley and Sons, Toronto, Ont. pp.90-115.
- McDowell-Boyer LM, Hunt JR and Sitar N (1986). Particle Transport through Porous Media. *Water Resources Research*, v. 22, no. 13, pp. 1901-1921.
- Mema V and Gyampo E (2011). Biofil Toilet Digester: An Innovative On-Site Treatment. Ghana Water Forum Journal First Edition, Pp 74-80
- Metcalf and Eddy, Tchobanoglous G, Burton FL, Stensel HD (2003). *Wastewater Engineering: Treatment and Reuse*, fourth ed. McGraw-Hill Inc., New York.
- Mihelcic JR (1999). *Fundamentals of Environmental Engineering*. John Wiley & Sons, Inc. New York
- Molla AS and Kaba T. (2011). Performance Evaluation and Situation analysis of Stablization ponds: The Case for Hawassa University Referral Hospital WSP, Hawassa Ethiopia. *LAP Lambert Academic Publishing*. GmbH & Co. KG, Saarbrücken, Germany. ISSN: 978-3-65911355-0
- Monney Isaac (2011). Assessing the impacts of sanitation in un-sewered urban slums on water resources: A case study of Old Fadama, Accra, Ghana. MSc Thesis, KNUST
- Montangero A and Strauss M (2002). Faecal sludge Treatment. EAWAG/SANDEC, Swiss Federal Institute for Environmental Science and Technology. IHE, Delft
- Munroe Glenn (2007): *Manual of on-farm vermicomposting and vermiculture*; Organic Agriculture Centre of Canada; EcoAction Program of Environment Canada.
- Nommik H and Vahtras K (1982). Retention and Fixation of Ammonium and Ammonia in Soils. In: *Nitrogen in Agricultural Soils*, F.J. Stevenson ed, Agronomy Series No. 22. *American Society of Agronomy Inc.*, Madison, WI. Pp 123-172.
- Odai SN and Dugbantey DD (2003). Towards pollution reduction in peri-urban water supply: A case study of Ashanti region in Ghana. *Diffuse Pollution Conference*, Dublin 2003

- Oliver Schmoll, Guy Howard, John Chilton and Ingrid Chorus, eds. (2006). Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources. *WHO Drinking-water Quality Series*. ISBN: 1843390795; IWA Publishing, Alliance House, 12 Caxton Street, London SW1H 0QS, UK, **Pp 109-114**.
- Olson HW (1928). The earthworms of Ohio. *Ohio Biological Survey Bulletin* 17(47-90)
- Park JE, Ahn TS, Lee HJ, & Lee YO (2006). Comparison of total and faecal coliforms as faecal indicator in eutrophicated surface water, 712-714. doi:10.2166/wst.2006.467
- Petrov BC (1946). The active reaction of soil (pH) as a factor in the distribution of earthworms. *Zoological Journal* 25(1): 107–110.
- Piet Lens, Grietje Zeeman and Gatze Lettinga (eds.) (2008). Decentralized Sanitation and Reuse: Concepts, Systems and Implementation. Department of Environmental Technology, University of Wageningen, The Netherlands.
- Powell GM, Willingham JM, and Rowlands M B, eds. (2002). Environmental Health Hand Book, Second Edition, Kansas State University, Research and Extension division. Topeka, Kansas, USA.
- Quano EAR, Lohani BN, Thanh NC (1978). Water Pollution Control in Developing Countries. Asian Institute of Technology. pp. 567.
- Reneau RB, Hagedorn C and Degen MJ (1989). Fate and Transport of Biological and Inorganic Contaminants from On-site Disposal Systems. In: *Journal of Environmental Quality*, Vol. 18, pp 135-144.
- Ronald W Crites, Joe Middlebrooks and Sherwood C Reed (2006). Natural Wastewater Treatment Systems: Chapter 8; Land treatment systems. Pp 379-435. ISBN:10: 0-8493-3804-2, CRC Press, Taylor & Francis Group, USA
- Sammy CK Tay, Stephen Y Gbedema and Thomas K Gyampomah (2011). High prevalence of Hookworm infection and apparent absence of *Ascaris Lumbricoides*: A case study at the Komfo Anokye Teaching Hospital in ghana. *IJPSR*, 2011; Vol. 2(5): 1217-1224
- Samudro G, & Mangkoedihardjo S (2010). Review on BOD, COD and BOD/COD ratio: A triangle zone for toxic, biodegradable and stable levels, *International Journal of Accademic Research* 2(4), 235–239.

- Satchell JE (1955). Some aspects of earthworm ecology. In: Keven, D.K.Mc E. (ed.): Soil zoology. Butterworths, London.
- Sato K, Iwashima N, Matsumoto T, Wakatsuki T and Masunaga T (2010). Wastewater treatment processes and mechanisms of organic matter, phosphorus, and nitrogen removal in a multi-soil-layering system. Paper presented on the 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010. Brisbane, Australia. Published on DVD.
- Schouw NL, Danteravanich S, Mosbaek H and Tjell JC (2001). Composition of human excreta-a case study from Southern Thailand. *The Science of the Total Environment* 286 (2002) 155-166
- Siegrist RL, Tyler EJ and Jenssen PD (2000). Design and Performance of Onsite Wastewater Soil Absorption Systems. In: *Proceedings of Nat. Research Needs Conference, Risk-Based Decision Making for Onsite Wastewater Treatment*, Washington University, St. Louis, Missouri. 19-20 May 2000.
- Singh NB, Khare AK, Bhargava DS, and Bhattacharya S (2005). Effect of initial substrate pH on vermicomposting using *P. excavatus*. *Applied Ecology and Environmental Research* 4(1): 85-97(2005)
- Sinha RK, Herat S and Valani D (2010). Earthworms - The Environmental Engineers: Review of Vermiculture Technologies for Environmental Management & Resource Development, *Int. J. of Environmental Engineering*, In Rajiv K Sinha, Sunil Herat & Sunita Agarwal (Eds.) Special Issue on 'Vermiculture Technology for Environmental Management and Resource Development, Vol. X, No. Y.
- Stephen AM and Cummin JH (1980). The microbial contribution to human faecal mass. *Journal of Medical microbiology*. Vol. 13 (1980) 45-56
- Strauss M, Heinss U and Montangero A (2000). On-Site Sanitation: When the Pits are Full ñ Planning for Resource Protection in Faecal Sludge Management. In: *FS Management-Review of Practices, Problems and Initiatives*; By: Martin Strauss and Agnes Montangero. Engineering Knowledge and Research Project - R8056, EAWAG/SANDEC
- Strauss M, Koné D, Koanda H and Steiner M (2006). Urban Excreta Management - Situation, Challenges and Promising Solutions. Eawag/Sandec, 1st International Faecal Sludge Management Policy Symposium and Workshop, May 2006, Senegal.

- Strauss M, Larmie SA, and Heinss U (1997). Treatment of Sludges from On-Site Sanitation: Low-Cost Options. In: *Water Science and Technology* 35(6). www.ruaf.org/sites/default/files/Chap6-Sanitation.pdf
- Subler Scott, Clive Edwards and James Metzger (1998). Comparing Vermicompost and Composts. In: *BioCycle*, July 1998, Pp.63-66.
- Tripathi G & Bhardwaj P (2004). Comparative studies on biomass production, life cycles and composting efficiency of *Eisenia fetida* (Savigny) and *Lampito mauritii* (Kinberg). *Bioresource Technology* 92(3): 275–283.
- UNEP-IETC (2002). United Nations Environment Programme Division of Technology, Industry, and Economics. International Source Book on Environmentally Sound Technologies for Wastewater and Stormwater Management. In: *Management of Wastewater and Faecal Sludge in Southern Africa*. HG Snyman, 2007. Water Research commission of South Africa, Gauteng, South Africa.
- UN-HABITAT (2009). Planning sustainable cities: Global report on human settlements. Nairobi, Kenya.
- US EPA (1980). Design manual for onsite wastewater treatment and disposal systems. US Environmental Protection Agency, Office of Water Program, Washington Dc 20460
- Usharani K, Umarani K, Ayyasamy PM, Shanthi K and Lakshmanaperumalsamy P (2010). Physico-Chemical and Bacteriological Characteristics of Noyyal River and Ground Water Quality of Perur, India. *Journal of Applied Sciences and Environmental Management*, 14(2) Pp. 29-35
- Van Cuyk S, Siegrist R, Logan A, Masson S, Fischer E and Figueroa L (2000). Hydraulic and purification behaviors and their interactions during wastewater treatment in soil infiltration systems. *Wat. Res.* Vol. 35, No. 4, pp. 953±964, 2001, Elsevier Science Ltd.
- Verstraete W, van de Caveye P and Diamantis V (2009). Maximum use of resources present in domestic "used water". *Bioresource Technology*, 100,5537-5545.
- Vinneras B and Jonsson H (2002). Faecal separation for nutrient management: Evaluation of different separation techniques. Swedish University of Agricultural Sciences, Urban Water 4 (2002) 321–329. Uppsala, Sweden.

- WHO (2004). Guidelines for Drinking Water Quality, 3rd ed., *World Health Organization*, Geneva
- WHO (2004). Nitrates and nitrites in drinking-water. *Rolling Revision of the WHO Guidelines for Drinking-Water Quality*. WHO/SDE/WSH/04.08/56
- WHO (2006). Guidelines for the Safe use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture. Vol.1, 2, 3 and 4. World Health Organization, Ed. Paris, France.
- WHO (2009). Wastewater Irrigation and Health; Assessing and Mitigating Risks in Low-Income Countries. Pay Drechsel, Christopher A. Scott, Liqa Raschid-Sally, Mark Redwood and Akiça Bahri, eds. Chapter-8: *Wastewater Treatment for Pathogen Removal and Nutrient Conservation for Developing Countries*.
- WHO/UNICEF (2010). Joint Monitoring Programme for Water Supply and Sanitation: Progress on sanitation and drinking-water – 2010 Update.
- WHO/UNICEF (2012). Joint Monitoring Programme for Water Supply and Sanitation: *Progress on Drinking Water and Sanitation: 2012 Update*.
- Williams A, Scholefield D, Dowd J, Holden N and Deeks L (2000). Investigating Preferential Flow in a Large Intact Soil Block under Pasture. In: *Soil Use and Management*, Vol. 16, pp 264-269, 2000.
- Winneberger JH, Francis L, Klein SA, and McGauhey PH (1960). Biological Aspects of Failure of Septic Tank Percolation Systems; Final Report. Sanitary Engineering Research Laboratory, University of California. In: Ernest V. Clements and Richard J. Otis, 1980; *Design Manual: Onsite Wastewater Treatment and Disposal Systems*. US EPA, Washington DC 20 460.
- Zanini L, Robertson WD, Ptacek CJ, Schiff SL and Mayer T (1998). Phosphorous characterization in sediments impacted by septic effluent in four sites in central Canada. In: *J. of Cont. Hydrology*, Vol. 33, pp. 405-429
- Zavala LMA, Naoyuki F, and Tetsuo T (2002). Characterization of faeces for describing the aerobic biodegradation of faeces. *Journal of Environmental Systems and Engineering*, 2002; 720 (VII-25):99-105.

INTERNET SOURCES

Biofilcom (Biological Filters and Composters); accessed on October, 08, 2012.
<http://www.biofilcom.com/pages/the-biofil-toilet-system.php>

GSAP (2012). Ghana Sustainable Aid Project, Micro flush biofil toilets. Retrieved on Tuesday October, 16, 2012. <http://www.dellchallenge.org/projects/gsap-microflush-biofil-toilet>

<http://ehs.ncpublichealth.com/oet/docs/cit/oswpmmod/Chapter4-Section1.pdf>

<http://www.healthhype.com/feces-faeces-formation-composition-color-and-odor.html>

James E. Alleman (1982). The history of fixed-film wastewater treatment systems. School of civil engineering, Purdue University, West Lafayette, Indiana 47907-1284. Retrieved on 28, Nov. 2012. <http://web.deu.edu.tr/atiksu/ana52/biofilm4.pdf>

LENNTech (2013). Water Treatment Solutions: retrieved on 24, April, 2013: <http://www.lenntech.com/processes/nitrates/nitrate-removal.htm#ixzz2RLft27zU>

OSC, Oregon Soil Corporation (2012). *Vermiculture: History of Vermicomposting*, 541-929-6050. Accessed on 28/11/2012. <http://oregonsoil.com/OrAgGrow/history.html>.

PMT (2012) Pakar Management Technology (M) Sdn Bhd, PMT building, C-02-13 & 15, Jalan Sri Kenari 12, Kajang, Selangor, Malaysia; Website: www.pakar.com.my; http://www.pakar.com.my/index.php?option=com_content&view=article&id=91&Itemid=95

PT. Biofil International (2012). West Jakarta Industry and warehousing complex, dadap1, Indonesia. Retrieved on 02, Dec, 2012. URL: <http://www.septictankbiofil.com>.

Sinha, R.K., Herat, S. Bharambe, G. & Brahmabhatt, A. (2009). Vermistabilization of sewage sludge (biosolids) by earthworms: converting a potential biohazard destined for landfill disposal into a pathogen free, nutritive & safe bio-fertilizer for farms; *J. of Waste Management & Research*; UK. (Published On-line 26 August, 2009) (<http://sagepub.com>)

UNEP (2002). Environmentally Sound Technologies in wastewater treatment for the implementation of the UNEP Global Programme of Action (GPA), January 2002. http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/8.asp

UNICEF, WHO and WSSCC (2008). 10 Things You Need to Know About Sanitation. Retrieved on December 09, 2012: www.unwater.org/wwd08/docs/10Things.pdf.

US EPA (2002). Onsite Wastewater Treatment Systems Manual: Chapter 4; Treatment processes and systems, Office of Water - <http://www.epa.gov/ow/>

vanRyneveld MB, Fourie AB. (1997). A strategy for evaluating the environmental impact of on-site sanitation systems. *Water Sa* 23(4):279-291. In: Jay P. Graham and Matthew L. Polizzotto (2013); Pit Latrines and Their Impacts on Groundwater Quality: A Systematic Review: <http://dx.doi.org/10.1289/ehp.1206028>.

WEF (2005). Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants, Water Environment Federation, 601 Wythe Street, Alexandria, VA 22314-1994 USA, <http://www.wef.org>

WSSCC (2012). UN-Water Factsheet on Sanitation. In: *UN-Water statistics*, WSSCC, retrieved on December, 2012. http://www.unwater.org/statistics_san.html.

CSGNetwork.com: Water Consumption Calculator; accessed 09 October 2012. URL: <http://www.csgnetwork.com/waterusagecalc.html>.



Appendixes

Appendix-I. Summary of result tables

Table 4.3. Temperature and pH measurements during various weeks of experimental run and at different soil types and corresponding sampling depths

Soil types & infiltration depth		Temperature (oC)			STDV	pH			STDV
		2 Wks run	5 Wks run	8 Wks run		2 Wks run	5 Wks run	8 Wks run	
Influent		28.23	29.14	29.00	0.49	8.16	8.75	8.86	3.97
Loamy Soil	0.3m	29.00	29.95	29.07	0.53	7.27	6.99	7.99	4.22
	0.8m	28.20	30.72	29.33	1.26	7.11	7.20	8.32	4.27
	1.5m	29.40	*	29.60	0.14	7.43	*	8.15	7.84
Sandy Soil	0.3m	30.10	31.04	30.00	0.57	8.09	7.84	7.80	4.24
	0.8m	*	29.80	*	*	*	8.19	*	*
	1.5m	28.27	31.80	30.70	1.81	5.04	7.34	7.83	4.86
Red Latrite Soil	0.3m	*	30.95	29.30	1.17	*	8.38	8.30	7.40
	0.8m	30.70	30.46	30.10	0.30	7.07	7.64	7.90	4.39
	1.5m	30.10	30.42	30.00	0.22	6.64	7.59	7.49	4.43
MLSF	0.45m	29.48	31.14	29.80	0.88	7.64	8.16	8.07	4.22

* missing value due to absence of sample from the particular port during sampling

Table 4.4. Conductivity and Total dissolved solids concentrations during various weeks of experimental run and at different soil types and corresponding sampling depths

Soil types & infiltration depth		Cond ($\mu\text{S}/\text{cm}$)			STDV	TDS (ppm)			STDV
		2 Wks run	5 Wks run	8 Wks run		2 Wks run	5 Wks run	8 Wks run	
Influent		2,333	2,511	2,870	273.59	1,172	1,253	1,437	135.85
Loamy Soil	0.3m	2,023	2,286	2,490	234.38	1,021	1,141	1,243	111.38
	0.8m	1,133	1,679	1,716	326.44	813	842	859	23.26
	1.5m	1,163	*	1,556	277.89	576	*	779	143.54
Sandy Soil	0.3m	2,540	2,614	2,630	48.01	1,275	1,306	1,313	20.22
	0.8m	*	2,560	*	*	*	1,280	*	*
	1.5m	938	1,232	1,081	147.18	469	617	540	74.18
Red Latrite Soil	0.3m	*	2,033	2,563	374.77	*	1,016	1,283	188.80
	0.8m	851	2,011	2,000	666.57	425	1,006	980	328.00
	1.5m	417	955	952	309.61	209	477	474	154.02
MLSF	0.45m	2,709	2,714	2,780	39.71	1,358	1,358	1,381	13.43

Table 4.5. TSS and BOD₅ concentrations during various weeks of experimental run and at different soil types and corresponding sampling depths

Soil types & infiltration depth		TSS (mg/l)			STDV	BOD ₅ (mg/l)			STDV
		2 Wks run	5 Wks run	8 Wks run		2 Wks run	5 Wks run	8 Wks run	
Influent		510.71	561.33	514.17	28.28	630.3	390.00	400.00	135.94
Loamy Soil	0.3m	290.48	197.92	95.44	97.56	90.12	54.00	78.00	18.38
	0.8m	58.52	78.73	77.56	11.34	180.35	226.80	76.00	77.23
	1.5m	*	25.58	8.49	12.08	240.12		54.00	131.61
Sandy Soil	0.3m	230.00	176.87	87.33	72.11	69.12	33.60	70.00	20.77
	0.8m	*	40.00	*	*	*	48.00	*	*
	1.5m	22.50	12.56	12.22	5.84	72.00	12.00	12.00	34.64
Red Latrite Soil	0.3m	230.77	*	57.58	122.46	*	15.00	10.00	3.54
	0.8m	158.44	33.33	41.67	69.95	2.28	12.60	5.00	5.35
	1.5m	16.13	4.23	7.44	6.15	6.03	6.60	4.00	1.37
MLSF		77.28	80.47	58.00	12.16	111.12	123.60	64.00	31.43

Table 4.6. Concentration of COD at different soil types and corresponding sampling depths

Soil types and infiltration depth		COD (mg/l)			STDV
		2 Wks run	5 Wks run	8 Wks run	
Influent		1,196	920	883	171.15
Loamy Soil	0.3m	1,000	384	299	382.67
	0.8m	936	459	245	353.58
	1.5m	912	*	232	480.83
Sandy Soil	0.3m	411	301	280	70.21
	0.8m	*	280	*	*
	1.5m	440	605	456	91.19
Red Latrite Soil	0.3m	*	100	85	10.37
	0.8m	180	54	32	79.77
	1.5m	288	27	11	155.56
MLSF		520	263	272	145.79

Table 4.7 Faecal and Total coliform levels during various weeks of experimental run and at different soil types and corresponding sampling depths

Soil types & infiltration depth		E-coli (CFU/100ml)			Total Coliform (CFU/100ml)		
		2 Wks run	5 Wks run	8 Wks run	2 Wks run	5 Wks run	8 Wks run
Influent		2.80E+06	7.50E+07	8.47E+07	5.98E+07	1.16E+08	1.56E+08
Loamy Soil	0.3m	2.45E+05	4.00E+04	5.60E+05	1.38E+05	3.66E+05	1.09E+06
	0.8m	6.00E+04	3.50E+04	1.23E+05	1.85E+06	4.15E+05	1.47E+05
	1.5m	1.50E+05	*	1.95E+05	1.07E+06	*	3.55E+05
Sandy Soil	0.3m	2.90E+05	3.80E+04	2.67E+05	5.23E+05	3.80E+04	4.20E+05
	0.8m	*	3.00E+04	*	*	3.00E+04	*
	1.5m	5.00E+04	4.67E+04	1.00E+06	1.45E+05	4.67E+04	1.05E+06
Red Latrite Soil	0.3m	*	1.05E+05	5.33E+04	*	3.70E+05	1.30E+05
	0.8m	5.33E+02	1.98E+03	5.00E+04	2.47E+03	6.58E+03	9.00E+04
	1.5m	1.05E+03	8.20E+02	9.33E+02	5.50E+03	2.20E+03	1.60E+03
MLSF	0.45m	1.02E+05	1.90E+05	5.67E+04	3.80E+06	2.50E+05	5.70E+05

Table 4.8 Faecal and Total coliform log removal achieved at different soil types and corresponding sampling depths

Soil types & sampling depth		E-coli Log Removal			Total Coliform log removal		
		2 Wks run	5 Wks run	8 Wks run	2 Wks run	5 Wks run	8 Wks run
Loamy Soil	0.3m	1.13	3.47	2.34	2.77	2.68	2.30
	0.8m	1.78	3.53	2.85	1.70	2.64	3.06
	1.5m	1.46	*	2.77	1.82	*	2.77
Sandy Soil	0.3m	0.90	3.49	2.69	2.13	3.67	2.73
	0.8m	*	3.60	*	*	3.74	*
	1.5m	1.82	3.38	1.90	2.76	3.60	2.33
Red Latrite Soil	0.3m	*	2.86	3.37	*	2.68	3.16
	0.8m	3.81	4.70	3.41	4.60	4.40	3.42
	1.5m	3.63	5.00	5.00	4.10	4.80	5.00
MLSF	0.45m	1.64	2.75	3.33	1.36	2.78	2.63

Table 4.9 Nutrient levels during the 2nd week of experimental run

Sampling port		Levels of Nutrients (mg/L)						
		T.K.N	NH ₄ -N	NO ₃ -N	NO ₂ -N	Total-N	PO ₄ ³⁻ -P	Total-P
Biofil effluent		267.65	252.17	6.00	0.48	267.13	100.21	125.99
MLSF		282.02	268.33	6.11	0.85	288.98	98.09	107.99
Red Lateritic Soil	0.8m	7.68	1.86	4.33	0.47	12.48	2.59	3.59
	1.5m	27.73	2.8	21.67	0.74	50.13	25.65	62.60
Sand Soil	0.3m	163.97	159.63	1.67	0.76	166.40	63.00	147.58
	1.5m	219.23	1.00	210.00	1.23	300.00	4.51	68.40

Table 4.10 Nutrient levels during the 5th week of experimental run

Soil type and sampling ports		Levels of Nutrients (mg/L)						
		T.K.N	NH ₄ -N	NO ₃ -N	NO ₂ -N	T.N.	PO ₄ -P	Total-P
Raw Blackwater		491.65	34.78	1.25	0.03	492.93	69.29	86.02
Biofil-effluent		371.19	54.91	0.26	0.01	371.46	47.71	56.3
Red Lateritic soil	0.3m	-	-	0.15	-	-	0.04	-
	0.8m	-	-	0.09	-	-	0.07	-
	1.5m	-	-	0.06	-	-	0.6	-
Sand soil	0.3m	-	-	0.73	-	-	2.8	-
	0.8m	-	-	0.58	-	-	2.83	-
	1.5m	-	-	1.2	-	-	0.11	-
Loamy soil	0.3m	-	-	2.04	-	-	0.28	-
	0.8m	-	-	0.47	-	-	0.04	-
MLSF	0.45m	-	-	0.2	-	-	55.42	-

Appendix-II. Statistical tables

Appendix-II-1. BOD

Tests of Between-Subjects Effects

Dependent Variable: BOD

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	81170.096 ^a	11	7379.100	3.550	.014
Intercept	106672.812	1	106672.812	51.325	.000
soil	60621.880	3	20207.293	9.723	.001
wks	7357.393	2	3678.696	1.770	.206
soil * wks	10057.477	6	1676.246	.807	.581
Error	29097.147	14	2078.368		
Total	218348.619	26			
Corrected Total	110267.243	25			

a. R Squared = .736 (Adjusted R Squared = .529)

Multiple Comparisons

BOD

Tukey HSD

Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	79.6780	23.59461	.021	11.0987	148.2573
	Red Lateritic Soil	117.2350	22.79456	.001	50.9811	183.4889
	MLSF	25.3504	30.86398	.843	-64.3578	115.0586
Sandy Soil	Loamy Soil	-79.6780	23.59461	.021	-148.2573	-11.0987
	Red Lateritic Soil	37.5570	23.59461	.414	-31.0223	106.1363
	MLSF	-54.3276	31.45948	.347	-145.7667	37.1115
Red Lateritic Soil	Loamy Soil	-117.2350	22.79456	.001	-183.4889	-50.9811
	Sandy Soil	-37.5570	23.59461	.414	-106.1363	31.0223
	MLSF	-91.8846	30.86398	.044	-181.5928	-2.1764
MLSF	Loamy Soil	-25.3504	30.86398	.843	-115.0586	64.3578
	Sandy Soil	54.3276	31.45948	.347	-37.1115	145.7667
	Red Lateritic Soil	91.8846	30.86398	.044	2.1764	181.5928

Based on observed means. The error term is Mean Square(Error) = 2078.368.

*. The mean difference is significant at the .05 level.

BOD

Tukey HSD Weeks of run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	37.2592	22.15233	.246	-20.7197	95.2380
	8 Weeks Run	54.9481	22.15233	.064	-3.0308	112.9269
5 Weeks Run	2 Weeks Run	-37.2592	22.15233	.246	-95.2380	20.7197
	8 Weeks Run	17.6889	21.49092	.695	-38.5589	73.9366
8 Weeks Run	2 Weeks Run	-54.9481	22.15233	.064	-112.9269	3.0308
	5 Weeks Run	-17.6889	21.49092	.695	-73.9366	38.5589

Based on observed means. The error term is Mean Square(Error) = 2078.368.

Appendix-II-2. COD

Tests of Between-Subjects Effects

Dependent Variable: COD

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.736E6 ^a	11	157780.138	21.444	.000
Intercept	2659036.017	1	2659036.017	361.386	.000
soil	738028.476	3	246009.492	33.435	.000
wks	355638.125	2	177819.062	24.167	.000
soil * wks	322381.459	6	53730.243	7.302	.001
Error	103010.333	14	7357.881		
Total	5004022.000	26			
Corrected Total	1838591.846	25			

a. R Squared = .944 (Adjusted R Squared = .900)

Between Soils Multiple Comparisons

COD Tukey HSD, Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	162.2321	44.39438	.012	33.1969	291.2674
	Red Lateritic Soil	461.2500	42.88905	.000	336.5901	585.9099
	MLSF	206.7083	58.07204	.015	37.9181	375.4986
Sandy Soil	Loamy Soil	-162.2321	44.39438	.012	-291.2674	-33.1969
	Red Lateritic Soil	299.0179	44.39438	.000	169.9826	428.0531
	MLSF	44.4762	59.19251	.875	-127.5708	216.5232
Red Lateritic Soil	Loamy Soil	-461.2500	42.88905	.000	-585.9099	-336.5901
	Sandy Soil	-299.0179	44.39438	.000	-428.0531	-169.9826
	MLSF	-254.5417	58.07204	.003	-423.3319	-85.7514
MLSF	Loamy Soil	-206.7083	58.07204	.015	-375.4986	-37.9181
	Sandy Soil	-44.4762	59.19251	.875	-216.5232	127.5708
	Red Lateritic Soil	254.5417	58.07204	.003	85.7514	423.3319

Based on observed means. The error term is Mean Square(Error) = 7357.881.

*. The mean difference is significant at the .05 level.

COD Tukey HSD, Weeks of run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	311.0972	41.68066	.000	202.0072	420.1872
	8 Weeks Run	373.4306	41.68066	.000	264.3406	482.5205
5 Weeks Run	2 Weeks Run	-311.0972	41.68066	.000	-420.1872	-202.0072
	8 Weeks Run	62.3333	40.43618	.302	-43.4995	168.1662
8 Weeks Run	2 Weeks Run	-373.4306	41.68066	.000	-482.5205	-264.3406
	5 Weeks Run	-62.3333	40.43618	.302	-168.1662	43.4995

Based on observed means. The error term is Mean Square(Error) = 7357.881.

*. The mean difference is significant at the .05 level.

Appendix-II-3. TSS

Tests of Between-Subjects Effects

Dependent Variable: TSS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	150950.253 ^a	11	13722.750	18.415	.000
Intercept	148354.537	1	148354.537	199.080	.000
soil	99547.086	3	33182.362	44.528	.000
wks	13678.838	2	6839.419	9.178	.003
soil * wks	23715.345	6	3952.558	5.304	.005
Error	10432.833	14	745.202		
Total	343916.250	26			
Corrected Total	161383.087	25			

a. R Squared = .935 (Adjusted R Squared = .885)

Multiple Comparisons

TSS Tukey HSD, Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	100.9554	14.12826	.000	59.8906	142.0201
	Red Lateritic Soil	157.3125	13.64920	.000	117.6402	196.9848
	MLSF	99.1458	18.48110	.001	45.4293	152.8624
Sandy Soil	Loamy Soil	-100.9554	14.12826	.000	-142.0201	-59.8906
	Red Lateritic Soil	56.3571	14.12826	.007	15.2924	97.4219
	MLSF	-1.8095	18.83768	1.000	-56.5625	52.9435
Red Lateritic Soil	Loamy Soil	-157.3125	13.64920	.000	-196.9848	-117.6402
	Sandy Soil	-56.3571	14.12826	.007	-97.4219	-15.2924
	MLSF	-58.1667	18.48110	.032	-111.8832	-4.4501
MLSF	Loamy Soil	-99.1458	18.48110	.001	-152.8624	-45.4293
	Sandy Soil	1.8095	18.83768	1.000	-52.9435	56.5625
	Red Lateritic Soil	58.1667	18.48110	.032	4.4501	111.8832

Based on observed means. The error term is Mean Square(Error) = 745.202.

*. The mean difference is significant at the .05 level.

TSS -----Tukey HSD, Weeks of run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	63.2153	13.26464	.001	28.4980	97.9326
	8 Weeks Run	85.9931	13.26464	.000	51.2758	120.7103
5 Weeks Run	2 Weeks Run	-63.2153	13.26464	.001	-97.9326	-28.4980
	8 Weeks Run	22.7778	12.86859	.215	-10.9029	56.4585
8 Weeks Run	2 Weeks Run	-85.9931	13.26464	.000	-120.7103	-51.2758
	5 Weeks Run	-22.7778	12.86859	.215	-56.4585	10.9029

Based on observed means. The error term is Mean Square(Error) = 745.202.

*. The mean difference is significant at the .05 level.

Appendix-II-4. Conductivity

Tests of Between-Subjects Effects

Dependent Variable: Cond

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.224E6 ^a	11	565792.571	1.117	.416
Intercept	8.223E7	1	8.223E7	162.318	.000
soil	4066061.094	3	1355353.698	2.675	.087
wks	1086677.619	2	543338.810	1.072	.369
soil * wks	906575.620	6	151095.937	.298	.928
Error	7092756.333	14	506625.452		
Total	1.006E8	26			
Corrected Total	1.332E7	25			

a. R Squared = .467 (Adjusted R Squared = .049)

Multiple Comparisons

Cond-----Tukey HSD, Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	-186.3929	3.68379E2	.956	-1257.1117	884.3260
	Red Lateritic Soil	283.0000	3.55888E2	.855	-751.4127	1317.4127
	MLSF	-978.5833	4.81875E2	.223	-2379.1847	422.0180
Sandy Soil	Loamy Soil	186.3929	3.68379E2	.956	-884.3260	1257.1117
	Red Lateritic Soil	469.3929	3.68379E2	.593	-601.3260	1540.1117
	MLSF	-792.1905	4.91172E2	.403	-2219.8156	635.4346
Red Lateritic Soil	Loamy Soil	-283.0000	3.55888E2	.855	-1317.4127	751.4127
	Sandy Soil	-469.3929	3.68379E2	.593	-1540.1117	601.3260
	MLSF	-1261.5833	4.81875E2	.084	-2662.1847	139.0180
MLSF	Loamy Soil	978.5833	4.81875E2	.223	-422.0180	2379.1847
	Sandy Soil	792.1905	4.91172E2	.403	-635.4346	2219.8156
	Red Lateritic Soil	1261.5833	4.81875E2	.084	-139.0180	2662.1847

Based on observed means. The error term is Mean Square(Error) = 506625.452.

Cond-----Tukey HSD, weeks of run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	-537.5833	3.45861E2	.297	-1442.7988	367.6322
	8 Weeks Run	-502.4722	3.45861E2	.342	-1407.6877	402.7433
5 Weeks Run	2 Weeks Run	537.5833	3.45861E2	.297	-367.6322	1442.7988
	8 Weeks Run	35.1111	3.35535E2	.994	-843.0769	913.2991
8 Weeks Run	2 Weeks Run	502.4722	3.45861E2	.342	-402.7433	1407.6877
	5 Weeks Run	-35.1111	3.35535E2	.994	-913.2991	843.0769

Based on observed means. The error term is Mean Square(Error) = 506625.452.

Appendix-II-5. TDS

Tests of Between-Subjects Effects

Dependent Variable:TDS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.472E6 ^a	11	133799.474	1.075	.442
Intercept	2.082E7	1	2.082E7	167.203	.000
soil	1019423.426	3	339807.809	2.729	.084
wks	220039.070	2	110019.535	.884	.435
soil * wks	241249.509	6	40208.252	.323	.914
Error	1743065.667	14	124504.690		
Total	2.544E7	26			
Corrected Total	3214859.885	25			

a. R Squared = .458 (Adjusted R Squared = .032)

Multiple Comparisons

TDS-----Tukey HSD, Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	-62.1786	1.82618E2	.986	-592.9711	468.6140
	Red Lateritic Soil	175.5000	1.76426E2	.755	-337.2943	688.2943
	MLSF	-456.4167	2.38882E2	.268	-1150.7434	237.9101
Sandy Soil	Loamy Soil	62.1786	1.82618E2	.986	-468.6140	592.9711
	Red Lateritic Soil	237.6786	1.82618E2	.577	-293.1140	768.4711
	MLSF	-394.2381	2.43491E2	.400	-1101.9615	313.4853
Red Lateritic Soil	Loamy Soil	-175.5000	1.76426E2	.755	-688.2943	337.2943
	Sandy Soil	-237.6786	1.82618E2	.577	-768.4711	293.1140
	MLSF	-631.9167	2.38882E2	.080	-1326.2434	62.4101
MLSF	Loamy Soil	456.4167	2.38882E2	.268	-237.9101	1150.7434
	Sandy Soil	394.2381	2.43491E2	.400	-313.4853	1101.9615
	Red Lateritic Soil	631.9167	2.38882E2	.080	-62.4101	1326.2434

Based on observed means. The error term is Mean Square(Error) = 124504.690.

TDS-----Tukey HSD, Weeks of experimental run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	-236.5278	1.71455E2	.378	-685.2746	212.2190
	8 Weeks Run	-215.3056	1.71455E2	.442	-664.0523	233.4412
5 Weeks Run	2 Weeks Run	236.5278	1.71455E2	.378	-212.2190	685.2746
	8 Weeks Run	21.2222	1.66336E2	.991	-414.1261	456.5705
8 Weeks Run	2 Weeks Run	215.3056	1.71455E2	.442	-233.4412	664.0523
	5 Weeks Run	-21.2222	1.66336E2	.991	-456.5705	414.1261

Based on observed means. The error term is Mean Square (Error) = 124504.690.

Appendix-II-6. Faecal Coliform

Tests of Between-Subjects Effects

Dependent Variable: FC (Faecal Coliform)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.263E11 ^a	11	6.603E10	2.132	.092
Intercept	4.560E11	1	4.560E11	14.728	.002
soil	2.416E11	3	8.053E10	2.601	.093
wks	1.344E11	2	6.722E10	2.171	.151
soil * wks	3.176E11	6	5.293E10	1.709	.191
Error	4.335E11	14	3.097E10		
Total	1.684E12	26			
Corrected Total	1.160E12	25			

a. R Squared = .626 (Adjusted R Squared = .333)

Multiple Comparisons

FC-----Tukey HSD, Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	-69863.0966	9.10729E4	.868	-3.3457E5	194846.4495
	Red Lateritic Soil	149335.4588	8.79848E4	.361	-1.0640E5	405069.1761
	MLSF	59819.4429	1.19132E5	.957	-2.8645E5	406084.5331
Sandy Soil	Loamy Soil	69863.0966	9.10729E4	.868	-1.9485E5	334572.6427
	Red Lateritic Soil	219198.5554	9.10729E4	.121	-45510.9907	483908.1014
	MLSF	129682.5395	1.21431E5	.714	-2.2326E5	482628.6010
Red Lateritic Soil	Loamy Soil	-149335.4588	8.79848E4	.361	-4.0507E5	106398.2586
	Sandy Soil	-219198.5554	9.10729E4	.121	-4.8391E5	45510.9907
	MLSF	-89516.0158	1.19132E5	.875	-4.3578E5	256749.0744
MLSF	Loamy Soil	-59819.4429	1.19132E5	.957	-4.0608E5	286445.6473
	Sandy Soil	-129682.5395	1.21431E5	.714	-4.8263E5	223263.5219
	Red Lateritic Soil	89516.0158	1.19132E5	.875	-2.5675E5	435781.1060

Based on observed means. The error term is Mean Square (Error) = 30965302123.719.

FC-----Tukey HSD, weeks of Experimental run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	58159.9117	8.55059E4	.779	-1.6563E5	281952.7296
	8 Weeks Run	-143891.9394	8.55059E4	.246	-3.6768E5	79900.8785
5 Weeks Run	2 Weeks Run	-58159.9117	8.55059E4	.779	-2.8195E5	165632.9062
	8 Weeks Run	-202051.8511	8.29529E4	.070	-4.1916E5	15059.0728
8 Weeks Run	2 Weeks Run	143891.9394	8.55059E4	.246	-79900.8785	367684.7573
	5 Weeks Run	202051.8511	8.29529E4	.070	-15059.0728	419162.7750

Based on observed means. The error term is Mean Square(Error) = 30965302123.719.

Appendix-II-7. Total Coliform

Tests of Between-Subjects Effects

Dependent Variable:TC (Total Coliform)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.405E13 ^a	11	1.278E12	7.666	.000
Intercept	9.297E12	1	9.297E12	55.786	.000
soil	4.967E12	3	1.656E12	9.934	.001
wks	4.507E12	2	2.254E12	13.523	.001
soil * wks	6.835E12	6	1.139E12	6.835	.002
Error	2.333E12	14	1.667E11		
Total	2.280E13	26			
Corrected Total	1.639E13	25			

a. R Squared = .858 (Adjusted R Squared = .746)

Multiple Comparisons

TC-----Tukey HSD, Soil types

(I) soil	(J) soil	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Loamy Soil	Sandy Soil	357440.4757	2.11283E5	.364	-2.5667E5	971550.0884
	Red Lateritic Soil	603206.2500	2.04119E5	.046	9919.9993	1.1965E6
	MLSF	-8.6075E5	2.76379E5	.034	-1.6641E6	-57436.6190
Sandy Soil	Loamy Soil	-357440.4757	2.11283E5	.364	-9.7155E5	256669.1370
	Red Lateritic Soil	245765.7743	2.11283E5	.658	-3.6834E5	859875.3870
	MLSF	-1.2182E6	2.81711E5	.003	-2.0370E6	-3.9938E5
Red Lateritic Soil	Loamy Soil	-6.0321E5	2.04119E5	.046	-1.1965E6	-9919.9993
	Sandy Soil	-245765.7743	2.11283E5	.658	-8.5988E5	368343.8384
	MLSF	-1.4640E6	2.76379E5	.001	-2.2673E6	-6.6064E5
MLSF	Loamy Soil	860750.0000	2.76379E5	.034	57436.6190	1.6641E6
	Sandy Soil	1.2182E6	2.81711E5	.003	399377.6588	2.0370E6
	Red Lateritic Soil	1.4640E6	2.76379E5	.001	660642.8690	2.2673E6

Based on observed means. The error term is Mean Square(Error) = 166658667831.932.

*. The mean difference is significant at the .05 level.

TC-----Tukey HSD, weeks of experimental run

(I) wks	(J) wks	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 Weeks Run	5 Weeks Run	772363.2867	1.98368E5	.004	253177.9276	1.2915E6
	8 Weeks Run	513235.1389	1.98368E5	.053	-5950.2201	1.0324E6
5 Weeks Run	2 Weeks Run	-7.7236E5	1.98368E5	.004	-1.2915E6	-2.5318E5
	8 Weeks Run	-259128.1478	1.92445E5	.394	-7.6281E5	244555.6345
8 Weeks Run	2 Weeks Run	-513235.1389	1.98368E5	.053	-1.0324E6	5950.2201
	5 Weeks Run	259128.1478	1.92445E5	.394	-2.4456E5	762811.9300

Based on observed means. The error term is Mean Square(Error) = 166658667831.932.

*. The mean difference is significant at the .05 level.

Appendix-II-8. One Way ANOVA test for impact of soil depth

		Sum of Squares	df	Mean Square	F	Sig.
BOD	Between Groups	7753.362	3	2584.454	.555	.650
	Within Groups	102513.880	22	4659.722		
	Total	110267.243	25			
COD	Between Groups	14039.876	3	4679.959	.056	.982
	Within Groups	1824551.970	22	82934.180		
	Total	1838591.846	25			
TSS	Between Groups	5613.576	3	1871.192	.264	.850
	Within Groups	155769.510	22	7080.432		
	Total	161383.087	25			
Cond	Between Groups	1.017E7	3	3389437.239	23.686	.000
	Within Groups	3148162.899	22	143098.314		
	Total	1.332E7	25			
TDS	Between Groups	2524508.129	3	841502.710	26.817	.000
	Within Groups	690351.756	22	31379.625		
	Total	3214859.885	25			
FC	Between Groups	1.092E11	3	3.640E10	.762	.527
	Within Groups	1.051E12	22	4.776E10		
	Total	1.160E12	25			
TC	Between Groups	3.701E12	3	1.234E12	2.140	.124
	Within Groups	1.269E13	22	5.767E11		
	Total	1.639E13	25			

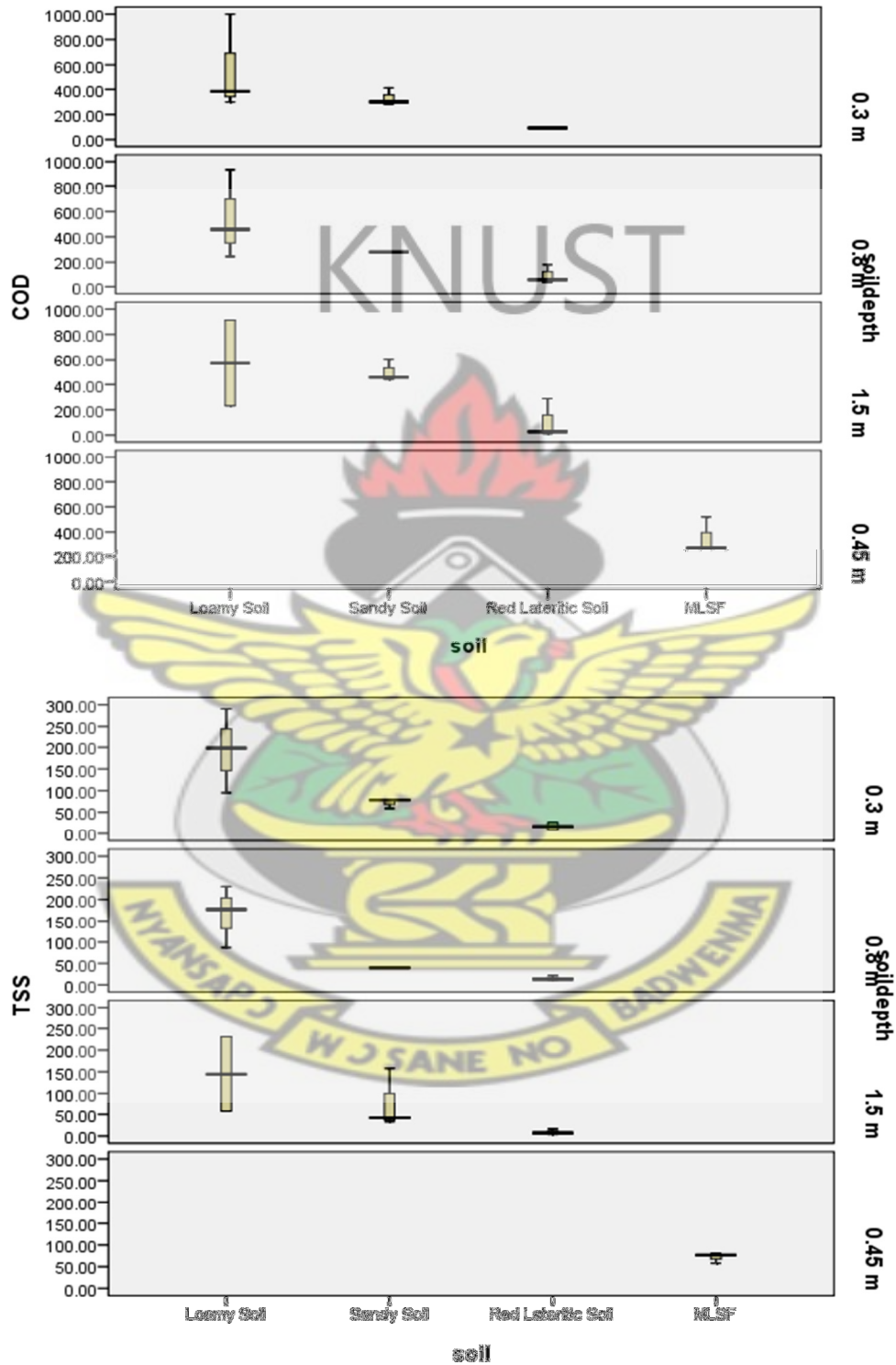
Multiple Comparisons (between various depths)

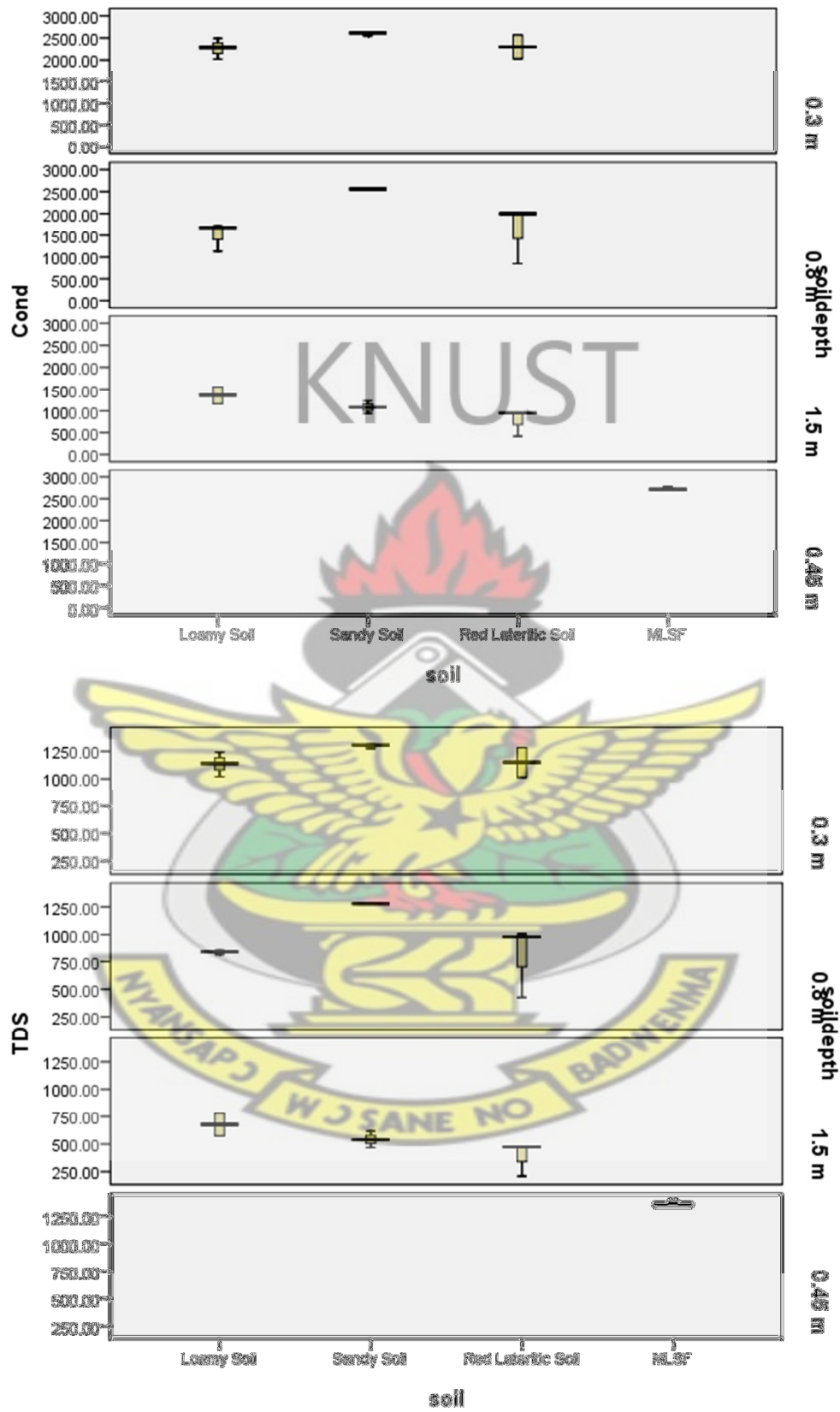
Tukey HSD, Depths

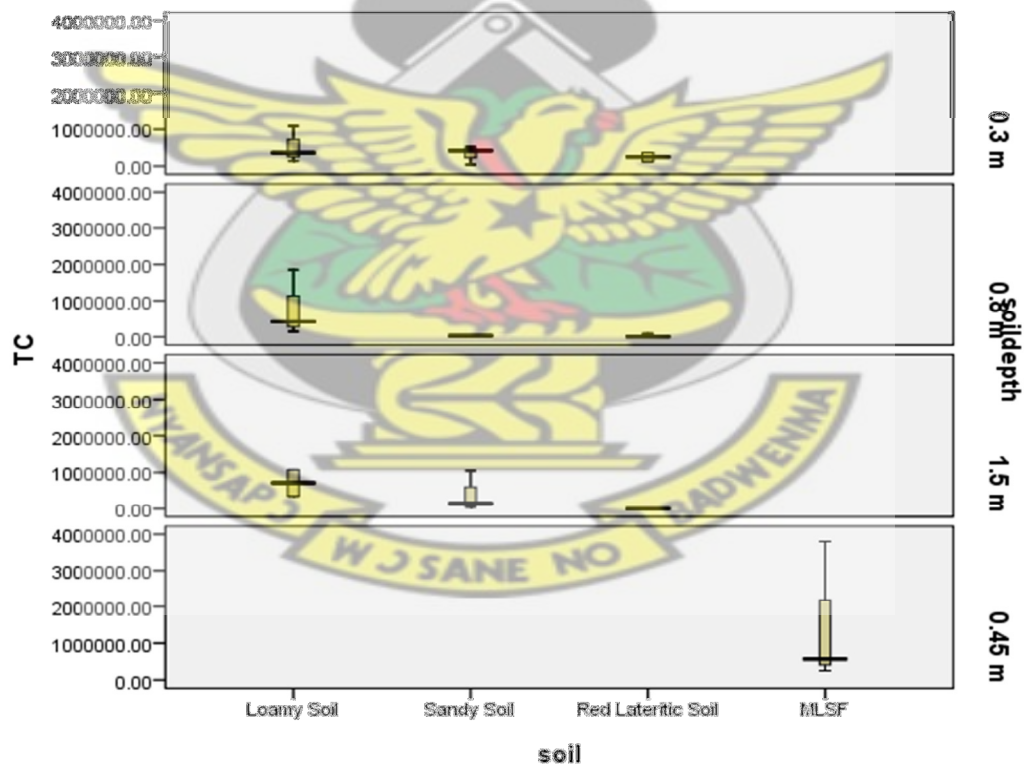
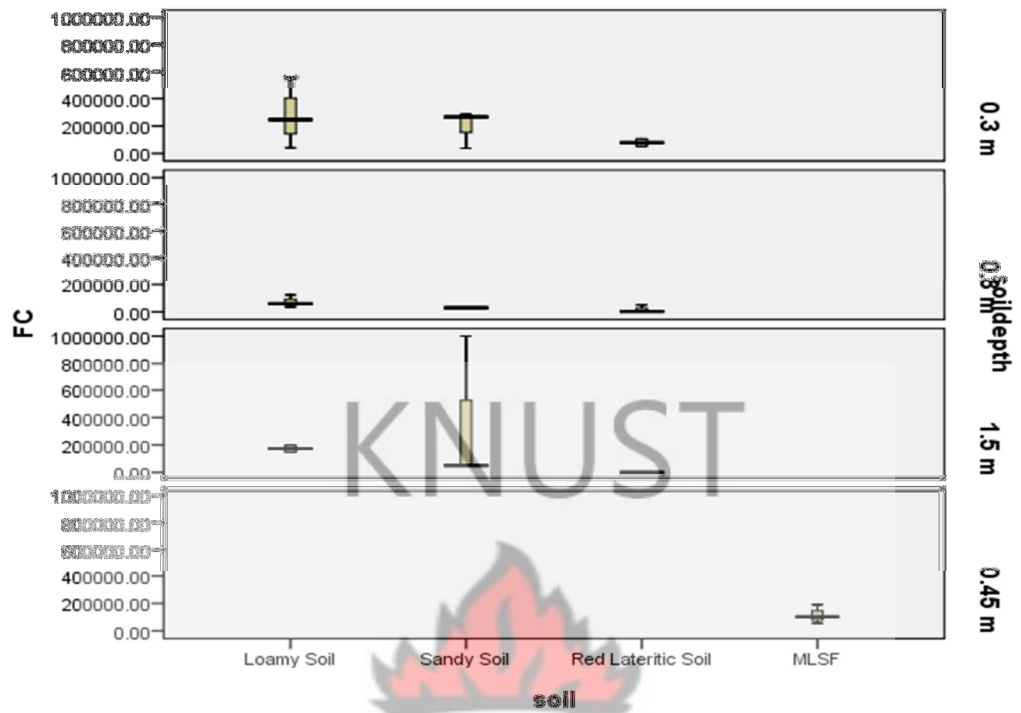
Dependent Variable	(I) soildepth	(J) soildepth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Cond	0.3 m	0.8 m	690.23214	1.95780E2	.010	146.5825	1233.8817
		1.5 m	1360.62500	1.89142E2	.000	835.4096	1885.8404
		0.45 m	-336.95833	2.56099E2	.563	-1048.1034	374.1867
	0.8 m	0.3 m	-690.23214	1.95780E2	.010	-1233.8817	-146.5825
		1.5 m	670.39286	1.95780E2	.012	126.7433	1214.0425
		0.45 m	-1027.19048	2.61040E2	.004	-1752.0566	-302.3243
	1.5 m	0.3 m	-1360.62500	1.89142E2	.000	-1885.8404	-835.4096
		0.8 m	-670.39286	1.95780E2	.012	-1214.0425	-126.7433
		0.45 m	-1697.58333	2.56099E2	.000	-2408.7284	-986.4383
	0.45 m	0.3 m	336.95833	2.56099E2	.563	-374.1867	1048.1034
		0.8 m	1027.19048	2.61040E2	.004	302.3243	1752.0566
		1.5 m	1697.58333	2.56099E2	.000	986.4383	2408.7284
TDS	0.3 m	0.8 m	313.32143	91.68019	.012	58.7406	567.9023
		1.5 m	682.12500	88.57148	.000	436.1766	928.0734
		0.45 m	-165.91667	1.19926E2	.522	-498.9324	167.0991
	0.8 m	0.3 m	-313.32143	91.68019	.012	-567.9023	-58.7406
		1.5 m	368.80357	91.68019	.003	114.2227	623.3844
		0.45 m	-479.23810	1.22240E2	.004	-818.6792	-139.7970
	1.5 m	0.3 m	-682.12500	88.57148	.000	-928.0734	-436.1766
		0.8 m	-368.80357	91.68019	.003	-623.3844	-114.2227
		0.45 m	-848.04167	1.19926E2	.000	-1181.0574	-515.0259
	0.45 m	0.3 m	165.91667	1.19926E2	.522	-167.0991	498.9324
		0.8 m	479.23810	1.22240E2	.004	139.7970	818.6792
		1.5 m	848.04167	1.19926E2	.000	515.0259	1181.0574

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

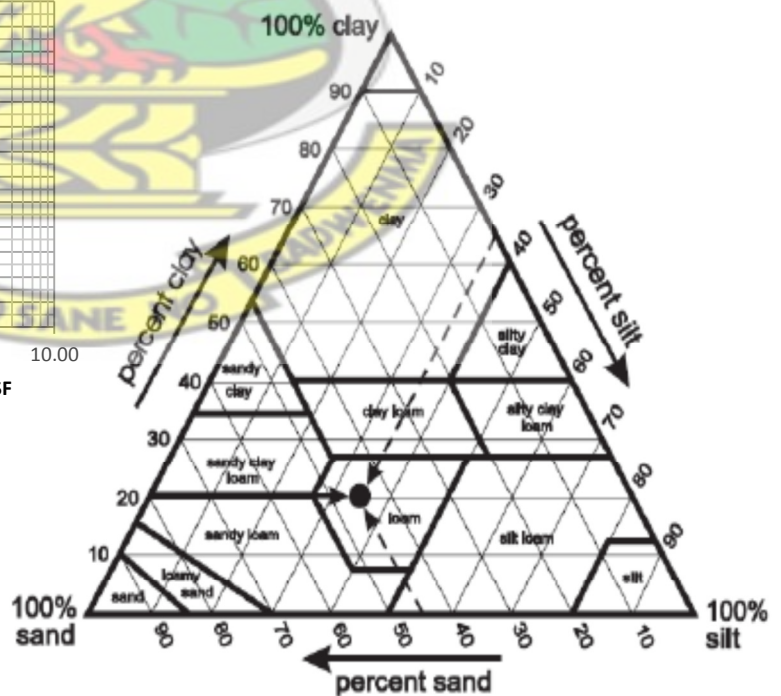
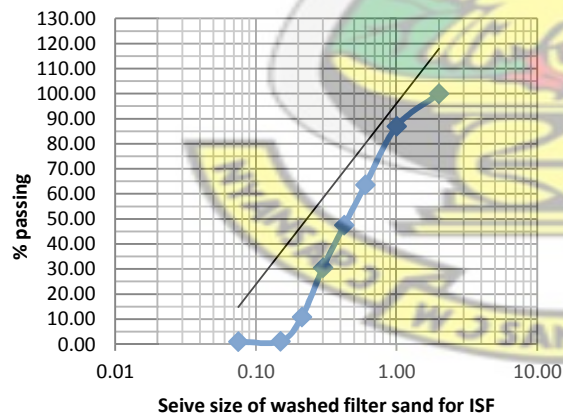
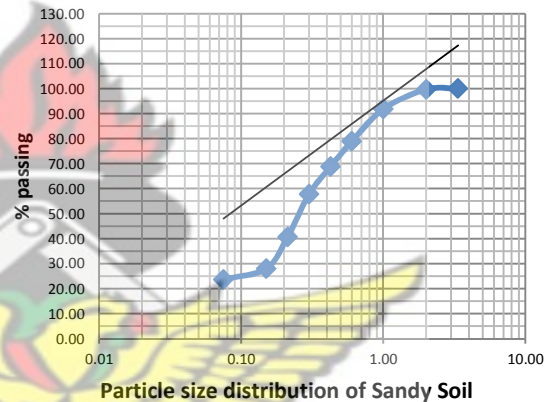
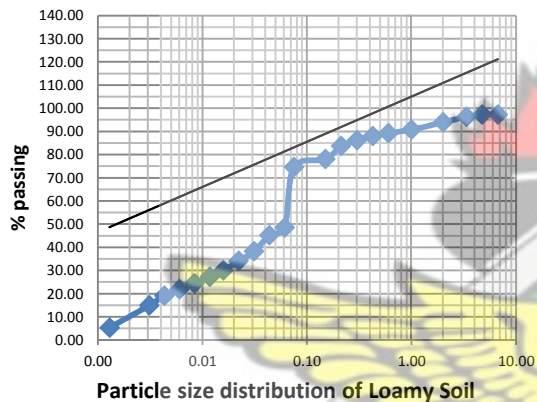
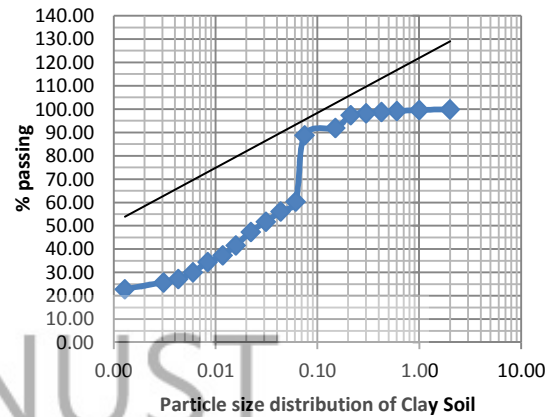
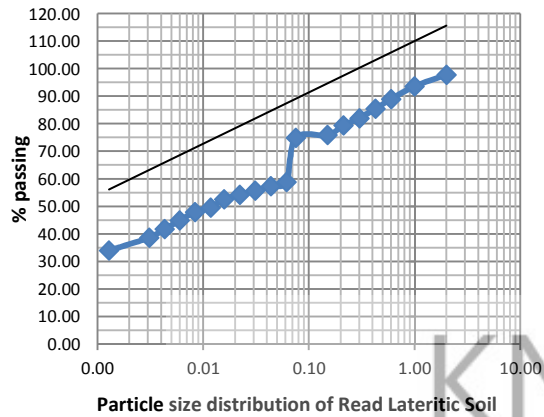
Appendix-III. Box plot of soil column treated effluent COD, TSS, conductivity, TDS, total coliform and faecal coliform at various infiltration depths during two months experimental period







Appendix-IV. Charts used for particle size analysis and soil classification tests



Appendix-V. Permeability data

Clay soil						Loamy Soil					
Test #	Volume (ml)	Time (min)	Permeability (ml/min)	q (cm/Sec)	k	Test #	Volume (ml)	Time (min)	Permeability (ml/min)	q (cm/Sec)	k
1	85	30	2.83	0.047	0.00007	1	250	15	16.67	0.278	0.00039
2	150	60	2.50	0.042	0.00006	2	265	27	9.81	0.164	0.00023
3	132.5	60	2.21	0.037	0.00005	3	275	24	11.46	0.191	0.00027
AVG	-	-	2.51	0.042	0.00006	4	280	30	9.33	0.156	0.00022
				k	0.0001	5	275	31	8.87	0.148	0.00021
				AVG	-	-	11.23	0.187	0.00026		
								k	0.0003		
Sandy Soil						Red Lateritic soil					
Test #	Volume (ml)	Time (min)	Permeability (ml/min)	q (cm/Sec)	k	Test #	Volume (ml)	Time (min)	Permeability (ml/min)	q (cm/Sec)	k
1	320	2	160.00	2.667	0.00377	1	300	11	27.27	0.455	0.00064
2	345	3	115.00	1.917	0.00271	2	285	14	20.36	0.339	0.00048
3	360	3	120.00	2.000	0.00283	3	270	15	18.00	0.300	0.00042
4	300	3	100.00	1.667	0.00236	4	300	19	15.79	0.263	0.00037
5	285	3	95.00	1.583	0.00224	5	300	20	15.00	0.250	0.00035
6	355	4	88.75	1.479	0.00209	AVG	-	-	19.28	0.321	0.00045
7	335	4	83.75	1.396	0.00197					k	0.0005
8	310	4	77.50	1.292	0.00183						
9	305	4	76.25	1.271	0.00180						
10	290	4	72.50	1.208	0.00171						
AVG	-	-	98.88	1.648	0.00233						
				k	0.0023						

NB: Formula and dimensions used to compute permeability coefficient, k

$k = qL/Ah;$ Where k = Coefficient of permeability in cm/sec q = discharge cm^3/sec L = Length of Specimen in cm A = Cross-sectional area of specimen (cm^2) h = Constant head causing flow in cm	diameter	7.5cm
	A (cm^2)	$\pi(d^2/4)$
		$\pi(7.5)^2/4)$
		44.18
	L (cm)	10
	h (cm)	160
	k	qL/Ah