UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCE

EVALUATION OF LANDFILL EFFECTS ON SOIL AND WATER SOURCES, A CASE STUDY OF THE WHEIN TOWN SANITARY LAND FILL, MONTSERRADO COUNTY-LIBERIA

BY

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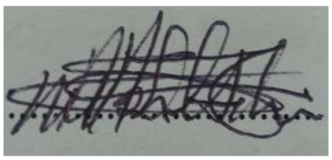
DECLARATION

This is to certify that I, Stephen M. Gibson carried out this research work in the Institute for Environment and Sanitation Studies, University of Ghana under the guidance of my supervisors. The thesis has never been presented, either in part or whole for a degree in this university or any institution. All cited works have been fully acknowledged.



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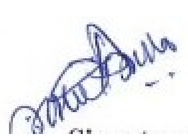

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ABSTRACT

The study investigated the perceptions of the inhabitants of Whein Town on the effects of the activities of Whein Town Sanitary landfill in Monrovia, Liberia, and evaluated real time health hazards posed on the community. The Whein Town Engineered Landfill was developed with an integrated solid waste management motive. Even though the landfill lifespan expired at the end of 2016, active landfill activities are still ongoing. Liners may have deteriorated, thereby resulting in infiltration of leachates into ground and surface water sources, resulting in their contamination and consequent health attendants. Frequent flooding of adjoining agriculture lands by leachates from the landfill is perceived to have reduced the quality of the land for its intended purpose. Inhabitants of Whein town therefore have every justification to believe that the improperly sited landfill, which is currently over-aged and ill-managed, is responsible for most of their predicaments. The study was therefore conducted to verify the effects of the landfill on soils, water sources as well as health of inhabitants of Whein Township.

Questionnaires were distributed to ascertain citizens' perceptions on the effect of the landfill activities in the study area. Total Dissolved Solids (TDS), pH, Electrical Conductivity (EC) and 5-day Biochemical Oxygen Demand (BOD_5) were analysed on samples of potable water sources from hand-dug well and stream water (surface water) as well as leachates from the landfill's wastes stabilization ponds. Calorimetric method was used to analyse the levels of 6 heavy metals (Zn, Cu, Pb, Cd, Cr, Fe) in the samples while Atomic Absorption Spectrophotometer was used to determine the levels of the same heavy metals in soils samples.

The potential ecological risk assessment method by Hakanson. L, (1980) was used to determine the level of contaminations of the soils by the heavy metals. The BOD and TDS levels were higher than WHO permissible limits while the heavy metals studied had appreciable levels to constitute contamination. It was inferred that leachates discharges were responsible for the contamination of the water sources. The results of heavy metal pollution assessment indicated that the mean contamination factor (Cf) values recorded for all the elements had a range of 0.0219mg/kg – 19.9506mg/kg and follows the descending order of: Cd > Pb > Cu > Zn > Cr. The degree of contamination (CD) index was 20.12mg/kg which indicated that there was considerable contamination by the heavy metals. The potential ecological risk assessment indices of single elements was in the descending order of Cd > Pb > Cu > Cr > Zn. Cadmium was the key influence factor causing the risk with its mean value as high as 601.73mg/kg. The range of the comprehensive potential ecological risk (RI) was 555.147mg/kg – 651.063mg/kg and which indicated a very strong degree of ecological pollution and damage in the soil.

It is therefore recommended that a critical assessment of the performance of the landfill be performed to possibly enable its urgent decommissioning since it has over-lived its useful life span. Also, safe drinking pipe borne water should be supplied to the community to discourage inhabitants from harvesting from their present sources of drinking water and further, blood analysis should be conducted to evaluate heavy metals body burdens of the inhabitants of the study area and its environs. This will help to diagnose and prepare for the on-set of any heavy metal-associated disease.

DEDICATION

I dedicate this thesis to the glory of God Almighty, the Environmental Protection Agency of Liberia (EPAL), the Liberia Forest Sector Program (LFSP) and to my beloved family and colleagues.

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Firstly, I pay my deepest gratitude to God Almighty for granting me continuous strength, wisdom, and passion to complete this investigative study. I am grateful to the management team of the Liberia Forest Sector Program (LFSP) for providing the timely and adequate funding through the Project Financial Management Unit (PFMU) / Ministry of Finance and Development Planning of Liberia for my full tuition payments.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
AWWA	American Water Works Association
BOD	Biochemical Oxygen Demand
CD	Degree of Contamination
CDM	Clean Development Mechanism
Cf	Contamination factor
$C_{i,}$	Concentration of each analyzed heavy metal
CNS	Central Nervous System
DO	Dissolved Oxygen
EMUS	Emergency Monrovia Urban Sanitations Project
EPAL	Environmental Protection Agency of Liberia
EPML	Environmental Planning and Management Act of Liberia
E^i_R	Potential ecological Risk factor of a Single element
ESIA	Environmental Social Impact Assessment
FAO	Food and Agriculture Organization
FDA	Forestry Development Authority

GPS	Global Positioning System
IDA	International Development Agency
IMF	International Monetary Fund
LIGIS	Liberia Institute of Statistic and Geo-Information Services
LRTF	Liberia Reconstruction Trust Fund
LWSC	Liberia Water and Sewer Corporation
MCC	Monrovia City Corporation
MHSW	Ministry of Health and Social Welfare
MME	Ministry of Mines and Energy
MPEA	Ministry of Planning and Economics Affairs
MPW	Ministry of Public Works
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MW	Monitor Well
NEOHP	National Environmental and Occupation Health Policy

NSPE –USA	National Society of Professional Engineers, United States of America
PCC	Paynesville City Corporation
PPA	Pollution Prevention Act
PNS	Peripheral Nervous System
RI	Potential Ecological Risk index
SDG	Sustainable Development Goals
S_i	Background Concentration or Pre-industrial value
SW	Stream Water
TDS	Total Dissolved Solids
T^i_R	Biological Toxic Response Risk Factor of each element,
UEEE	Used Electronics and Electrical Equipment
UELG	Used and End – of – Life Goods
UN	United Nations
UNDP	United Nation Development Fund
UNEP	United Nation Environmental Program

UNEP-IETC	United Nation Environmental Program- International Environmental Technology Centre
USGS	United State Geological Survey
UNICEF	United Nation International Children Education Fund
US-EPA	United State Environmental Protection Agency
US-MSWGRD	United State - Municipal Solid Waste Generation, Recycling and Disposal Department
W C	Well Control
WEF	Water Environment Federation
WSPs	Waste Stabilization Ponds

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CHAPTER ONE

INTRODUCTION

1.1 Background

Waste may generally be described as the "useless" by-product of human activity. The Waste Framework Directive (EU) (2008) has however inferred that, waste is anything intended for recycle, recovery, reuse, or refine by a process from that which produced the original resources. Globally, waste disposal is one of the major environmental problems that confront municipal authorities. In most developing countries, generation and accumulation of solid wastes usually outstrip the collection and disposal leading to major challenges in the management of solid wastes in cities and urban centres (Douti *et al*., 2017). Solid Waste Management is the discipline associated with generation, storage, collection, transport, processing and disposal of waste (Tchobanoglous and Kreith, 2002). An integrated solid waste management is indicated to include selection and application of suitable techniques, technologies and management programs that achieve sound environmental waste management objectives and goals.

Source reduction or recycle, incineration and landfill are some methods of waste management worldwide but of all the options, landfill is most popular, because its operations is the cheapest and its site can contain huge volume of waste. Meanwhile, Section 1.1 of the "Waste Hierarchy" gives high priority to preventing waste primarily, therefore when waste is created; it should be prepared for re-use, recycling, recovery and lastly disposal through incineration or in landfill. Even though waste may be incinerated, the residues from its operations are disposed off finally in landfills. In 2011, most (53.6%) of the municipal solid wastes generated in the United States of America were deposited in

1,908 landfills; 44% of England's 68 million tonnes of waste produced in 2002/2003 were land filled; China landfills between 70 and 80% waste generated, whilst disposal of wastes in landfills constitutes about 80% of the total waste generated in Canada (U.S.EPA, 2013). According to Bagchi, (1994), landfill is an engineered deposition of waste onto or into land, such that pollution or harm to the environment is prevented, and the land is capable of being restored for future use.

A landfill is carefully designed to eliminate soil, water sources and air contaminations, but if there is any contamination, the level may be minimized in all forms. Elliotte *et al., (*2009) noted that it is mainly used in low income countries due to its low economic advantages.

Worldwide, municipal solid waste has the potential of posing danger to public health and the environment when its management system does not meet sound environmental management standards. A standardized landfill site is carefully selected, well-constructed and maintained through engineering techniques, to ensure minimal pollution of air, water and soil, and risks to public health. A standardized landfill system involves, placing wastes in sanitary landfills with appropriate technique of controlling and collecting leachates and gases produced (Alloway *et al.*, 1997; Eludoyin *et al.*, 2010; Swati *et al*., 2014), as well as other pollutants.

Engineered or sanitary landfills are often lined with layers of permeable materials to restrict or limit leachates seeping into soils and ground water. However, Lamb *et al*., (2012) intimated that, landfills operation may result in serious adverse consequences on the environment and public health, if not managed properly. Therefore, they are potential sources of ground and surface water sources, soils, plants and air pollutions from leachates, gases and other contaminants produced and released.

Landfills attract pests, and emit unpleasant gases and odours, which may be hazardous to public health. A gas such as methane is also explosive. Poyry Environment GmbH, (2010) inferred that, methane is explosive, when it reaches the range of 5% to15% volume in the air.

Presently, in Monrovia, the capital city of Liberia, aside a 10 hectares Whein Town Sanitary Landfill, most wastes are gathered, dumped and burnt in open dumpsites along streets corners, market grounds and vacant lands. Prior to construction and commissioning of the Whein Town Sanitary Landfill in 2012, disposals of municipal solid wastes were in a dumpsite in Fiamah community and other opened dumpsites managed by the government of Liberia through the Monrovia City Corporation (MCC) in Monrovia. By then, uncontrolled burning practices were on the increase, hence creating a source and increasing nuisance for nearby communities and resulting in increased numbers of mosquitoes, flies, cockroaches, and rats' populations. Earthtime INC, (2008) stated that, the need to decrease adverse impacts from conventional landfills and uncontrolled waste burning prompted the construction of Whein Town Sanitary landfill on the outskirt of Monrovia.

In 2004, the United Nation International Children Fund (UNICEF) provided technical supports to the MCC for a landfill site locations and conceptual designs. Further, with UNICEF's funding supports, the Liberia Reconstruction Trust Fund (LRTF) conceived the constructions of Whein Town Sanitary Landfill, as an "Emergency Intervention" to collect half of the waste generated within Monrovia and its environs (Earthtime INC, 2008). The LRTF in 2009 began supporting the "Emergency Monrovia Urban Sanitation Project" (EMUSP), which gave birth to the Whein Town Saniatry Landfill, the first engineered landfill in Liberia (Earthtime INC, 2008). Hence, in 2012, the landfill's compound was entirely fenced with boundary non-combustible wire screens to intercept scattering litter and stop trespassing. However, and not for long after, segments of the fence collapsed, thereby providing means for scattered litter in the community to enter the stream waters especially in the wet season, and allowing entry to unauthorized individuals, and scavengers, who go in search of vegetables, crops and recyclable resources as the inadequate landfill's securities assigned to monitor the compound are unable to safeguard the entire site.

The 18 metres long weighbridge positioned to weigh wastes' vehicles entering and leaving the site, computers and visual display screens, and printing equipment are non-functional. Further, majority of the waste management equipment at site are in need of significant repairs, maintenance or have broken down completely. Eight Waste Stabilization ponds (WSPs) were constructed to manage the landfill's leachates, but presently, only five amongst eight ponds are functional, while the channel (pipes) installed to transmit leachates into the WSPs are partially functional due to lack of maintenance and services over a long period of time. At the same time, segments of the liners installed, at the edges of the primary ponds and around the perimeter of the main wastes disposal cells have deteriorated, thereby resulting in overflow of untreated leachates into adjacent ponds, adjoining land (soils) and streams (Appendix 1), especially during the raining season. Presently, the inadequate space at the landfill has prompted the MCC to accelerate the development of Cheesemanburg Sanitary Landfill, which is currently under constructions.

1.2 Problem Statement

Earthtime INC, (2008) noted that, "the proper operations of the Whein Town sanitary landfill and its facilities are expected to reduce health risks associated with the open unsanitary disposal of wastes that promotes the breeding of disease vectors and pests, as well as the contamination of groundwater, surface water and soil which all lead to an increase in the incidences of parasitic infections, hepatitis, malaria, plague along with gastrointestinal disease including cholera and typhoid".

Generally, landfill serves as final disposal site for wastes, but it adversely affect public health and the environment as wastes decompose and produce leachates, gases and other contaminants. Hence, landfills' contaminants may percolate or migrate into soil and water sources, if not controlled and properly managed when released. Liberia is a tropical climate country with rainfall between 2,000 to 4,000 millimetres per year and a high water table, with average depth ranging from 7 to 13 metres below ground level (United Nations/ World Bank/ International Monetary Fund, 2003 -2004); hence, easily making water accessible to shallow wells development and contaminants from point and non-point sources.

Majority of the inhabitants of Whein Town depend on shallow wells for their potable water source. Meanwhile, Earthtime INC, (2008) declared that, the location of the landfill in Whein Town poses a significant threat on surface water, as the facility is located within extensive seasonal rain waterway drainage, few metres away from a creek and an adjoining swamp. Therefore, the contaminations of the streams as a result of inadequate control or mismanagement of generated leachates and other contaminants may affect groundwater during its replenishment through the water cycle, as the water table in the area is less than 1.5 metres below ground level.

The Whein Town Sanitary Landfill was identified and developed with an integrated solid waste management motive. However, Earthtime INC, (2017) noted that, the landfill lifespan expired at the end of 2016, and is due to be decommissioned by mid- 2017. Yet, active landfill activities are ongoing even though liners may have deteriorated, thereby resulting in the infiltration and migration of leachates and other contaminants into adjoining land and ground and surface water sources respectively. Additionally, the erosion of heaps of waste, coupled with inadequate, or lack of proper management of the site, may pose serious public health threats to the inhabitants of Whein Town community, especially those within the immediate vicinity of the landfill. In March, 2016, after residents protested against their water sources being contaminated from the landfill's activities, the government of Liberia quickly constructed two 500 litres potable water reservoirs as corrective measures. But, due to inadequate and irregular refilling of the reservoirs, the residents quickly reverted to the use of lined and unlined wells' as sources of water for drinking and other household activities to survive.

Currently, all but five of the eight waste stabilization ponds (WSPs) at the facility are partially functional, while the conveying channels that convey the leachates into the WSPs are partially blocked due to inadequate and irregular maintenance. Further, segments of the liners at the perimeters of the main deposit site cells and WSPs have deteriorated, or have been removed from their original positions, resulting to leakage and overflow of unguarded and untreated leachates into storm water, flood plains, surface water and adjoining soils, especially during raining season.

Presently, inhabitants of the study catchment think the migrated and infiltrated leachates and other contaminants have more or less improved their soils. Consequently, active agricultural activities are in progress; at the same time the near-by stream waters are being used for agricultural and fishing purposes (Appendix 2) respectively. Additionally, pesticides and fertilizers are being used to enhance agricultural yield. Depending on the adjoining soils and water resources for gardening products, fishing, and household activities respectively may exposed the inhabitants to health risks as the soils, water sources, vegetables, crops and fishes are susceptible to contaminations from the landfill. The porous soils and water sources within proximity to the landfill get contaminated, when leachates, percolate and migrate, or are accidentally released into water sources. Sanusi, (2013) reported that, the quality of air, soil and water from contaminations within and around landfills sometimes constitute health hazard to near-by communities. Hence, humans and other species may encounter health hazards from contaminants through food web as in the case of the inhabitants of the studied catchment, as a result of ingesting fruits, vegetables, crops and other plants and animals products that may have acquired contaminants through roots, leaves and mouth ingestions and eventually biomagnified.

Although the adjoining soils and water sources in the study area may be contaminated, but the extent of contaminations are unknown. Currently, there is no report of any study in literature that examines the effects of Whein Town Sanitary Landfill on water sources and soils quality, as well as the inhabitants' perceptions on the operation of the landfill in the study catchment. Hence, there is a need to conduct this study, as it offers the chance to provide empirical data on water sources, leachates and soils qualities within the study area. It is anticipated that information from this research will be useful in making decisions for

Chessmanburg Sanitary Landfill project, as well as forecasting the need to execute the decommissioning of Whein Town Engineered Landfill site. The study also generates necessary data that could prove useful to the Environmental Protection Agency of Liberia (EPAL), Non-Governmental Organizations (NGOs), Community dwellers as well as, environmentalists and researchers.

1.3 Research Question

Considering the neglected state of Whein Town Sanitary Landfill, many questions that need investigative solutions readily come to mind, for instance;

i. How heavy is the leachate production from the landfill?

ii. Does the leachate contain heavy metals, and to what extent, is the landfill design capable of containing the leachate?

iii. To what extent are water sources and agricultural soils within the vicinity contaminated?

iv. What are the communities' perceptions and assessment of the effects of the landfill on their daily lives?

v. What are the real time health implications?

1.4 Research Objectives

Based on the research questions enumerated above, the main objective of this study is to ascertain citizens' perceptions on the effect of the landfill; and to evaluate real time health hazards the landfill poses to neighborhood communities.

The specific objectives of the study are:

i. To assess the levels of some Physico-Chemical parameters, in soils and water sources in the study area;

ii. To determine the levels of heavy metals in leachates from the landfill, some drinking water sources and the surrounding agricultural soils;

iii. To assess the contamination factors (Cf) and degree of contamination (CD) of heavy metals in soils within the surrounding areas of the landfill;

iv. To verify the ecological risk imposed by individual heavy metals within the vicinity of the landfill;

v. To evaluate the comprehensive potential ecological risk index of the heavy metals in the soils and make recommendations.

1.5 Significance of the Study

The findings of the study will serve as a source of information on the impacts of the landfill activities on soils and water sources quality, and perceptions of the inhabitants in the study area for a wide range of stakeholders. It would help raise awareness of important challenges relating to the environmental health of the inhabitants and the provision of potable water. The overall effect will be to encourage local and international supports and to strive for more effective environmental management plans for the site and community. The study also generates necessary data that could prove useful to the proponent of the landfill, the Environmental Protection Agency of Liberia (EPAL), Non-Governmental Organizations (NGOs), the study community dwellers, as well as environmentalists and researchers.

1.6 Scope of the Study

A total of one hundred and fifty two (inclusive of replica) water samples were collected from active wells, surface or stream water, semi-functional wastes stabilization ponds, and monitor wells positioned in the study community and the landfill's compound respectively. Ninety six soils samples including duplication were collected in the study community for analysis. Additionally, one hundred and twenty five questionnaires were administered to some inhabitants of the study catchment. The study community where the questionnaires were administered constituted: Telecom Community - Block C; Telecom Earth Station Community- Block D; Oldfield Community - Block F; and the Whein Town Old field Community - Block G. The study was conducted from September 2018, to January 2019 to cover both wet and dry seasons. The Physico-chemical parameters considered are: pH, Electrical Conductivity (EC), Biochemical Oxygen Demand (BOD), Total Dissolved Solids (TDS), Cadmium (Cd) Copper (Cu^{+2}), Lead (Pb^{+2}), Chromium (Cr), Zinc (Zn^{+2}), and Iron (Fe^{+2}).

CHAPTER TWO

LITEATURE REVIEW

2.1 Global Waste Disposal Systems in the World

The continuous generation of wastes, which the earth is presently unable to manage naturally is due to increasing population and industrialization, coupled with needs and wants of Earth's inhabitants. Gathering, handling, proper management and disposal of municipal solid waste (MSW) in an organized and safe manner, resulting to no adverse environmental consequence are human's concern at the moment. Waste should be avoided if not, it should be reduced, reused, recycled or recovered and only disposed off, if it cannot be converted into something useful (Waste Framework -EU, 2008).

Waste management is a process involving the collection, proper and adequate handling, transportation, recycling and final disposal through incineration or land-filling. Hence, all of these activities are attained through appropriate and sound management of equipment and site. Generally, municipal solid wastes disposal involves recycling, incinerating and land-filling, though Section 1.1 of the "Waste Hierarchy" gives high priority to preventing waste primarily. Prior to population growth and industrialization, sanitary landfilling and incinerating were not common solid wastes deposal methods in most developing countries but open dumps, referred in this text as "conventional landfills", were rather the preferred method employed by most communities as the importance of sanitary landfills and incinerators were not adequately broadcast, which may have been due to less wastes productions and environmental consequence then.

Currently, most rural and urban communities in developing countries use conventional landfills for solid waste disposal, as inadequate sanitary landfills are constructed as alternative to minimized or avoid environmental pollutions.

The United Nations Conference on Environment and Development (Agenda 21, Rio 1992), Chapter 21 emphasizes reducing wastes through the concepts of reuse, recycle and recovery. In Accra, Ghana and Lagos, Nigeria the reused or revamped sector provides income to more than 30,000 people (Secretariat of the Basel Convention, 2012). The management of used electronics and electrical equipment (UEEE) considered "wastes" serve as important economic and social factors in developing countries. However, the Basel Convention's framework focused generally on three pillars: (i) the universal coordination for the trans-boundary movement of wastes; (ii) the sound environmental management of wastes; and (iii) reducing the production of wastes (Secretariat of the Basel Convention, 2012), throughout the world.

Incineration is a waste disposal option and an alternative to landfills in developed countries though it creates bottom ash which ends up in landfills according to the "Waste Hierarchy". The Primary objectives for incinerating municipal solid waste are: to reduce the amount of wastes (residues) to be landfilled and to produce energy in the form of heat (World Bank Technical Guidance Report: Incineration 1999). Incineration is implemented both on small and large scales basis in several countries that afford the costs of constructions, maintenance and operations. However, the failed cases of incineration in Tanzania and Nigeria demonstrate that incinerators are not sustainable for Africa, due to costs of construction, operation and maintenance (UNEP-IETC, 1996).

2.2 Landfills

According to the “Waste Hierarchy”, the final disposal of wastes should be in landfills. Dumping of municipal solid waste in landfills is one of the cheapest methods in waste management practices for organized waste management in many parts of the world (El-Fadel *et al.*, 1997; Jhamanani *et al.*, 2009; Longe *et al.*, 2010). It is predominantly used in low income countries, unlike developed countries with financial capabilities, where recycle and incineration methods are often used to reduce the volume of the wastes, before final disposal in landfills. For landfills classification, Elliotte *et al.*, (2009) intimated that, there are two classified landfills: Engineered (Sanitary) landfills and Conventional landfills (Opened dumps).

2.2.1 Sanitary (Engineered) Landfills

A sanitary landfill is a systematic, controlled and managed disposal site that host wastes of all kinds. It is a site that is carefully sited, designed, constructed and operated via a defined protocol. In the words of Bagchi, (1994), “a sanitary landfill is an engineered deposit of wastes onto or into land such that, pollution or harm to the environment is prevented”. Its operational criteria or activities include: waste disposal, compacting and subsequent application of soil cover to reduce pollution and nuisance to the environment. Swati *et al.*, (2014) noted that, sanitary landfill site allows final disposal of solid wastes in a protected manner, thereby minimizing impacts on the environment, wherein it is often lined with layers of permeable material and sheets of plastic to keep leachates from leaking into soils and ground waters.

2.2.2 Conventional Land Filling (Open Dumps)

Conventional landfills (open dumpsites) are unsystematic, uncontrolled and unmanaged disposal sites. They may be legal or illegal sites, which are found in pits, and on abandoned and vacant lands. In most developing countries for over decades, open dumping and burning of waste are the habits of the inhabitants. Classical unlined sanitary landfills and dumpsites are known to release large amounts of hazardous chemicals into ground and surface waters, and soils as well as into the air, through leachates and landfill gases (Oyibako, 2014).

2.3 Advantages or merits of Landfills

Generally, landfill serves as a final site for wastes disposal. It has a low cost of construction and flexible operation (Narayanan, 2007). It also serves as an alternative source for recyclable resources. Oyibako, (2014) noted that, landfills serve as alternative source for raw materials for recycling, thereby giving substance to the adage "one man's meat is another's poison". Landfills presumed of receiving valuable wastes are sites scavengers assemble, in pursuance of opportunities of earning income from gathering recyclable resources. They employed the recovery concepts to recover or extract resources no longer fit for their initial intended purposes; later these recovered resources are transformed into usable materials, or used in usable forms to repair spoiled used equipment.

Generally, gases are produced at landfills. The gases such as methane, carbon dioxide, and hydrogen sulphide may be captured and used for heat or power generation. Leachate is also produced from the interaction of degradable wastes, bacterial, and rainwater or moisture through biological, chemical, and physical processes. However, the sludge produced from leachates treatment via waste stabilization ponds could be used for remediation of contaminated soil; nursery growth medium; improve degraded soils and capping of the landfill. At the same time, the organic degradation resources dumped may be recovered through composting process, or can be recycled to compost for agricultural or landscaping purposes (Earthtime INC, 2008). Landfills operations also provide job opportunities for wastes equipment operators; laboratory technicians, wastes sorters and security guards; it also provides opportunities for air, soils and water sources quality evaluation in the environs of its operation by proponent, relevant government and non governmental entities.

One of the functional landfill criteria involves the availability of cover material or soils. A daily waste cover reduces the possibilities of fire, odour, gas migration, and other nuisances, and to an extent prevents scavenging activities. Ground and surface water monitoring mechanisms are installed to monitor the possibility of water contaminations and to establish corrective measures (Criteria for Solid Waste Disposal Facilities, 1993).

2.4 Landfill and Pollution

Though landfill serves as final disposal site for wastes, it comes with many disadvantages that may affect the environment and pose public health risk to human if they are not handled appropriately. The disadvantages are that the implementation processes which include resources and materials gathering and construction are slow. It requires large area of land, and there exists possibility of leaching or infiltration of pollutants and toxic metals from the site into ground and surface water sources, and soil (Narayanan, 2007).

The possibility of landfill gases migration into the atmosphere, causing nuisance and global warming when not contained adequately may be high.

Akaeze, (2001) intimated that, landfills and their surrounding areas are often heavily polluted, resulting in water, air and soil pollution through the spread of dangerous chemicals, infiltrating or migrating into underground and surface waters. Sanitary landfills like conventional landfills contaminate soils and water sources through leachates, if they are not designed and managed appropriately to prevent percolation of contaminants (Lars and Gavriels, 1999).

Leachate is a liquid produced during the interaction of moisture or rainwater, bacteria and heterogeneous biodegradable wastes that accumulate through various biological, chemical, physical processes. Generally, leachate contains large amounts of organic matter, ammonia-nitrogen, and heavy metals, chlorinated organic and inorganic salts (Renou *et al.,* 2008; Robinson 2005). Thomas *et al.,* (2009) intimated that, alcohols, acids, aldehydes and short chain sugars are organic constituents. The organic constituent of leachates is often measured through analysis of parameters such as Carbon Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC).

The inorganic components of leachates include heavy and trace metals which are non-degradable elements, having the atomic weights between 63.546 and 200.590; and a specific gravity greater than 4.0. Heavy metals are members of a loosely-defined subset of elements that exhibit metallic properties (Duffus, 2002). Heavy metals are used extensively in electronics, machines and other equipment. They migrate or infiltrate into the aquatic and food chains of humans and animals from a variety of anthropogenic sources as well as from the natural geochemical weathering of soils and rocks (Gautam, Sanjay, Sharma *et al.,* 2014). Some heavy metals are dangerous to human health, whilst few are necessary for humans' growth and survival in minute amount. Several of them may cause corrosion while others are carcinogenic or toxic, affecting, among others, the central nervous system, the kidneys or liver or skin, bones, or teeth (Connell, 1984; Kennish, 1992; Zevenhoven *et al.*, 2001).

Copper (Cu) is a reddish heavy metal with a face-centered cubic crystalline structure. Lenntech (2012), noted it can be found in food, in drinking water and in air. Long-term exposure to copper can cause irritation of the nose, headaches, stomach aches, vomiting and diarrhea (Agency for Toxic Substances and Disease Registry, 2004).

Cadmium (Cd) is a toxic heavy metal that occurs via anthropogenic activities such as landfills, industrial emissions, and application of fertilizer amongst others. It is also found in batteries, paints, electrical equipment and natural occurrences such as eroding of soils, and weathering of rocks, amongst others. Excessive amounts of (Cd) in soil for instance may lead to its contaminations, resulting in uptake by crops and vegetables grown for human consumption.

Lead (Pb) is a toxic metal that occurs naturally in the environment; however, its concentrations in the environment are from anthropogenic activities as it is found in lead storage batteries, solder, plumbing pipes, cable covering, and interior paints amongst others. It causes serious hazards if not handled appropriately due to its high toxic nature. Inorganic lead affects on average the Central Nervous System (CNS), Peripheral Nervous System (PNS), haematopoietic, renal, cardiovascular and reproductive system, whilst organic lead toxicity tends to predominantly affect the Central Nervous System (Kaana and Anhwange, 2013). Volatile organic compounds and non-methane organic compounds are the components of gases describe as toxic to the environment and human health.

According to Yunus and Igbal (1996), volatile organic compounds, particularly esters, organosulphur, hydrogen sulphide and ammonia are sources of odour emission at landfills. The generation of landfill gases continues for years after disposal of waste at landfills, whilst the production of leachates starts right from the initial dumping of biodegradable wastes. The more organic waste preset in a landfill, the more gases such as carbon dioxide, methane, nitrogen and hydrogen sulphide may be produced by bacteria during decomposition.

2.4.1 Soil Pollution

Soil serves as a bio-filter in the ecosystem. Hence, soil structure and texture are important factors in identifying the rate of infiltration of produced landfill contaminants downward and exchange of gases through aeration. Soils at sites and within environs of landfills become contaminated by leachates and gases emitted from refuse dumped in landfills which are not properly constructed, regulated, monitored and managed effectively. Leachates, gases and other contaminants generated at landfills may infiltrate or migrate and adversely impact the quality of the adjoining soils where no protective liner or clay material is used at the bottom and perimeters of landfills; or where the liner has deteriorated or has been removed from the initial position through accident or natural means.

The deposition of chemicals contaminants including metals, the wet deposition of gases, and seepage of gases from landfills may suppress microbial activity throughout the soil ecosystem (Finnecy and Pearce, 1986). Contaminants from soil may also be taken up by plants which are subsequently consumed, either by humans or by agricultural livestock, thereby causing contaminants to enter human's food chain (Science for Environment Policy In-depth Report: Soil Contamination, 2013).

2.4.2 Surface and Ground Water Pollution

Water pollution is the presence of excessive amounts of pollutants in water, such that it is not suitable for drinking, bathing, cooking or other uses (Olaniran, 1995). Ground and surface water sources may become contaminated from natural occurrences through the hydrological cycle as well as anthropogenic activities. Tyagi *et al.*, (2002) noted that groundwater has long been considered one of the purest forms of water available in nature. However, due to anthropogenic activities it gets contaminated from pollutants released from human's day to day activities and from natural occurrences. Some of the natural occurrences that result in release of contaminants and subsequent contamination of water sources are weathering of minerals, erosions, and volcano eruptions amongst others; as anthropogenic sources on the other hand involve mining, the use of pesticides and fertilizer, landfills activities, and incinerations amongst others. In the case of ground water pollution, impurities such as trace and heavy metals and dissolved minerals are the main constituents.

2.5 Landfill operations in Liberia

Prior and after the Liberian civil crisis, domestic and commercial solid wastes in central Monrovia were collected, transported and disposed off in opened dumpsites by Monrovia City Corporation (MCC). However, due to the entity's lack of human, financial and technical resources it operated at a reduced capacity with fewer operational wastes equipment, which resulted to heaps of wastes and uncontrolled open burning, primarily on streets and vacant plots (UN/ World BANK/ IMF, 2003 -2004; Earthtime INC, 2008).

In 2008 however, about 15% of the wastes generated in Monrovia was collected and dumped at open dumpsites in and around the capital city, Monrovia. In addition Wilson Ltd,

(2011) noted that, the Whein Town facility then an opened dumpsite began its operations in June 2008, where it received approximately 300 tonnes of high organic content wastes per day. Subsequently, in 2009, the Whein Town Sanitary landfill was envisaged (Pöyry Environment GmbH, 2010); a landfill which is the first in Liberia was constructed by Zoomlion and commissioned by the government of Liberia in 2012. Yet, the Chessmanburg Sanitary Landfill is presently under construction to serve as a long term alternative to it. Currently, collection, transportation and disposal of municipal solid wastes in Monrovia and its environs are implemented by MCC, Paynesville City Corporations (PCC), and private registered Solid Wastes Management firms operating in the country. Meanwhile, the inadequate budget to execute a sound waste management system, coupled with fewer waste management equipment and human resources currently hampered wastes collection, which result to wastes being piled in communities, on street corners, vacant lands, and market grounds and openly burnt on day to day basis.

2.6 Legal Framework

In Liberia, laws are passed by the National Legislature, which is comprised of Senators (30) and Representatives (73). In the case of an Environmental Bill to be passed, the draft bill is first sent to the Committee on Natural Resources and Environment. Thereafter, the Committee reviews, assesses and presents the bill to Plenary with appropriate amendments for debate, public hearing and subsequent enactment by the Legislature (Earthtime INC, 2008; Earthtime INC, 2010). Article 7 of the 1986 Constitution of Liberia, sets the fundamental basis for the constitutional, institutional and legislative frameworks for protection and management of the environment.

It also encourages public participations in the protection and management of the environment and natural resources (Earthtime INC, 2010). However, the main entities in Liberia responsible for sanitary landfill sitting, constructions, operation and management are the Ministry of Public Works, Ministry of Health and Social Welfare which housed (NEOP), Monrovia City Corporation and the Environmental Protection Agency of Liberia.

2.6.1 Entities involved with Landfill's Management

UNEP (2007) noted that, the three main legal documents that grant authority in the field of the environment and waste management sector, are three acts, namely: the Act Creating the Environmental Protection Agency of Liberia (EPAL), the Act Adopting the Framework of the Environmental Protection and Management Law and the Act that established the Environmental Policy of the Republic of Liberia (all approved on 26 November 2002 and published on 30 April 2003). The Act Adopting the Environmental Protection and Management Law contains specific Sections 37, 38 and 39 which identify the role of the EPAL regarding wastes management in Liberia as the coordinator and monitoring body for setting policies and guidelines. Additionally, Section 6-C of the Environmental Protection and Management Law empowers the entity to collect, analyze and prepare basic scientific data and relevant information pertaining to pollution, degradation and environmental quality (UNEP, 2007). Further, Section 64 also requires the acquisition of licenses for the generation, storage, handling, transportation and disposal of hazardous waste; while Section 71 requires the acquisition of a "Pollution Emission License" for any project or activity which is likely to pollute the environment (Environmental Protection Management Law of Liberia, 2002; Act Creating the EPAL, 2002; Earthtime INC, 2008).

Meanwhile, the EPAL has worked on setting new environmental standards as several quality standards have been prepared, among which include: environmental quality standards on Air Quality; Water Quality Standards; Noise Level Standards and Waste Management Standards.

The Monrovia City Corporation is responsible for constructions, operations and maintenances of landfills in Liberia. In 1975, the Public Health Law granted this entity the responsibilities of ensuring clean sanitary conditions in Monrovia (Earthtime INC, 2008). The entity also shares the responsibilities of planning, development, operation and maintenance of none sewer, domestic and public sanitation facilities in collaboration with the Liberia Water and Sewer Corporation (LWSC), and Ministry of Health (UNEP, 2007).

The Ministry of Health housed the National Environmental and Occupational Health (NEOH) Department, which was established in 2007. The NEOH has the mandate of identifying environmental and occupational health needs, such as environmental sanitation, water quality and safety, vector control and chemical safety, waste management, health promotions and pollution controls (Earthtime INC, 2008; Pöyry Environment GmbH, 2010). According to UNEP (2007) “the Ministry of Public Works (MPW) is in principle responsible for the installation of the entire infrastructure required for waste management delivery services, including waste collection and transfer stations and the construction of engineered landfills”. The entity also coordinates water, sanitations and hygiene (WASH) activities in Liberia.

CHAPTER THREE

MATERAILS AND METHODS

3.1 Location of Liberia

Liberia is a country on the West Coast of Africa with a surface area of 111,279 km^2 and dry land is about 96,160 km^2. It lies between longitudes of 7°30' and 11°30' West and latitudes 4°18' and 8°30' North. The country covers a surface area of about 43,506 square miles. Liberia is bordered on the west by Sierra Leone (306 km); north by Guinea (563 km); east by Côte d'Ivoire (716), and on the south by the Atlantic Ocean. Liberia has low relief topography with a coastline approximately 560 km long. The land is characterized by unbroken sand strips; dominated by lagoons and marshes (Earthtime INC, 2010).

3.2 Location of Monrovia

Monrovia is the capital city of Liberia, and hosts the studied catchment, Whein Town community. Monrovia lies along Cape Mesurado peninsula, between the Atlantic Ocean and Mesurado River. It extends north of Cape Mesurado into Montserrado County, where St. Paul River forms the city's northern boundary (Earthtime INC, 2008; Pöyry Environment GmbH, 2010). Liberia has a population of 4.98 millions while, Montserrado county, which hosts Monrovia has a population of about 1.2 millions. The Bernard-Farm community, which includes Whein Town community, Forestry Development Authority (FDA) Community, Omega Tower community, and portion of Pipeline Road community has a population of 6,645 (Liberia Institute of Statistic and Geo Information Services, 2014).

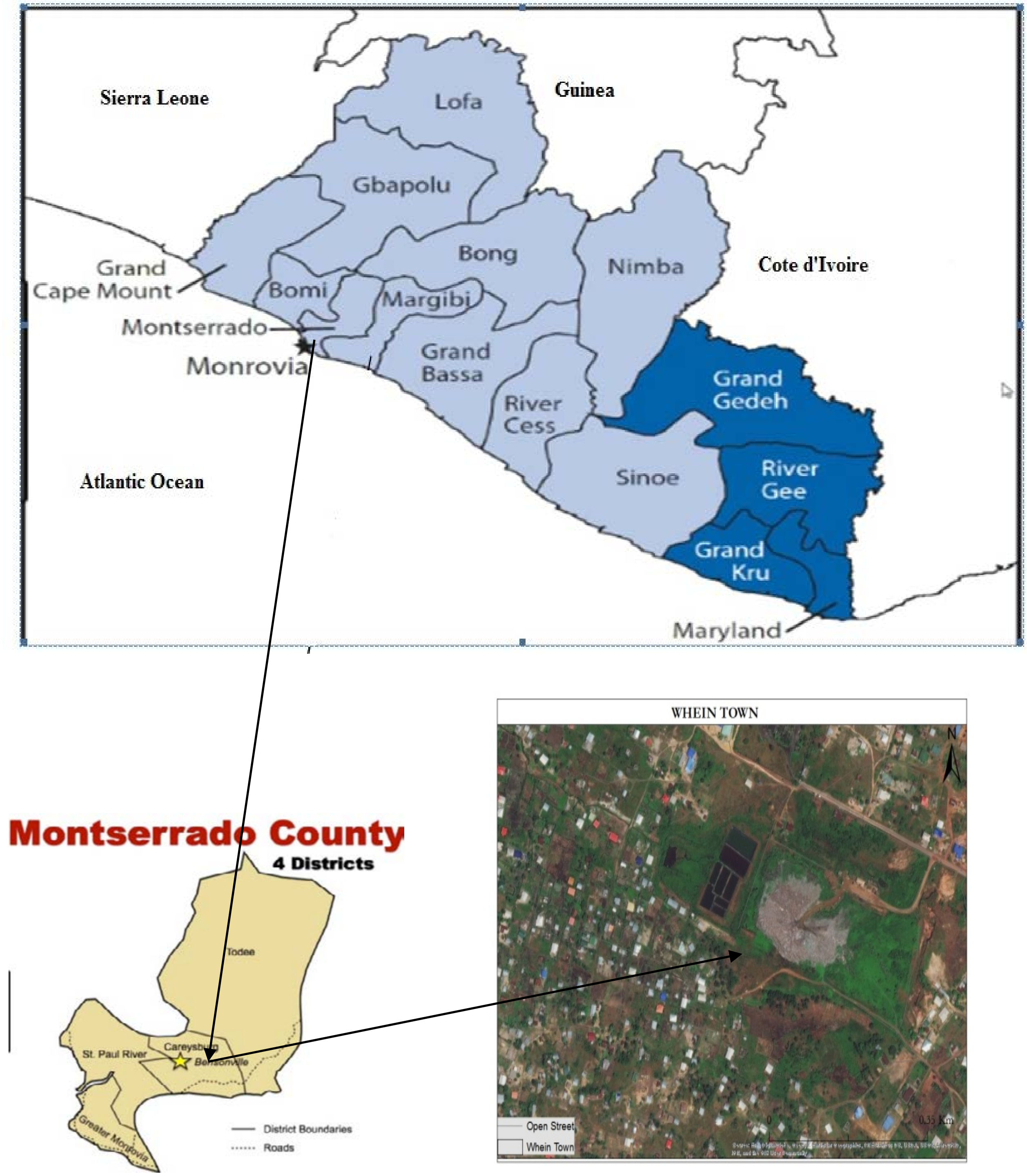


Figure 3.1: Google Earth (2019) map and images showing Liberia, Montserrado county and the study community

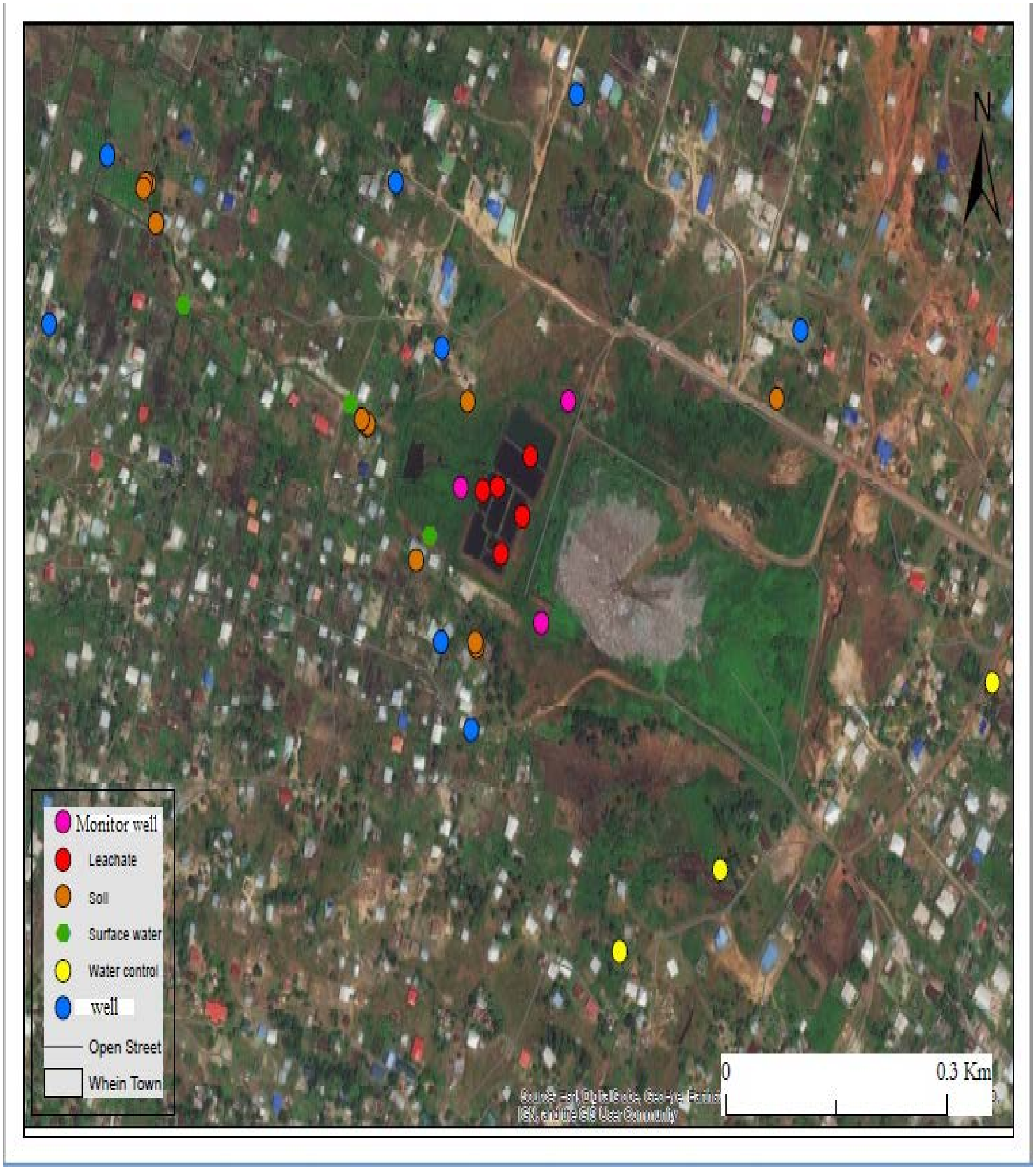


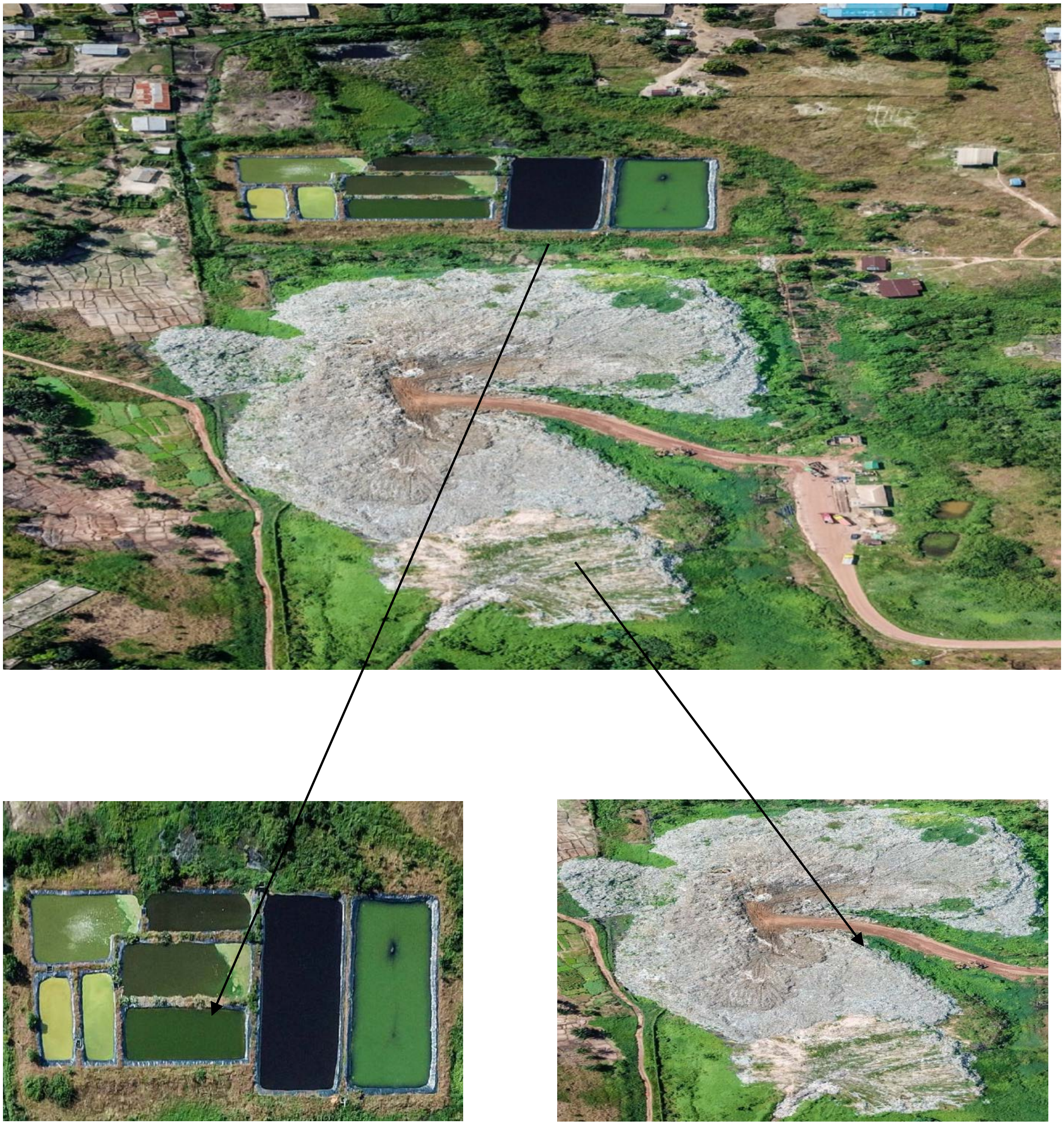
Figure 3.2: Google Earth (2019) image of study site showing sampled points

3.2.1 Location of Whein Town

Whein Town community is located on the outskirts of Monrovia. It lies 13 km North-East of Monrovia, 7.5 km East of Gardnersville, 3.9 km South-West of Mount Barclay and 7 km North-North-East of Paynesville. The catchment elevation ranges between 10 and 66 m above sea level. The site is approximately 25 acres in area and is surrounded by scattered residential settlements at a distance between 0.5 km and 1.5 km (Clean Development Mechanism Project Design Document, 2006; Earthtime INC, (2008)

3.2.2 Topography and Drainage of the Landfill

The Whein Town Sanitary Landfill site has a very prominent hill that is eroded, thereby leaving the soil exposed. The topography of the site is sloping towards west, and with high small hill of approximately 20 metres above sea level (Pöyry Environment GmbH, 2010). There is a hill on the site that formed the largest water shed serving South-West of the community and at the North-Western extreme segment of the site is a shallow valley, which begins the upper catchment area of a local seasonal stream. Surface or stream water drains to adjacent mangroves and on to a seasonal watercourse that runs west and eventually south to the Atlantic Ocean (Earthtime, 2008; Pöyry Environment GmbH, 2010). Additionally, the site is characterized by presence of several stream water bodies ranging of mangroves, springs, seasonal drainage systems and creeks. The creeks flow to the Eastern side of the landfill on the opposite side of the water shed, and separated distance by 3 and 4 km (Earthtime INC, 2008).



Waste Stabilization ponds Landfill (main deposit site)

Figure 3.3: Earth Time (2019) image showing the landfill

3.3 Rational for the Choice of Study Communities

The study catchment is comprised of four blocks, and majority of the inhabitants depend on ground water for drinking and household purposes. They also use the soils for agricultural activities, as they think the soils are rich with nutrients from leachates and other compounds from the landfill. Additionally, the stream water (surface water) containing leachates and other contaminants from the landfill flowed across the community through man-made drainages and used for irrigation, recreation and fishing purposes during the rainy season. The fishes, frogs, crabs and other species caught and the vegetables and crops grown are harvested and consumed or sold on the local markets.

3.4 Reconnaissance and Data Collection

A reconnaissance survey was first conducted in the study area during the month of September 2018, to assess baseline information of the landfill and Whein Town community, including number of households, type of housing, and social background of the inhabitants. The data for this study was obtained through primary and secondary sources. The primary data comprised quantitative and qualitative data collected from a cross-sectional survey involving field sampling of soils, leachates, surface and ground waters and subsequent laboratory analyses as well as face-face interview and a set of structured questionnaires respectively. The structured questionnaires comprised of combinations of opened and closed ended questions which were administered to solicit information on inhabitants’ perceptions regarding the impacts of the sanitary landfill in the community. Respondents' responses were further combined with the results of the laboratory analysis of the soils, surface and ground waters to determine the extent of the impacts of the landfill. Government and non-governmental agencies were used as a theoretical basis to achieve the research objectives on the study catchment as, relevant secondary data from published articles, thesis, books, the Environmental Protection Agency of Liberia (EPAL) and other governmental and non governmental entities were used to achieve the objectives of the research.

3.5.1 Questionnaire Administration and Sample Size

The population of Bardners-Farm community, made up of Forestry Development Authority (FDA), Omega Towel, Pipelline (portion), and Whein Town communities is about 6,645 (Liberia Statistical Geo Information Services, 2014). However, only residents within 1 km of the vicinity of the landfill were involved in questionnaire administration. The sample size of the respondents was determined using Yamane's equation (Yamane, 1967) at a confidence level of 95% and 5% margin of error.

$$n = \frac{N}{1+N(e)^2}$$

Where: n = sample size

N = total population and

e = the margin of error

This gives a sample size of 337. Since, only about a third of the population live within about 1 km of the landfill, the quotient was divided by 3 to approximate the sample size (125) needed for the questionnaire administration. The selected respondents comprised students, local entrepreneur, and employees as well as unemployed persons living in the study catchment.

3.5.2 Sample Collections

Collection of samples made up of soils, leachates, stream water and groundwater for the study was carried out on seasonal basis. Samples were taken at the peak of the rainy (September, 2018) and dry (January, 2019) seasons. Three replicates were taken for each sampling point and the mean values recorded during both seasons. Two wells were sampled from each of the four communities' in the study catchment. The control samples were collected on a gradient; No.1 (218.48 m), No.2 (278.41 m) and No.3 (368.89 m) away from landfill. The coordinates for each sample site was determined using the Global Positioning System (GPS). Appendix 3 showed the coordinates of the sampling points in and from the landfill's compound.

3.5.3 Surface and Ground Water Sampling

The sampling of ground and surface waters was done in accordance with the procedure recommended by the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) described by Clesceri. L. S (1998). The physical and chemical characteristics of the water samples from the study area were evaluated during both wet and dry seasons respectively. Gloves were changed at each sampling point to ensure sampling bottles were not contaminated. All of the bottles containing the samples were previously clean through washing in non- ionic detergent and copiously rinsed with tap water. Additionally, at the sampling points, each bottle was rinsed 3 times with the sample. Each bottle containing the sample was carefully labelled, noting the date, time and monitoring location identification code, placed on ice and transported to the Environmental Protection Agency of Liberia (EPAL) laboratory for the analysis (Appendix

4). Samples from 11 active used wells and 3 landfill's monitor wells were collected using a drawing bucket and syringes respectively. The coordinates (Appendices 5, 6 and 7) of the samples sites were taken using GPS, whilst the collected samples were stored under cool and dark conditions in ice jugs containing ice.

Three samples with 3 duplicates (each) were collected from the stream water in the watercourse and GPS coordinates (Appendix 8) were taken. The water samples were collected into sterile bottles that were rinsed with the stream water prior to sampling. In the course of taking BOD samples, care was taken so as not to trap any gas or bubbles.

3.5.4 Leachate Collection

Samples of leachates including duplicates were collected with syringes from five of the 8 Waste Stabilization Ponds and filled in 0.5 ml bottles avoiding overflow and trapping of air bubbles. At each sampling point, a clean syringe was used to avoid the previous leachate contaminating the next cell's leachate. Sampling points coordinates (Appendix 9) were taken via GPS and the bottles carefully labelled, placed on ice and transported to the EPAL laboratory. Gloves were changed at each sampling point to ensure sampling bottles were not contaminated.

3.6.5 Soil Sampling

Twelve soil samples including duplicates were sampled from locations within proximity to the landfill site (Appendix 10). An Auger was used at a depth of the soils between 45 and 50 cm each. Sterile gloves were changed at each sampling point to ensure sampling zipped bags are not contaminated. Each sample was collected, placed in zipped bag, carefully labelled and stored in a container. The coordinates for each sampling site was taken via GPS, and the samples were transported to the EPA's Laboratory for detailed analysis.

3.7 Laboratory analysis

3.7.1 Water Samples Analysis

The analysis of water samples was conducted in the Environmental Protection Agency of Liberia (EPAL) laboratory, located in Sinkor, Monrovia as prescribed by the Standard Methods for the analysis of Water and Wastewater (APHA, 1992). The Dr890 Colorimeter (Hach Brand), the Oxitop BOD_5 Monometer (BOD method) and Absorption Spectrophotometer Schimadzu Model AA-6650, were used to analyzed all the selected parameters in both soils and waters samples. Standard stock solutions for each metal analyte were prepared using respective " Analar" grade reagents dissolved in deionized water for each analyte in order to prepare the calibration curves. The results were provided in milligrams per litre (mg/L) milligrams per kilogram (mg/kg) or µS/cm as appropriate. Samples for metal analysis were acidified to $pH < 7$ by adding nitric acid to avoid forming speciation or complexes.

3.7.2 Determination of pH in Water and Waste Water Using Dr/890 Colorimeter (HACH)

pH was determined using the Phenol Red method. The colorimeter was calibrated prior to use by filling a glass cell with 10 ml deionized distilled water and placed in the colorimeter cell holder at a temperature between 21°C and 29°C. The pH of deionized water was then read when the colorimeter was switched on, where pH of 6 indicates proper calibration. A Sample was then introduced into the cell, 1 ml phenol red indicator added and the pH subsequently read when the colorimeter was switched on once again.

For the determination of pH and Electric Conductivity in soil samples: 10g of soil was weighed into an extraction cup, and 10 ml of distilled water was dispensed into cup and allowed to stand for 15 minutes. The solution was agitated (stirred) on the mechanical shaker for 30 minutes, and filtered thereafter. The pH and Electric Conductivity were determined on the filtrate using an EC and pH meter.

3.7.3 Determination of Copper

Copper was determined using the Bicinchoninate method. The colorimeter was calibrated by filling a cell to 10 ml mark with deionized water and placed in the cell holder; and zero registered after the colorimeter was switched on, which indicated proper calibration. Prior to the analysis, pH of the acid-preserved sample was adjusted between 4 to 6 pH with 8 N KOH.

A second cell was filled to the 10 ml mark with blank sample and CuVer 1Copper Reagent Powder pillow was introduced to prepare the analyzed sample. The cell was swirled vigorously for chemical reactions to take place, and was allowed to settle for two minutes. The prepared cell was placed in the cell holder and the result was recorded after the instrument was switched on.

3.7.4 Total Chromium

Total Chromium was determined using the Alkaline Hypobromite method. For calibrations, a clean cell was filled to 25 ml mark with deionized water and placed into the cell holder. The colorimeter was switched on, and a reading of zero Cr indicated perfect calibration. Another cell was filled to 25 ml mark with the sample. Chromium 1 Reagent powder pillow was introduced into the cell and inverted repeatedly to mix. The prepared cell was placed in boiling water for a five minutes reaction, and later a running tap water was used to cool the cell to 25^{o}C. A second reagent containing Chromium 2 Reagent powder pillow was introduced into the cell, capped and inverted repeatedly to achieve chemical mixing. Additionally, a third reagent containing Acid Reagent powder pillow was introduced into the sample cell, inverted again to mix; then a final reagent of Chroma Ver 3 Chromium Reagent powder pillow was introduced, capped and the cell was inverted repeatedly to mix. The prepared sample was placed into the colorimeter cell holder and the result was recorded after switching on.

3.7.5 Determination of Total Iron (Fe)

Total iron was determined using the FerroVer Method. Prior to the analysis, the colorimeter was calibrated to zero (Fe) as a clean cell was filled to 10 ml mark with deionized water placed in the cell holder and switched on. A second clean cell was filled to 10 ml mark (sample) and Ferro Ver Iron Reagent Powder pillow was introduced into the prepared sample. The cell was capped and inverted for chemical reaction, after which an orange colour appeared indicating the presence of iron. The prepared cell was placed in the cell holder, and the reading was taken after the colorimeter was switched on.

3.7.6 Determination of Zinc

Total zinc was determined using the Zincon Method. Pre- digestion of sample was employed using mild digestion, where the pH was adjusted to 5.0 with N Sodium Hydroxide Standard Solution. Initially, a glassware was rinsed with 1:1 mixture of Hydrochloric acid and deionized water and a 25 ml cell was filled to 20 ml mark with the sample. The ZincoVer 5 Reagent Powder Pillow was introduced into prepared sample cell, capped and inverted several times to dissolve the reagent, which resulted in an orange sample. To calibrate the colorimeter, 10 ml of the orange solution was measured into another cell, placed into the cell holder and the instrument read zero (Zn) after switching on. A 0.5 ml of cyclohexanone was introduced into the remaining orange solution using plastics squeezer, the cell was capped and agitated vigorously till the sample turned red-orange, brown or blue, which indicated the presence of zinc. The prepared sample was placed into the cell holder for immediate reading.

Mild Digestion: A 100 ml sample was transferred to a 150 ml volumetric flask and 5 ml mixture of 1:1 hydrochloric acid and water was introduced into it. The prepared sample was heated using steam until the volume reduced to 20 ml. The sample was filtered to remove insoluble material and the digested sample was adjusted to pH 4 via the introduction of 5.0 N Sodium Hydroxide Standard Solution. The sample was transferred into a 100 ml volumetric flask, and deionized water was introduced to reach it to its initial 100 ml mark (D890 Colorimeter).

3.7.7 Determination of Biochemical Oxygen Demand (BOD_5)

The Biochemical Oxygen Demand (BOD) method is employed to measure the amount of oxygen consumed by living organisms / organic matter during a period of five (5) days at a temperature of 20°C. The measurement, using OxiTop BOD_5 instrument is based on a pressure measurement in a closed bottle, where organic matter in the BOD_5 bottle consume the oxygen and form CO_2. Two airtight bottles were filled with sample and dilution water and incubated under a temperature of 20°C for five days. In BOD self-checks bottles containing a manometer, the reduction in oxygen cause a definite pressure difference which was measured by a pressure sensor. The measured pressure difference was converted to BOD_5 value (mg BOD_5 L^{-1}). The Dissolved Oxygen content was measured prior and after the incubation, and the BOD was computed from the difference between the initial and the final Dissolved Oxygen (DO). Where there was less amount of oxygen due to dilution, the BOD was computed from the formula below: BOD_5 mg/L = D1 – D2/ P

Where D1 = DO of the diluted sample immediately after preparation;

D2 =DO of the diluted sample after five (5) days incubation at 20°C (mg/L)

P = Decimal volumetric fraction of the sample used.

3.7.8 Determination of Total Dissolved Solids

A gravimetric method was employed to determine the Total Dissolved Solids (TDS). A clean empty 250 ml beaker was oven dried at a temperature of 180°C and weighed to a constant weight; and 200 ml of sample water was filtered into the weighed beaker, heated and allowed to evaporate at a temperature of 105°C to dryness. The dried sample was cooled in a desiccator and weighed. Drying and weighing between the weight of the empty beaker and the beaker with its contents is the weight of the dry residue. The total dissolved solid in mg/L was computed as followed: TDS (mg/L) = Weight of dry residue (mg) / Volume of sample (ml) x 10^6.

3.7.9 Digestion of Soil samples to Determine Zinc, Lead, Cadmium, Chromium and Copper

A 1.0g of soil sample was weighed into a digestion tube and digested with 10 ml of Ternary mixture (20ml of $HClO_4$, 500ml of HNO_3; 50ml of H_2SO_4) and was placed on a hot plate at 95°C for 30 minutes under a fume hood. After cooling, the digested sample was filtered into 100 ml volumetric flask using Whatman NO.42 filter paper and made up to the mark with distilled water. Light was generated from a hollow cathode lamp at wavelength unique or characteristic to each analyte. Each analyte was atomized, using an atomizer to create free atoms from the samples. Air acetylene gas was used as source of energy for production of free atoms for Cadmium, Copper, Lead, Chromium, and Zinc. The sensitive light detected, then measured the light and translated the responses into the analytical measurement. The resultant solution was analyzed for metals of interest using the AAS.

3.8 Questionnaire and Data Processing

Data collected from the questionnaires was analysed using the Statistical Package for Social Sciences (SPSS) version 23.0 and results are presented in simple descriptive tables. In order to establish a probable link between the operation of the landfill site and the patients' case reportage at nearby health facilities, health data was collected from out-patient department

(OPD) of two health facilities within the study catchment. The facilities were Robert Moore Clinic and Hope Clinic.

Microsoft (2010) was used to interpret physico-chemical results and data obtained from the soils and water sources were presented as graphs, tables and appendices. Generally, the mean concentrations values obtained from the water sources samples analyzed for dry and wet seasons were compared with WHO guidelines for drinking water. Likewise, to evaluate the extent of the studied heavy metals contamination in the sampled soils several indices such as Contamination Factor, Degree of Contamination, Comprehensive Potential Ecological Risk and Potential Ecological Risk Factor of a Single Element were employed, using the mean values obtained from both seasons. Also the mean soils concentration values obtained were compared with WHO/FAO 2001 standards for agricultural soils.

3.8.1 Contamination Factor (Cf)

Contamination factor (Cf) is employed to evaluate or to determine the extent of contaminations of each heavy metal in sampling sites. It is computed for individual elements to supply vital information about the degree and extent of the element's contamination in the soils. The Contamination factor calculation involves comparing concentration of elements with their geochemical background reference as it is calculated for individual elements. The method of evaluation provides vital information about the extent of anthropogenic influence on heavy metal load in agricultural soil (Ahmed *et al.*, 2016). According to Hakanson's (1980) the Contamination factor (Cf) index is formulated as

$$Cf = \frac{C_i}{S_i} \qquad [1]$$

Where $C_{i,}$ is the concentration of each analyzed metal (Zn, Pb, Cr, Cd and Cu); and S_i is the background (geochemical background reference) concentration of each metal. Hakanson. L (1980), imparted that, Cf < 1, indicates low level of pollution; Cf ≥ 1 but ≤ 3, moderate pollution; Cf ≥ 3 but ≤ 6, indicates high level of pollution; and Cf > 6, indicates very strong level of pollution. The pre –industrial background (S_i) value for each element is (Cd = 0.06, Cr = 71.22, Cu = 20.39, Pb = 19.35 and Zn = 51.07 mg kg^{-1} or mpp^{-1}) respectively (Hakanson, L (1980).

3.8.2 Degree of Contamination (CD)

Degree of contamination (Cd) is defined as the sum of all the contamination factors. Contamination factor and degree of contamination methods are used to determine the contamination status of the soils in this study. The degree of contamination (CD) method involved the accumulation of single indices (Cf) determined separately and then combined to determine the general quality of the sampled soils. The CD provides the overall information about the soils' contamination caused mainly by anthropogenic activities. It involves an assessment of the soils contamination by comparing the heavy metals concentration with those of background value of the heavy metals in soil. The degree of Contamination can be imputed as:

$$CD = \sum_{i-1}^{n} CF \ldots., \qquad [2]$$

Where CD, is the sum of the contamination factors for heavy metals, and Cf is the contamination factor of individual metal in the sampled soils. Hakanson. L (1980), Ahdy and Khaled, (2009) intimated that: Cd <6, indicates low degree of contamination; CD ≥ 6 but < 12, indicates moderate lever of contamination; CD ≥12 but < 24, indicates considerable degree of contamination; and CD ≥ 24, indicates very high contamination degree.

3.8.3 Potential Ecological Risk Factor of a Single Element (E^i_R)

The potential ecological risk index of a single heavy metal (E^i_R) is employed to assess the quality and concentration of each heavy metal and its effect pose on microorganism or the ecosystem at each site. It is computed by multiplying each contamination factor value obtained in equation (1) with the biological toxicity factor of the heavy metal in the sampled soils. The biological toxicity factor of each of the considered element in this study is: Zinc 1; Copper 5; Lead 5; Cadmium 30; Chromium 2 (Hakanson. L, 1980), and also according to him the potential ecological risk factor is defined as:

$$E^i_R = T^i_R \times C^i_f \qquad [3]$$

Where T^i_R, is the biological toxic response risk factor of each element, and C^i_f is the contamination factor of the individual element considered. According to Jiang *et al.*, (2014), $E^i_R < 30$, indicates slight level of pollution; $E^i_R \geq 30$ but < 60, represents medium degree of pollution; $E^i_R \geq 60$ but < 120, indicates strong level of pollution; $E^i_R \geq 120 < 240$, very strong level of pollution; $E^i_R \geq 240$ extremely strong level of pollution.

3.8.4 Comprehensive Potential Ecological Risk Index (RI)

The comprehensive potential ecological risk index (RI) provides a mean to quantitatively access ecological risk posed by multiple element pollutions in the sediment (Li, X., Liu, L., *et al.,* 2012) and in soil. The potential ecological risk index (RI) is used to assess the quality and concentration of heavy metals present in the studied sample and the effects they may cause in the soils, microorganisms and crops found in the considered studied catchment.

It provides the cumulative potential ecological risk the heavy metals may pose in the in the environment. The potential ecological risk index (RI**)** is calculated as the sum of the cumulative ecological risk factors of heavy metals obtained in equation 3. According to Hakanson. L, (1980), Ecological Risk Index (RI) can be computed as:

$$RI = \sum_{i-1}^{n} E_R^i \qquad [4]$$

Where RI is the sum of the ecological risk factors for the heavy metals, and E^i_R is the ecological risk factor of individual considered studied heavy metals. Jiang *et al*., (2014) imparted that, RI < 40, indicates slight level of pollution; RI ≥ 40 but < 80, indicates medium level of pollution; RI ≥ 80 but < 160, strong level of pollution; RI ≥ 160 but < 320, very strong level of pollution.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

A study to ascertain citizens' perceptions on the effect of the landfill activities and to evaluate real time health hazards the landfill pose to Whein Town community was carried out in Liberia, and results obtained are presented in the sub-sections following.

4.1 Demographic Profile of Respondents

Demographic data of respondents were extracted from the questionnaires administered to them. A sample of the questionnaire is presented as Appendix 11.

Sixty percent of the respondents were males and forty percent females (Table 4.1). Majority of them (74%), where within the age group of 20 – 50 years (Table 4.2). Ninety two percent of them had good formal educational background, at least up to Junior High School level (Table 4.3).

This demographics imply that majority of the respondents were not only active individuals, but also cognitively well-endowed who, to a large extent, could accurately express their opinions based on what they had observed. Their views therefore ought to be respected and given some credibility. The fact that 55% of them were employed in one way or the other (Table 4.4) indicates they were largely productive and therefore responsible individuals. All the respondents live within a radius of about 500 metres of the landfill site. About 46% of them are within 200 metres radius while 54% were located beyond 200 metres from the landfill (Table 4.5).

Table 4.1: Gender of respondents

Gender	Percentage (%)	Frequency
Male	60	62
Female	40	35

Table 4.2: Ages of Respondents

Age range	Percentage (%)	Frequency
11 – 20 years	11	11
21 – 30 years	26	27
31 – 40 years	30	31
41 – 50 years	18	19
>50 years	15	16

Table 4.3: Educational Status of respondents

Level	Percentage (%)	Frequency
Junior High	11	11
Senior High	56	58
University	25	26
Never Schooled	9	9

Table 4.4: Employment status of respondents

Employment	Percentage (%)	Frequency
Employed (public or civil servant)	15	16
Self-employed	39	41
Unemployed	45	47

Table 4.5: Distances between landfill and residence of respondents

Distance	Percentage (%)	Frequency
90 – 130 m	17	18
151 – 200 m	31	32
201 – 250 m	12	12
251 – 300 m	15	16
301 – 350 m	18	19
351 – 400 m	3	3
401 – 500 m	6	6

4.2 Citizens' Perception on the effects of the landfill and its activities

4.2.1 Drinking Water Sources and Quality

Three main drinking water sources were identified in the community namely, stream water, borehole, and hand-dug wells, and of all these, hand-dug wells (100%) and sachet water (74%) were the main ones (Table 4.6) depended on for drinking. To the respondents, water supply from the hand –dug wells is always available, guaranteed and comes at no cost hence their most trusted source. (Table 4.7). Sachet water even though cleaner, comes with financial cost and so not always depended on.

The stream water is hardly used for potable purpose because its quality is not acceptable, though in extreme cases it is treated adequately and used (Table 4.7). Boreholes would have been a better alternative however, this was not available. Only one borehole was present in the entire study area hence it could not be a dependable source for drinking water for the entire populace of the study area. The quality of waters from the stream, borehole and hand–dug wells was not acceptable to respondents since they had taste, odour, and colour challenges (Appendix 12). Colour of the water was considered to be the main challenge, followed by taste, and then odour (Table 4.8).

The cause of the poor water quality was attributed to the location of the landfill in the community as well as its poor management (Table 4.9). Visit to the landfill site corroborates the view of the correspondents. It was observed that the primary waste stabilization pond had the leachates in it heavily spilling over and flooding up to about 100 metres of adjourning land. The situation becomes worse whenever there is the slightest down pour of rain.

The seeping of the leachate into the hand–dug wells, boreholes (monitoring wells) obviously may be responsible for the unbearable taste, odour, and colour challenges of their water sources. The observation of Saarela (2003) that areas near landfills have a greater possibility of groundwater contamination by leachates from dumpsite, lends credence to the respondents' observations and attributions of water pollution to the landfill.

Table 4.6: Sources of potable water

Water source	Percentage (%)	Frequency
Hand dug-well	100	104
Borehole	5	5
Stream	2	2
Sachet water	74	77

Table 4.7: Reasons for potable water preference

Reasons for preference	Percentage (%)	Frequency
Hand dug-wells, because of their proximity	100	104
Hand dug-well, its water is always available and not for sale	97	101
Hand dug-well, because there is no other alternative	99	103
Borehole, because it is the only source available to us	4.8	5
Spring water, because of its proximity	2	2

Table 4.8: Problems associated with potable water

Quality challenge	Percentage (%)	Frequency
Taste	94	98
Smell / odour	89	93
Colour	96	100

Table 4.9: Causes of poor water quality of hand-dug wells, streams and boreholes

Causes of poor quality	Percentage (%)	Frequency
Leachate from landfill polluted ground water during replenishment	88	92
The inadequate and poor management of the landfill	99	103
Polluted stabilization water spilling into wells during rainy season	100	104
Flood in community from polluted landfill drainage water during rainy season	93	97
Soil is polluted by dirty water and landfill leachate, resulting to water pollution	89	93

4.2.2 Landfill as a Nuisance and Sources of Sickness and Disease

Almost all the respondents (99.8%) were unanimous in opinion that the landfill was not properly managed, a situation that has led to constant flowing of leachates into the drinking water sources, scattering of waste all over the neighborhood, multiplication of disease vectors such as mosquitoes and house flies as well as the stench from the landfill. In their estimation, puddles of ponds of leachates brooded mosquitoes that carry malaria parasites. The filthy nature of the studied catchment also encourages breeding house flies that could be responsible for the occurrence of diarrhea, cholera and typhoid. The atmospheric pollution could result in respiratory problems. The out-patient reports from two medical centres, the Robert Moore and Hope Clinics in the Whein Town Community indicate that Malaria, Typhoid and Diarrhea are among the top ten diseases often reported (Fig 4.1). In spite of the water quality challenges, respondents still depend on the bore-hole and hand-dug wells since these were the only sources for their survival.

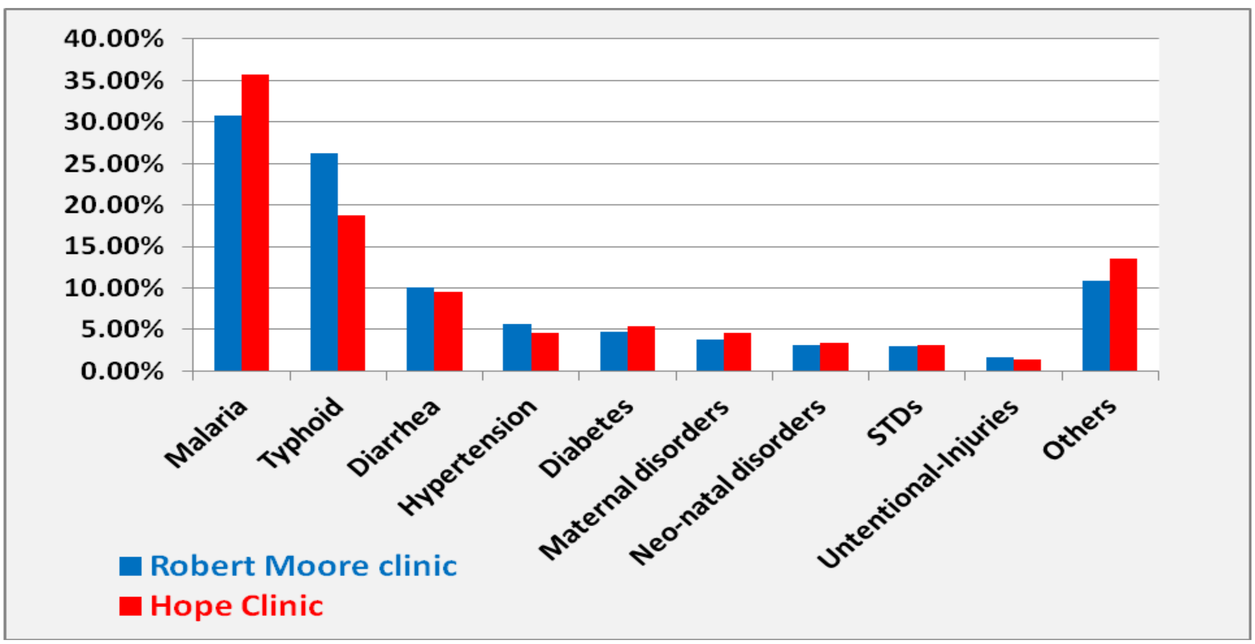


Figure 4.1: Top ten sicknesses reported at two health centers in the study area

Consumption of the polluted waters, they believed also gave them persistent stomach upsets, nausea, diarrhea and cholera (Table 4.10). In their estimation, the least that the responsible authorities could do was to monitor the quality of the water sources and take appropriate actions yet, this has also been neglected.

The only thing they could do to help themselves is treat the water by, for instance, boiling, filtering and chlorination before drinking. Disinfection by use of chlorine tablets is desirable but not a popular option because it is not available and even if it were, it would have to come at a cost. It is an established fact that heavy metals often leached from landfills and contaminate water sources when not managed properly like in the case of the Whien Town Sanitary Landfill. Laboratory examinations on samples of drinking water sampled revealed the presence of the heavy metals Cd, Cr, Zn, Cu, Pb and Hg. The mere presence of these chemicals in the water sources constitute further health hazard, irrespective of the levels.

Table 4.10: Perceived diseases experienced by respondents after ingestion of water

Sickness	Percentage (%)	Frequency
Diarrhea	62	64
Typhoid	91	95
Cholera	49	51
Nausea	15	16
Stomach upset	89	93

4.3 Physico-Chemical Parameters in Leachate and Water Sources

Appendices 13 - 16 present seasonal results of physico-chemical parameters on leachates and water sources analyzed. The study established and proved accurately the perception that both soils and portable water sources in the catchment contained trace or heavy metals concentration. Heavy metals are elements that have a density of about 4 - 5 times higher than that of water (approximately 1g/cm^3).

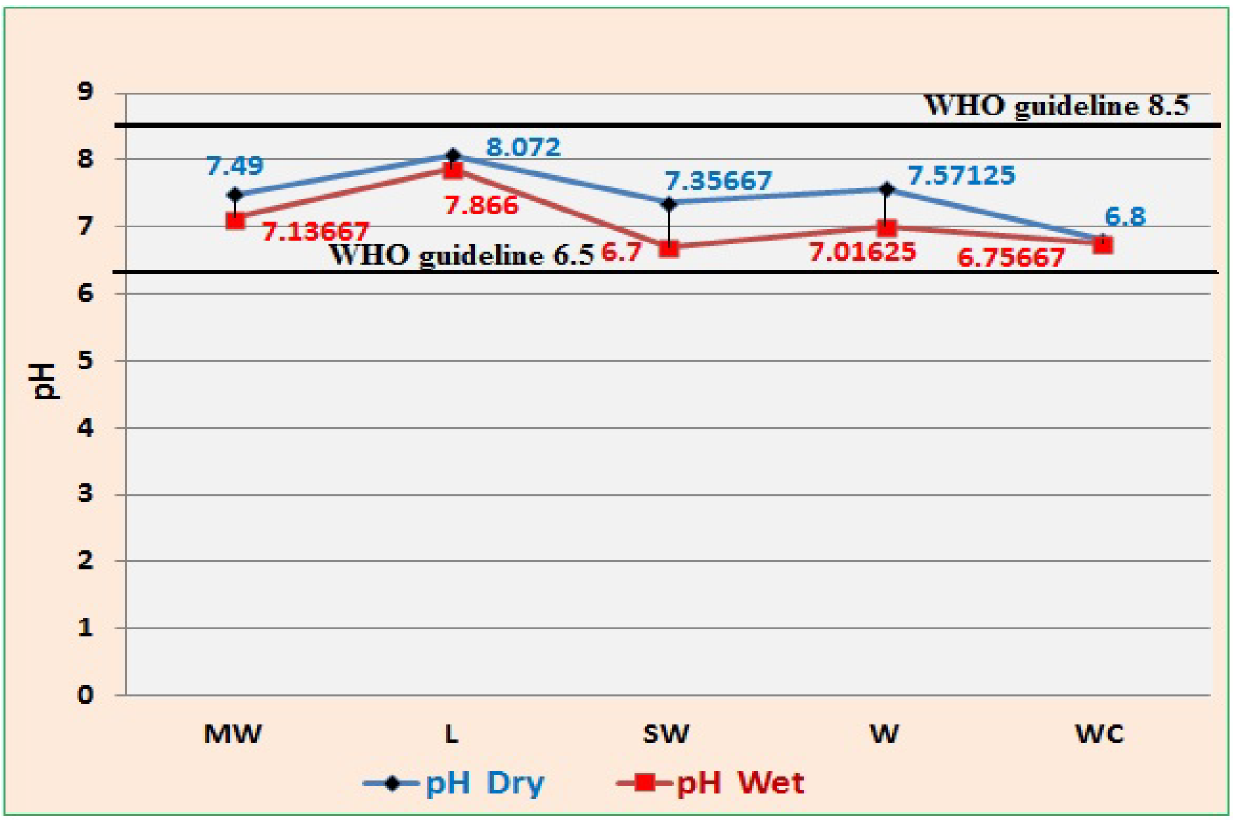


Figure 4.2: Mean pH values in leachates and water sources

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

4.3.1 pH of leachate and water Sources

The mean pH values obtained for water sources and leachates from the landfill are presented in Figure 4.2; the values recorded for dry and wet seasons, along with their mean are found in Appendix 13. The mean pH values recorded ranged from 6.8 to 8.072 (dry season); leachates recorded the highest value, while well (hand dug-well) controls recorded the lowest value. For the wet season, the mean pH values recorded ranged from 6.713 to 7.866; leachates recorded the highest value (7.866), while well (hand dug-well) controls recorded the lowest value (6.713). The mean pH values for both seasons recorded were in descending order of: leachates (7.969) > monitoring wells (7.3133) > wells (hand dug-well) (7.29375) > stream waters (7.02833) > well (hand dug-well) controls (6.75667).

The dry season in general recorded the higher pH compared to the wet season. Accordingly, all the water sources pH values were within WHO guideline limit of 6.5 – 8.5 (WHO, 2004). The mean pH values recorded for leachates, monitoring wells, stream waters and wells (hand dug well) indicated slight alkalinity, except for well (hand dug-well) controls (slightly acidic) (Figure 4.2).

4.3.2 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is the amount of oxygen needed by microorganisms to breakdown organic matters in a medium. Analysis of BOD_5 is employed to measure the amount of oxygen consumed by microbes during a period of five (5) days. According to Kurup, Rajini *et al.*, (2010) water with BOD level less than 4 mg/L are considered as clean, while those greater than 10 mg/L are considered contaminated or unsafe.

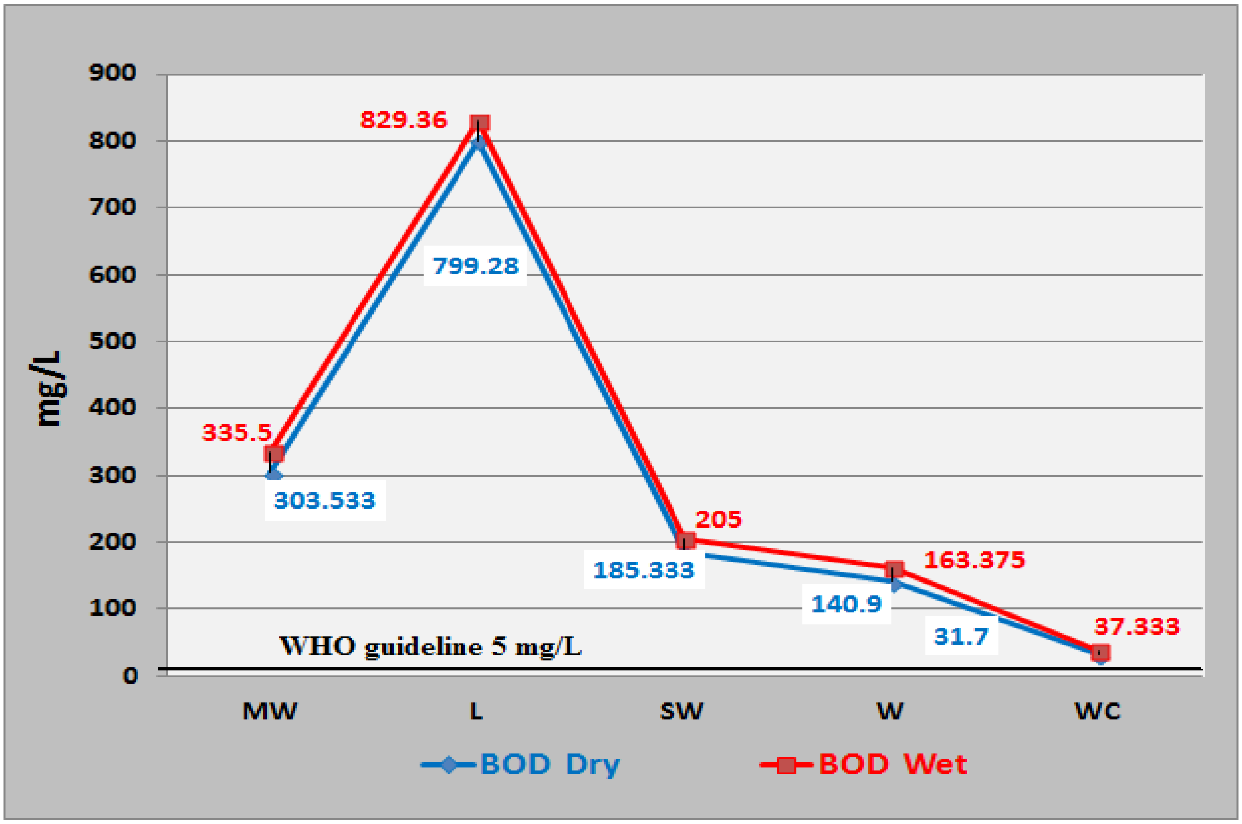


Figure 4.3: Mean BOD values (mg/L) of leachate and water sources

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand- dug well (control)

The mean Biochemical Oxygen Demand (BOD) values recorded for monitoring wells, leachates, stream waters, wells (hand dug-well), and well-controls (hand dug well) samples are presented in Figure 4.3. The values recorded for dry and wet seasons' concentrations, and mean are found in Appendix 14. The mean BOD values recorded ranged from 31.7mg/L to 799.28mg/L (dry season); leachates recorded the highest value (799.28mg/L), while well-controls (hand dug-wells) recorded the lowest (31.7mg/L). For wet season, the mean BOD values recorded ranged from 37.333mg/L to 829.36mg/L; leachates recorded the highest value (829.36mg/L) compared to well-controls (hand dug-well) that recorded the lowest

(37.333 mg/l). Mean BOD values recorded (dry and wet seasons) were in descending order of: leachates (814.32mg/L) > monitoring wells (319.517mg/L) > stream waters (195.167mg/L) > wells (hand dug well) (152.135mg/L) > well controls (hand dug wells) (34.5165mg/L).

Comparatively, the water sources values were above WHO standard (5mg/L). Meanwhile leachates did not meet the category of mature leachates, which concentration range from (1,000 to 4,000mg/L). According to Farquhar, (1989) BOD that ranged from 1000 to 4,000mg/L represents a mature landfill (5 to 10) years old; and BOD concentration of old leachates (10 to 20 years) range from 50mg/L to1000mg/L. Hence, the mean leachates value obtained where in old landfill's leachate category; yet Whein town engineer (sanitary) landfill has not reached ten years of operation.

The BOD values recorded on leachates may be due to the fact that the landfill site was initially used as a conventional landfill up until 2012, before it was transformed and commissioned as a sanitary landfill. Wilson Ltd, (2011) reported that, open dumping of wastes at the site started as far back as 2008. Generally, the BOD levels were higher at all the stations during the wet season compared to dry season; this may be as a result of increased released of organic matter from the landfill site. The drinking water sources are considered contaminated as their BOD concentration levels are above 5mg/L (Figure 4.3). The BOD Concentration levels recorded in the potable water sources may be attributed to infiltration or discharged of leachates into the stream water that eventually seeped into soils and ground waters.

4.3.3 Total dissolved Solids (TDS)

Total Dissolved Solids (TDS) constitute inorganic salts and organic matter that arise from natural occurrences and anthropogenic activities. Though, there is no firmed guideline value suggested by WHO for TDS, its level between 600 - 1000 mg/L make water pleasant and suitable for consumption (WHO, 2004) but beyond this range, there is quality problem.

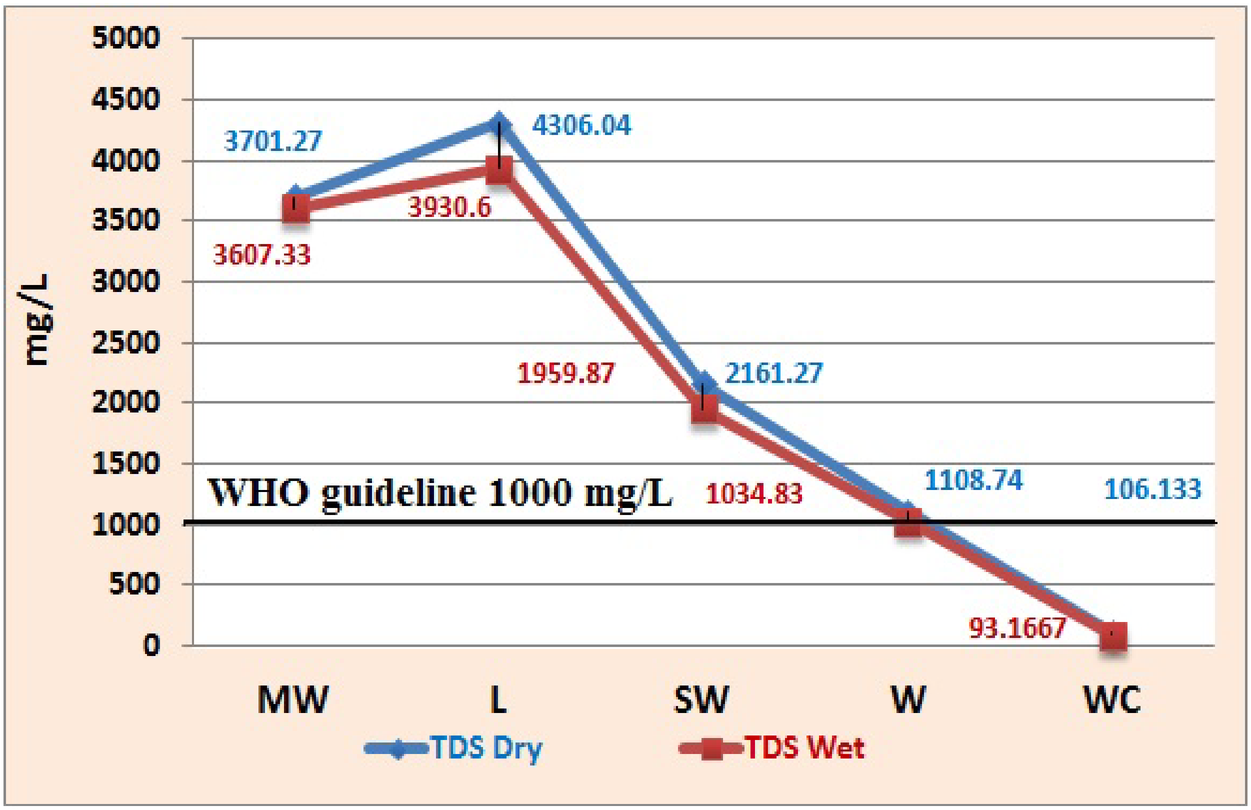


Figure 4.4: Mean TDS values (mg/L) in samples

MW – Monitoring wells; L - Leachates; SW - Stream watesr;
W - Hand-dug wells, WC - Hand-dug well (controls)

Figure 4.4 revealed the mean TDS values recorded for monitoring wells, leachates, stream waters, wells (hand dug-wells), and well-controls (hand dug-well) samples; and values recorded for dry and wet seasons, along with their means are found in Appendix 15. The mean Total Dissolved Solids values obtained ranged from 106.133mg/L to 4306.04mg/L (dry season); well-controls (hand dug-well) recorded the lowest value (106.133mg/L); while leachates recorded the highest value (4306.04 mg/L). For wet season, the mean TDS values recorded ranged from 93.1667mg/L to 3930.6mg/L; leachates recorded the highest value (3930.6mg/L), while well-controls (hand dug well) recorded the lowest value (93.1667mg/L). The dry season TDS values recorded were generally higher compared to the wet season. The mean TDS concentrations obtained values for both seasons were in the descending order of: leachates (4118.32mg/L) > monitoring wells (3654.3mg/L) > stream waters (2060.57mg/L) > wells (hand dug-well) (1071.79mg/L) > Well-controls (99.65mg/L).

As disclosed in figure 4.4, aside from well controls that registered a value that of 93.1667 for wet season, leachates, stream waters, mentoring wells and wells (hand dug-wells) recorded concentration values were above WHO recommended permissible value of 1000 mg/L in drinking water. Meanwhile, according to Farquhar, (1989) young (0-5 years) and mature (5-10 years) landfill TDS concentrations usually ranged from 10,000 to 25,000 mg/L, and 5,000 to10,000 mg/L respectively, while an old landfill (10 to 20, > 20 years) TDS values ranged from 2,000 to 5000 and < 1000mg/L respectively. However, the concentration values obtained in leachates are slightly below 5000 mg/L for both seasons (Figure 4.4) which indicates old landfill's leachates. Hence, on the contrary Whein Town Sanitary Landfill is less than ten years old; but again this may be linked to the open dumped of wastes in 2008 before its transformation into an engineered landfill in 2012. The concentration levels registered in the potable water sources may be as a result of leachates and other contaminants that may have infiltrated, leached or migrated into soils and stream waters, which subsequently affected underground waters as the water table in Whein Town and its environs is about 1.5 m deep (Earthtime INC, 2008). Groundwater and surface water are connected by their transitional zone in a hydrologic continuum; hence contamination of one usually affects the other (United States Environmental Protection Agency (USEPA), 2000).

4.3.4 Electrical Conductivity (EC)

Electrical Conductivity (EC) is a measure of the ability of water to conduct an electrical current. EC in water may be affected by the presence of inorganic dissolved solids like nitrate, sulpate and phosphate anions or cations like sodium and magnesium. The EC concentration in groundwater may also be affected from the soil (geology) through which the water flows.

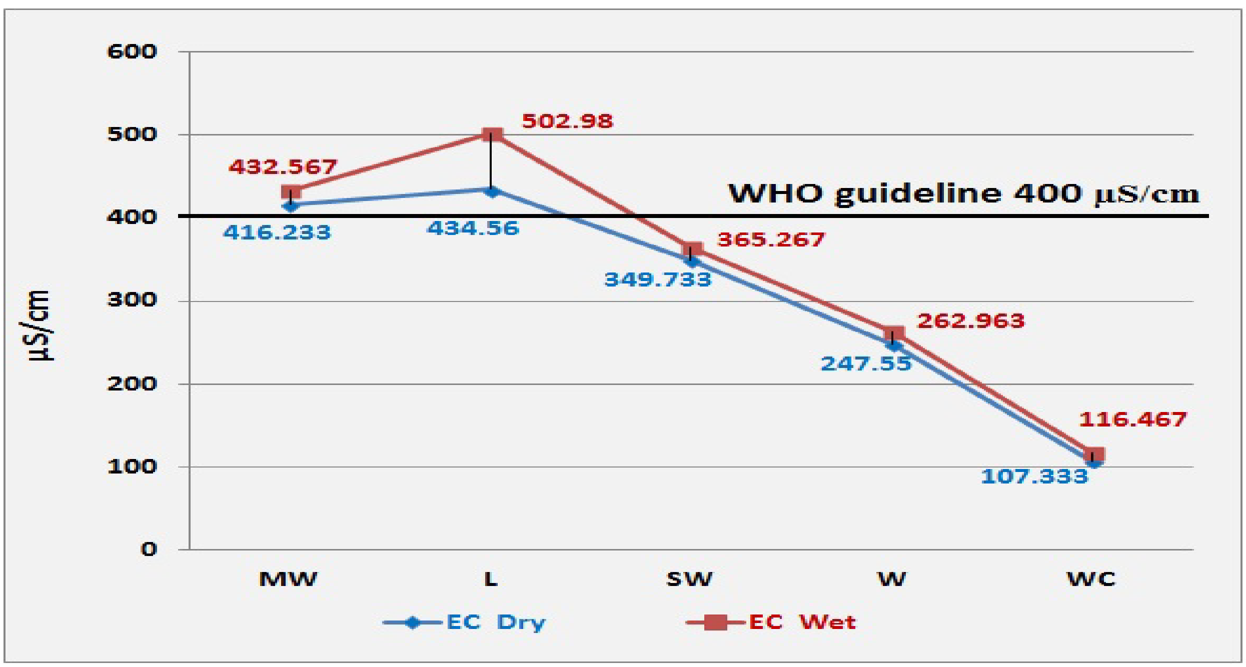


Figure 4.5: Mean EC values (µS/cm) in samples

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

The mean Electrical Conductivity values obtained for water sources and leachates are presented in Figure 4.5. The values recorded in dry and wet seasons' samples and mean are presented in Appendix 16. The mean EC concentration recorded values ranged from 107.333µS/cm to 434.56µS/cm (dry season); leachates recorded the highest value (434.56 µS/cm), and well-controls (hand dug-wells) recorded the lowest (107.333µS/cm). For wet season, the mean EC values recorded ranged from 116.467µS/cm to 502.98µS/cm; leachates recorded the highest (502.98µS/cm), while well-controls (hand dug-well) recorded the lowest value (116. 467µS/cm). Mean EC concentration values recorded from dry and wet seasons were in descending order of: leachates (468.77µS/cm) > monitor wells (424.4µS/cm) > stream waters (357.5µS/cm) > wells (hand dug-well) (255.256µS/cm) > well-controls (hand dug-well) (111.9µS/cm).

The wells, well-controls (hand dug-wells) and stream waters were within WHO guideline (400 µS/cm), while leachates and monitor wells were above (Figure 4.5). Generally, the EC concentration values increased during the wet season compared to the dry season. Conductivity usually depends on the concentration of dissolved solids; therefore variation of conductivity depends on variation of dissolved solids. The order of EC is seen to perfectly follow that of the Dissolved Total Solids however; unlike TDS the dry season mean EC concentration values were higher than that for the wet season. What exactly is responsible for this is not understood and therefore needs further investigation.

4.4 Heavy Metals Analysis of Leachate and Water Sources

4.4.1 General Trend of Heavy Metals

The heavy metals concentration values obtained showed definite seasonality in all samples, with the wet season's concentration levels higher. With the exception of Zn, the levels of all other heavy metals in samples from monitoring wells (MW), leachates (L) and stream waters (SW) were consistently higher than their corresponding WHO limits. Water from hand-dug wells, generally therefore were safe for potable usage, with respect to heavy metal content.

The decreasing order of heavy metal levels in the samples were: Leachates > Monitoring wells > Stream waters > Wells (hand-dug wells) > Well-controls (hand dug well). The only exception to this order is for the levels of copper where the mean concentration in the stream waters was higher than that determined for monitoring wells. The monitoring wells are boreholes which were intentionally sunk within the immediate vicinities of the landfill for the purpose of monitoring the levels of contaminants from the landfill and also to judge the potential of the landfill to pollute or contaminate immediate adjoining areas. The high levels of heavy metals in the water samples from the monitoring wells therefore means the landfill was actually negatively impacting the quality of water from this source.

The stream water which runs close to the landfill (less than 70 metres) similarly will be affected by discharges from the landfill and hence the high levels of heavy metals registered in its samples is not out of place. Controlled hand-dug wells were however located upstream of the landfill, therefore it was difficult for leachates and overflows from the stabilization ponds to move uphill or against the slope to contaminate them. Even though some of them were nearer than the other hand dug-wells to the landfill, their heavy metal concentration levels were always lower. It can therefore be categorically inferred that discharges from the landfill influenced the levels of heavy metals in monitoring wells, stream waters and to some extent, the other hand-dug wells down gradient. This is particularly so when it is a common experience that the stabilization ponds always leaked and also often overflow during the rainy season. The specific concentration levels of each heavy metal, their seasonality and other details of them in each sample type are taken in turns and presented in the sub-sections following.

4.4.2 Zinc (Zn)

Zinc is one of the vital elements found in food and water, but serves as contaminant when its concentration exceeds the required amount after ingestion in humans. Potable water containing zinc above 3 mg/L (WHO guideline) may be unpleasant for human ingestion and unacceptable (WHO, 2004).

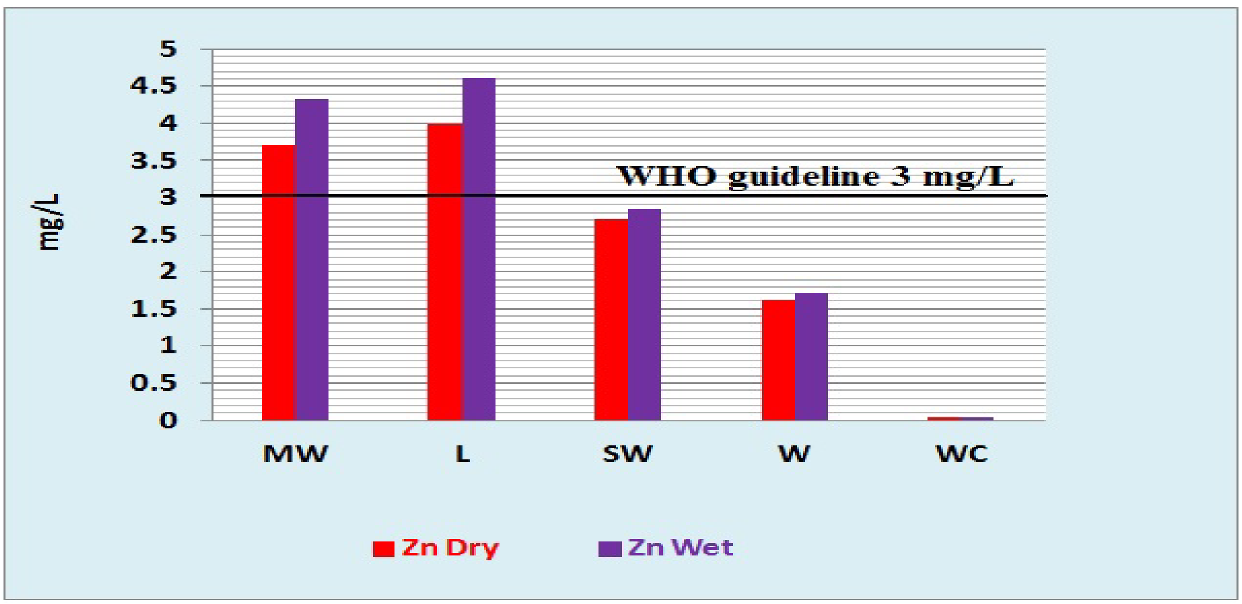


Figure 4.6: Mean Zn values (mg/L) of various samples

MW – Monitoring well; L - Leachate; SW - Stream water;
W - hand-dug well, WC – well-control (hand-dug well)

Figure 4.6 shows the mean Zn values recorded for monitor wells, leachates, stream waters, wells, and well-controls (dug-out wells) samples. The mean Zn concentration values recorded ranged from 0.03533mg/L to 3.9952mg/L (dry season); leachates recorded the highest value (3.9952mg/L), while well-controls (hand dug-well) recorded the lowest value (0.0353mg/L). For wet season samples, the mean Zn values recorded ranged from 0.044mg/L to 4.617mg/L; leachates recorded the highest (4.617mg/L), while well-control recorded the lowest value (0.044mg/L). Mean zinc concentration values recorded for both seasons varied in descending order of: leachates (4.3061mg/L) > monitoring wells (4.02317mg/L) > stream waters (2.76767mg/L) > wells (hand dug-well) (1.66913mg/L) > well-controls (hand dug-well) (0.03967mg/L).

The presence of zinc in surface and ground waters may be attributed to the leachates that spilled, leached or migrated from the waste stabilization pond and landfill into adjoined soils and stream waters or runoff. It may also be attributed to natural weathering of rocks and minerals. Comparatively, the potable water sources recorded concentrations were within WHO guideline of 3mg/L, whereas monitor wells, stream waters and leachates were above WHO permissible value (Figure 4.6). The presence of Zn in leachates indicates the wastes dumped contained batteries, tyres, solders, and alloys of metals. According to (Mohamed A. Hassaan *et al.*, 2016) some heavy metals (Cr, Cu, Zn, Cd, Pb) are used in batteries, pigments and paints, specialist alloys and steel production, hence both the manufacturing and disposal or recycling of these alloys in scrap metal can lead to environmental pollution.

4.4.3 Copper (Cu)

Copper is an important element found in food and water. It is also used in industries to produce copper resources. Notwithstanding, it pollutes soil and water sources when released from waste, wastewater and household sources that contain copper element. It exhibit colour and unpleasant taste in water when it is surplus above requirement. Long-term exposure of copper to humans causes irritation of the nose, mouth and eyes, headaches, stomach aches, dizziness, vomiting and diarrhea; it may cause liver and kidney damage and even death (Agency for Toxic Substances and Disease Registry, 2004).

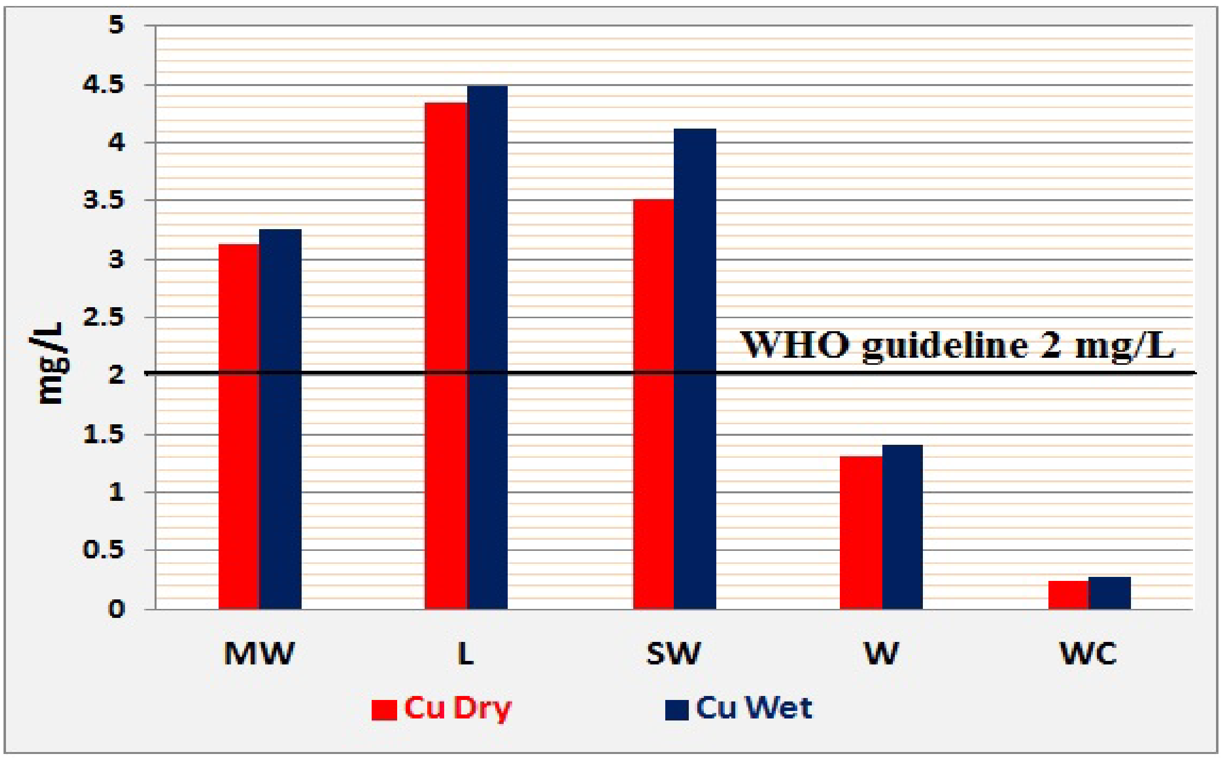


Figure 4.7: Mean Cu levels in samples matrices

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

Mean Copper concentration values recorded in leachates and water sources are presented in Figure 4.7; the values recorded for dry and wet seasons, along with their mean are disclosed in Appendix 17. The mean copper values recorded ranged from 0.25033mg/L to 4.3412mg/L (dry season); with leachates recording the highest value (4.3412mg/L), while well-controls (hand dug well) recorded the least (0.25033mg/L). For wet season samples, the mean copper levels obtained ranged from 0.26967mg/L to 4.488mg/L; leachates recorded the highest value (4.488mg/L), and well-controls (hand dug well) recorded the least value (0.26967mg/L).

Mean Copper values recorded for both seasons were descending in order of: leachates (4.4146mg/L) > stream waters (3.8125mg/L) > monitoring wells (3.198mg/L) > wells (1.36088mg/L) > well-controls (hand dug well) (0.26mg/L). Figure 4.7 showed potable water sources concentration values were within WHO guideline (2mg/L) for drinking water (WHO, 2004), while leachates, monitoring wells and stream waters were above the standard. The presence of copper in potable water sources may also be attributed to the used of fertilizers for agricultural purposes in the study catchment and landfill's spilled leachates.

4.4.4 Lead (Pb)

Lead (Pb) is used in the production of batteries, plastics, and lead based paints. It may be released from such sources in the waste (Hassaan *et al.*, 2016)

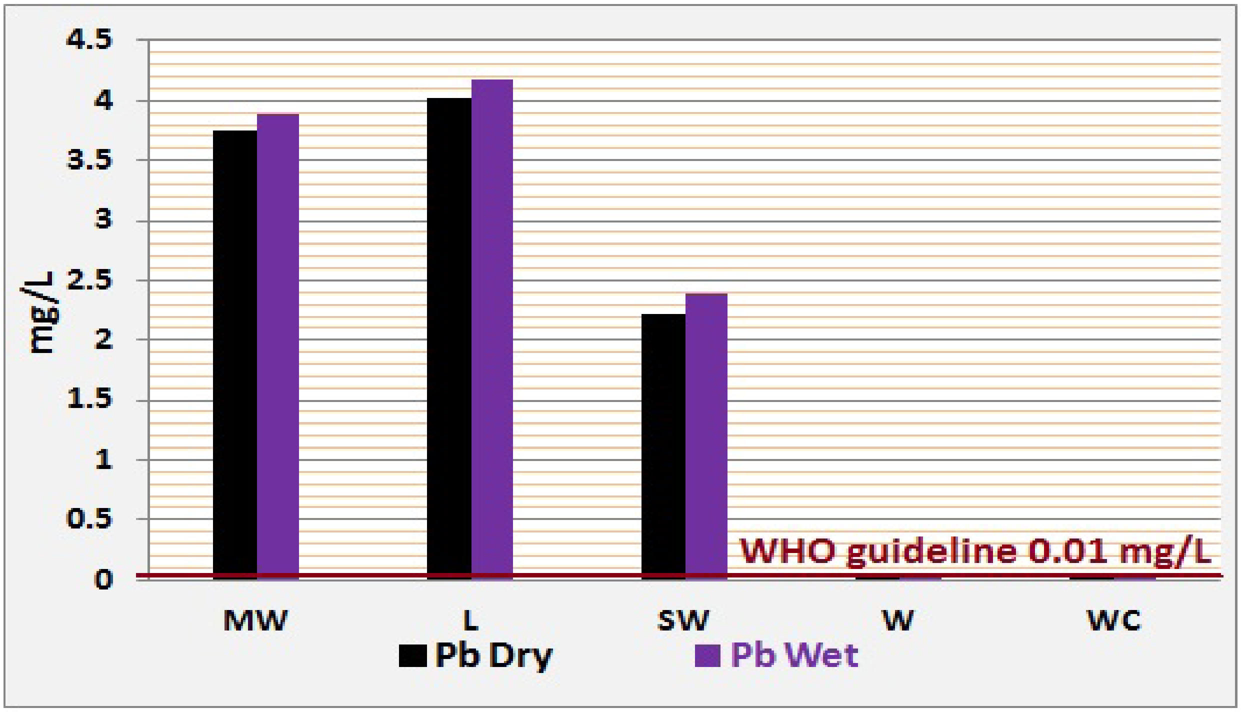


Figure 4.8: Mean Lead (Pb) values (mg/L) in various samples

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

Figure 4.8 presents the mean Lead values recorded in the various samples. The values recorded for dry and wet seasons, along with their mean are presented in Appendix 17.

Mean (Pb) concentration values registered ranged from 0.011mg/L to 4.0178mg/L (dry season); leachates recorded the highest value (4.0178mg/L); while well-controls (hand dug well) recorded the lowest value (0.011mg/L). For wet season, the mean lead concentrations ranged from 0.011mg/L to 4.1716mg/L; leachates recorded the highest value (4.1716mg/L), while well-controls (hand dug-well) recorded the lowest (0.011 mg/L). Mean (Pb) concentration values recorded for both seasons in leachates and water sources were in descending order of: leachates (4.0947mg/L) > monitoring wells (3.8225mg/L) > stream waters (2.30533mg/L) > wells (hand dug-well) (0.02354mg/L) > well-controls (hand dug-well) (0.011mg/L). All the samples concentration values recorded were above WHO guideline 0.01mg/L (WHO, 2004) (Figure 4.8). Notwithstanding, the potable water sources concentration values were only slightly above WHO guideline. The presence of lead in the potable water may be attributed to agricultural activities in the studied area, where fertilizers are used; it could be as a result of the used of lead batteries and materials (e.g plastics, pipes) which are commonly find in the studied catchment apart from the landfills' compound.

4.4.5 Cadmium (Cd)

Cadmium (Cd) is a heavy metal that is used in the production of plastics, fertilizers, batteries amongst others. It can be found in waste, sewage sludge, and leachate. It enters the environment from natural weathering of minerals, rocks and eroded soil and from anthropogenic activities. Cadmium is found in soils, mud, humus and organic matter and it is a major anthropogenic pollutant (Dominique Crowley *et al.*, 2003).

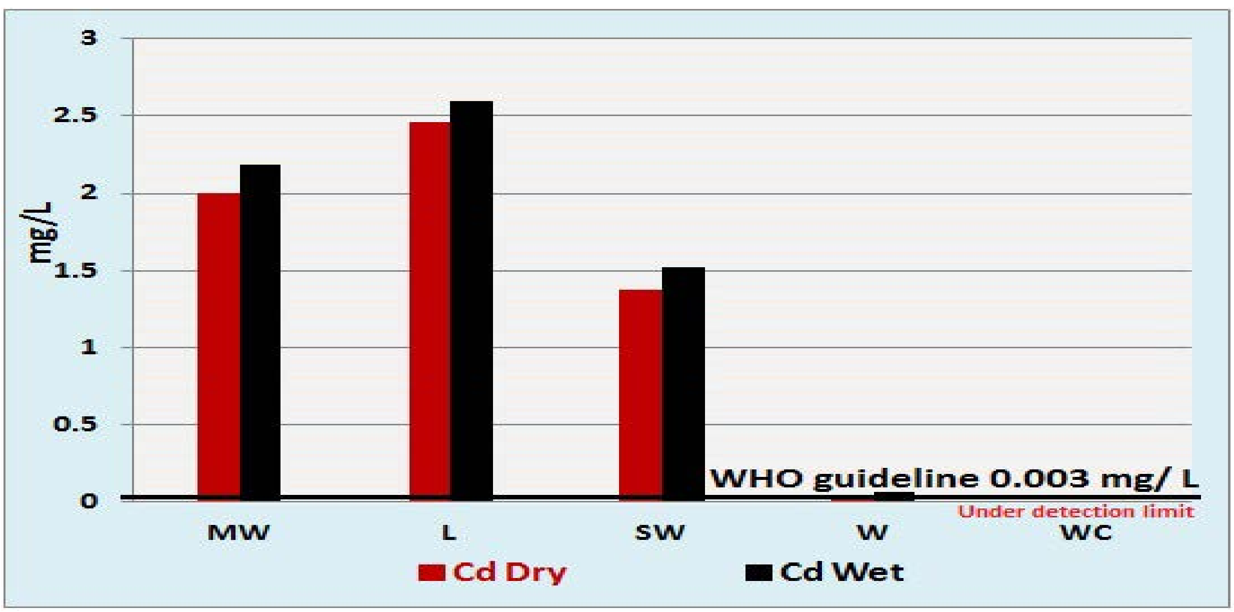


Figure 4.9: Mean Cadmium (Cd) values (mg/L) in various samples

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

The mean Cadmium concentration values recorded in the various samples are presented in Figure 4.9. Mean Cadmium concentration values recorded ranged from 0.01567mg/L to 2.4616mg/L (dry season); leachates recorded the highest concentration value (2.4616mg/L), while wells (hand dug well) recorded the lowest value (0.01567mg/L) and well controls (hand dug-well) value was under detection limit. For the wet season, the mean Cadmium concentration values obtained ranged from 0.065 mg/L – 2.5926mg/L; leachates recorded the highest value (2.5926mg/L), and wells recorded the least value (0.065mg/L). The concentration values for both seasons varied along the order of: leachates (2.5271mg/L) > monitoring wells (2.094mg/L) > stream waters (1.4505mg/L) > wells (hand dug-well) (0.04033mg/L) > well-controls (hand dug-well) (under detection limit). All the Concentration levels of Cadmium in the water sources were above WHO guideline of 0.003mg/L (WHO, 2004) (Figure 4.9).

The results indicate that wastes deposited at the landfill contained cadmium as leachates recorded the highest value. The presence of Cd in potable water may be attributed to agricultural activities and use of batteries by inhabitants of the studied area, as well as the discharged leachates from the landfill that entered or infiltrated in the soils, and ground and surface waters.

4.4.6 Chromium (Cr)

Chromium is produced through natural occurrences as it is spread in the Earth's crust. Trivalent (Cr_3) and hexavalent (Cr_6) chromium are the two principal forms found in potable water; and haxavalent chromium is a more lethal form frequently found at low levels in drinking water (California Environmental Protection Agency Fact Sheet, 2009).

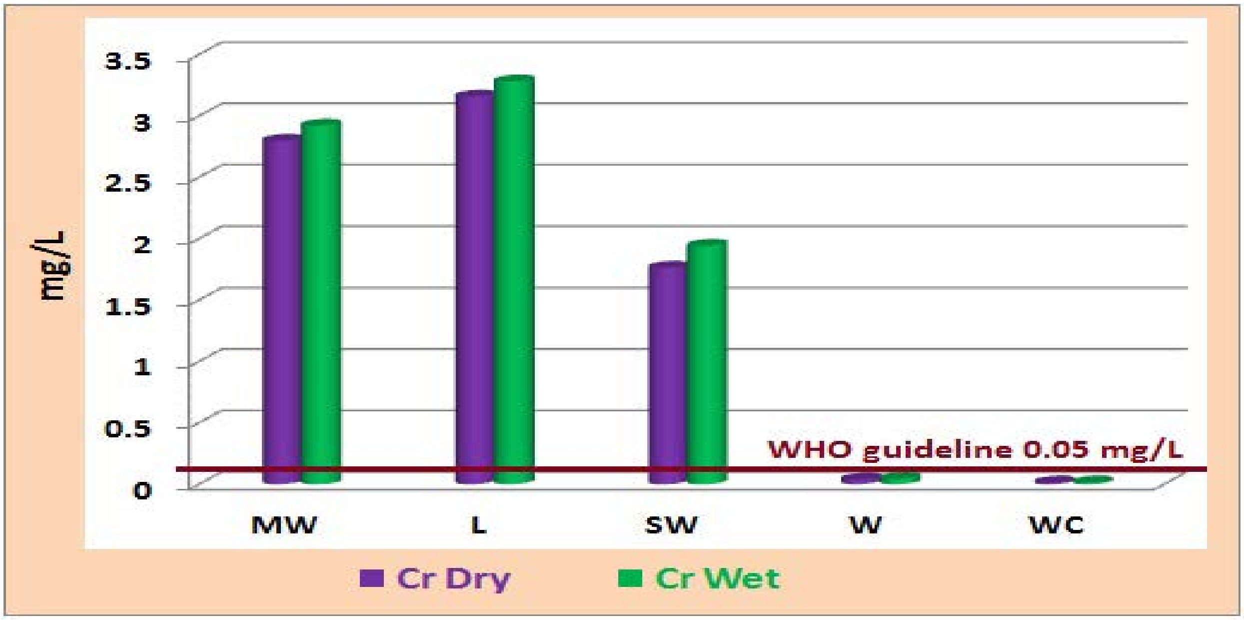


Figure 4.10: Mean Chromium (Cr) values in samples

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

Mean Chromium (Cr) concentration values recorded for water sources and leachates are presented in Figure 4.10. The mean chromium (Cr) concentration values recorded ranged from 0.012mg/L – 3.1566mg/L (dry season); leachates recorded the highest value (3.1566mg/L), while well-controls (hand dug well) recorded the lowest value (0.012mg/L).

For wet season samples, the mean Chromium concentration values registered ranged from 0.013mg/L – 3.2798mg/L; leachates registered the highest value (3.2798mg/L), while well-controls (hand dug-well) recorded the lowest (0.01mg/L). Chromium mean concentration levels recorded for both seasons were in descending order of: leachates (3.2182mg/L) >

monitoring wells (2.858mg/L) > stream waters (1.8515mg/L) > wells (hand dug wells) (0.04225mg/L) > well-controls (hand dug well) (0.0125mg/L).

The potable water concentrations were within WHO guideline of 0.05mg/L (WHO, 2004), except for the stream waters, monitoring wells and leachates (Figure 4.10). The presence of chromium in the potable water sources may be attributed to natural weathering of minerals and leachates that infiltrated or migrated into adjoining soils, flood plains and surface water from the landfill.

4.4.7 Iron (Fe)

Iron is found in the earth's crust and it is used in manufacturing industries to produce steels and alloys of metals. Its presence in water sources may be due to natural occurrences and anthropogenic activities. Iron is a crucial element for growth and survival of living organisms (Valko *et al.*, 2005). It is an essential element in human diet; nevertheless, it causes danger to public health when it exceeds its required concentration in the environment. The taste and aesthetic of drinking water may be affected when its concentration exceed WHO's limit. When iron (ferrous iron) in water gets exposed to air, it is oxidized to ferric iron, which produces unpleasant colour. It is a reactive metal that rusts very easily in the presence of oxygen; and the visible colours observed in water sources and soil may be as a result of iron-oxides.

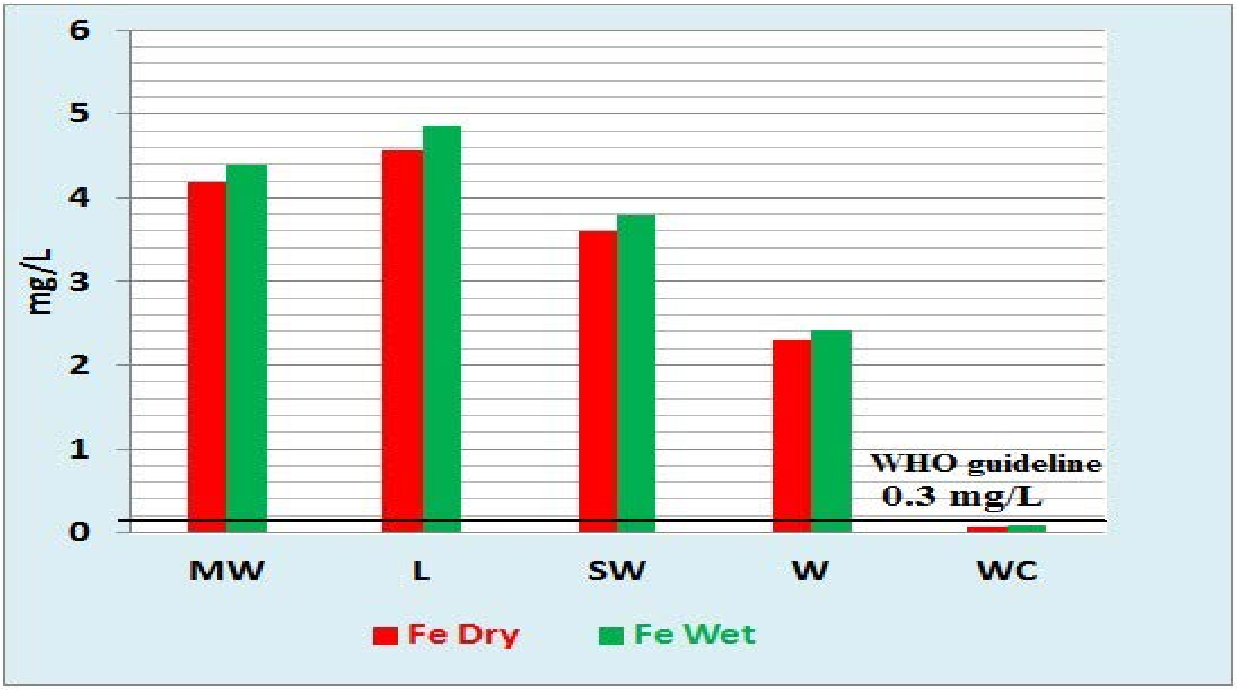


Figure 4.11: Mean Iron values (mg/L) in samples resources

MW – Monitoring well; L - Leachate; SW - Stream water;
W - Hand-dug well, WC - Hand-dug well (control)

Figure 4.11 showed the mean Iron values in leachates and water sources, while the values registered for dry and wet seasons are presented in Appendix 17. The mean (Fe) concentration values obtained ranged from 0.074mg/L – 4.5668mg/L (dry season); leachates recorded the highest value (4.5668mg/L), as well-controls (hand dug-well) recorded the lowest value (0.074mg/L). For wet season, the mean Fe value ranged from 0.08233 mg/L – 4.8698 mg/L; leachates recorded the highest (4.8698mg/L), while well-controls (hand dug-well) recorded the lowest value (0.08233mg/L). Mean Iron values registered for both seasons were in descending order of: leachates (4.7183mg/L) > monitoring wells (4.29417 mg/L) > stream waters (3.69983mg/L) > wells (2.357mg/L) > wells-controls (hand dug well) (0.07817mg/L). Apart from potable waters that were within WHO guideline of

3mg/L, all other water sources were above WHO standard (Figure 4.11) which may be attributed to the wastes dumped in the landfill and leachates produced at the site.

4.5 Soil Properties

Generally, soil is an important natural resource that acts as a bio-filter in the ecosystem, hence, metals in agricultural soil is of great fears and interest due to their accumulative and non-degradable tendency (Facchinelli *et al.*, 2001). Appendix 18 presents the seasonal variation of pH and heavy metals in soil samples.

4.5.1 pH in Soil

The pH values recorded in twelve sampled soils for dry and wet seasons are presented in Appendix 18. The values recorded for both seasons were acidic, with a range of 5.48 to 5.93. Generally, the wet season samples were slightly more acidic, falling in the range of 5.48 to 5.87 as compared to the dry season 5.63 to 5.93. At low pH, metals are found in solution hence they become more available for plant uptake. Since they are released into soil solution, they are also easily leached (Olalekan *et al.*, 2013).

4.5.2 Heavy Metals (Zn, Cu, Pb, Cd, Cr and Fe) in soil Samples

The six heavy metals mean concentration values recorded in the sampled soils are presented in Appendix 18, while Figure 4.12 showed the mean concentration of each metal in the twelve sampled soils. Zinc concentration levels recorded for the dry season ranged from 1.412mg/kg to 3.369mg/kg, while the wet season recorded concentration levels ranged from

1.41mg/kg to 3.587mg/kg. The mean concentration over both seasons (2.077mg/kg) was below WHO/FAO (2001) permissible limit of 300mg/kg for soil. Copper recorded concentration values ranged from 1.121mg/kg to 1.419mg/kg for the dry season, with a mean value of 1.222mg/kg and the wet season concentration values recorded ranged from 1,127mg/kg to 1.465mg/kg with a mean value of 1.241mg/kg. The mean values of each season fell below the WHO/FAO (2001) permissible limit of 100mg/kg for soil. Lead registered concentration values ranged from 1.221mg/kg to 1.303mg/kg (mean 1.256mg/kg) for dry season and 1.217mg/kg to 1.333mg/kg (mean, 1.273mg/kg) for the wet season. The recorded means were below the WHO/FAO (2001) permissible limit of 50mg/kg for soil.

Cadmium concentration values registered ranged from 1.101mg/kg to 1.295mg/kg (mean, 1.552mg/kg) for dry season; the wet season, recorded values ranged from 1.114mg/kg to 1.306mg/kg (mean, 1.573mg/kg). The means were below the WHO/FAO (2001) permissible limit of 100mg/kg for soil. Similarly, Chromium recorded concentration values ranged from 1.502mg/kg to 1.819mg/kg for the dry season, while the values obtained for the wet season ranged from 1.503mg/kg to 1.838mg/kg. The range of the values obtained for both seasons fell below the WHO/FAO (2001) permissible limit of 3mg/kg for soil. Iron concentration levels recorded in the twelve sampled soils ranged from 1.221mg/kg to 1.979mg/kg. The heavy metals mean concentrations values (in mg/kg) obtained were in descending order of: Zn (2.077) > Cr (1.563) > Fe (1.527) > Pb (1.265) > Cu (1.232) > Cd (1.197). Zinc recorded the highest value (2.077mg/kg), while Cadmium recorded the lowest value (1.1970mg/kg) (4.12).

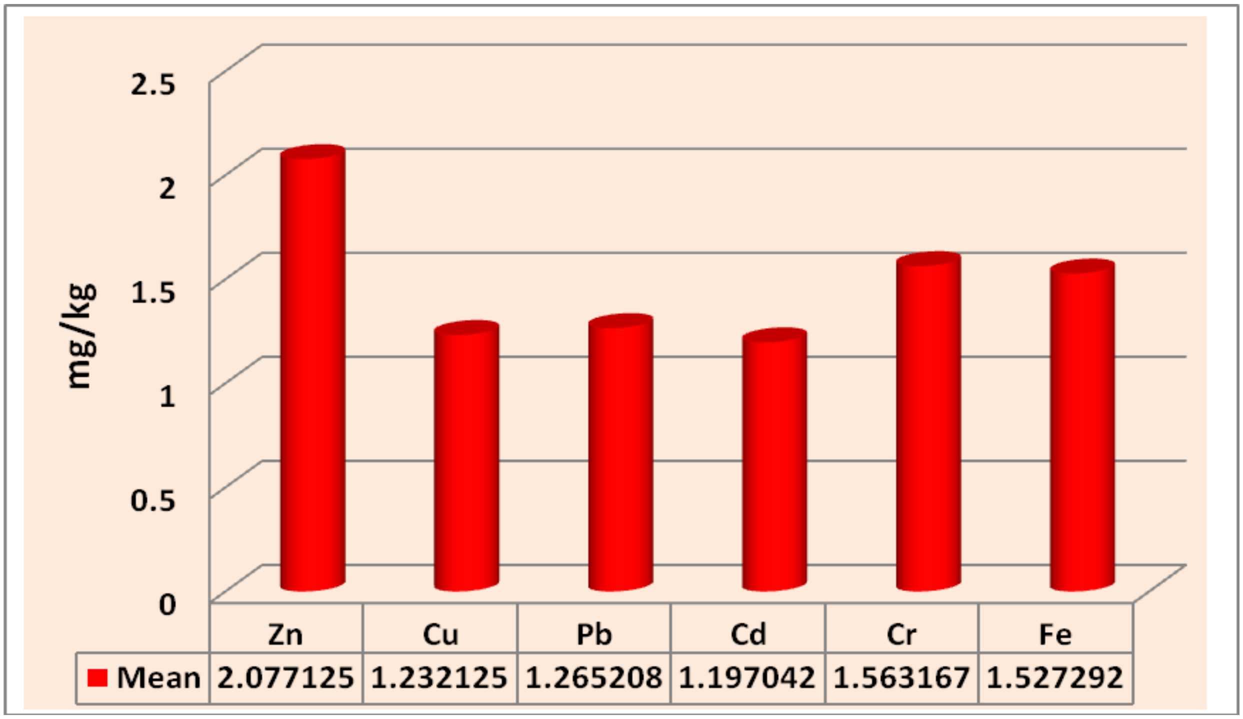


Figure 4.12: Mean metals' concentration level in soil samples

4.6 Assessment of Heavy Metal Pollution and Ecological Risk

4.6.1 Contamination factor (Cf) and Degree of contamination (CD) by elements

Contamination factor (Cf) gives an indication of the anthropogenic input of each heavy metal in soil (Keshavarzi and Kumar, 2019). Contamination factors and Degree of Contamination of the studied elements are presented in Table 4.11.

Table 4.11: Contamination factor and Degree of Contamination of elements in sampled soils

	Contamination factor (Cf)					
Location	**Zinc**	**Copper**	**Lead**	**Cadmium**	**Chromium**	Degree of Contamination (CD)
S1	0.0276	0.0551	0.0627	18.575	0.0213	
S2	0.0646	0.0673	0.0681	21.675	0.0220	
S3	0.0355	0.0593	0.0667	20.183	0.0217	
S4	0.0343	0.0601	0.0670	20.258	0.0216	
S5	0.0338	0.0601	0.0661	20.916	0.0214	
S6	0.0326	0.0565	0.0649	19.558	0.0213	
S7	0.0329	0.0562	0.0630	18.592	0.0211	
S8	0.0299	0.0554	0.0627	18.517	0.0212	
S9	0.0290	0.0549	0.0627	18.483	0.02115	
S10	0.0487	0.0644	0.0658	21.392	0.0224	
S11	0.0508	0.0648	0.0665	19.758	0.0225	
S12	0.0681	0.0707	0.0679	21.5	0.0256	
Maximum	0.0681	0.0707	0.0681	21.675	0.0256	**21.907**
Minimum	0.0276	0.0549	0.0627	18.483	0.0211	**18.649**
Mean	0.0407	0.0604	0.06534	19.9506	0.0219	**20.127**

The contamination factor is grouped into four grades as presented in Table 4.12. Mean Cf values recorded for all the elements ranged from 0.0219mg/kg to 19.9506mg/kg, and follows the descending order of: Cd > Pb > Cu > Zn > Cr. The Contamination factor recorded values for all the elements, with the exception of cadmium indicated low level of pollution since the value for each was less than 1.

The anthropogenic input of these metals into the soils of the studied catchment was therefore low. Similar results were reported by Keshavarzi and Kumar, (2019) for agricultural soil of north-eastern Iran where contribution by Cu, Zn and Mn were found to be minimal. The Cf values ranking obtained in this study are similar to Guo *et al.*, (2010) reported Cf ranking of the same studied heavy metals in Tianjin, China.

Cadmium with a mean recorded concentration of 19.9506mg/kg indicated very strong level of pollution. At all the sampled sites Cadmium contamination factor recorded values ranged from 18.483mg/kg to 21.675mg/kg, which inferred all the sites are very strongly polluted from Cadmium as each of their value was greater than 6.

The degree of contamination (CD) is the sum of all the contamination factors; it provides the overall information on cumulative pollution input of all the metals in the studied soils. As showed also in Table 4.11 the mean CD values recorded (20.127mg/kg) for all the elements in the sampled soils suggests that there is considerable degree of contamination by these elements. This contamination can be attributed to cadmium since the contribution by all other elements was negligible. The landfill and agricultural activities in the studied area could account for the degree of contamination.

Table 4.12: Grading and interpretation Cf and CD

Contamination Factor (Cf)	
Scope of Contamination factor (Cf)	Interpretations
Cf < 1	indicates low level of pollution
Cf ≥ 1 but ≤ 3	indicates moderate pollution
Cf ≥ 3 but ≤ 6, and	indicates high level of pollution
Cf > 6,	indicates very strong level of pollution
Degree of contamination (CD)	
Scope of degree of contamination (CD)	Interpretations
CD < 6	indicates low degree of contamination
CD ≥ 6 but < 12	indicates moderate degree of contamination
CD ≥12 but < 24 and	considerable degree of contamination
CD ≥ 24	very high contamination degree

Source: Hankanson. L (1980); Ahdy and Khaled, (2009)

4.6.2 Single (E^i_R) and Comprehensive Potential Ecological Risk (E^i_R) assessment of heavy metals in sampled soils

The ecological risk assessment as proposed by Hakanson. L, (1980) was used to evaluate the potential ecological risk of the selected studied heavy metals. This method comprehensively examines the synergy, toxicity, concentration and ecological sensitivity of heavy metals by organisms (Douay *et al.*, 2013, Jiang *et al.*, 2014, Protano *et al.*, 2014). By this method, the potential ecological risk index of single metals (E^i_R) and the comprehensive potential ecological risk index (RI) were calculated and presented in table 4.13. The grading of standards of the potential risks in the studied soils are summarised in table 4.14.

Table 4.13: Ecological Risk index of five studied heavy metals in soils

Location	**Ecological Risk index for a single element (E^i_R)**					**RI**
	Zinc	**Copper**	**Lead**	**Cadmium**	**Chromium**	
S1	0.0276	0.2755	0.3135	557.25	0.0426	
S2	0.0646	0.3365	0.3405	650.25	0.044	
S3	0.0355	0.2965	0.3335	605.49	0.0434	
S4	0.0343	0.3005	0.335	607.74	0.0432	
S5	0.0338	0.3005	0.3305	627.48	0.0428	
S6	0.0326	0.2825	0.3245	586.74	0.0426	
S7	0.0329	0.281	0.315	587.76	0.0422	
S8	0.0299	0.277	0.3135	555.51	0.0424	
S9	0.0290	0.2745	0.314	554.49	0.0423	
S10	0.0487	0.322	0.329	641.76	0.0448	
S11	0.0508	0.324	0.3325	592.74	0.045	
S12	0.0681	0.3535	0.3395	645	0.0512	
Maximum	**0.0681**	**0.3535**	**0.3405**	**650.25**	**0.0512**	**651.0633**
Minimum	**0.0276**	**0.2745**	**0.3135**	**554.49**	**0.0422**	**555.1478**
Mean	**0.04065**	**0.302**	**0.32675**	**601.0175**	**0.043875**	**601.7308**

Biological toxicity factor (T^i_R) Zinc = 1; Copper = 5; Lead =5; Cadmium = 30; Chromium =2

It can be observed from Table 4.13 that the scope of the potential ecological risk indices of the five heavy metals are E^i_R (Zn) 0.027mg/kg – 0.0681mg/kg, E^i_R (Cu) 0.275mg/kg – 0.353mg/kg, E^i_R (Pb) 0.313mg/kg – 0.340mg/kg, E^i_R (Cd) 554.49mg/kg – 650.25mg/kg and E^i_R (Cr) 0.042mg/kg – 0.051mg/kg.

In terms of the mean potential ecological risk indices of the five metals, the descending order of magnitude is Cd > Pb > Cu > Cr > Zn. All the heavy metals, with the exception of Cd, indicated only slight level of pollution. Exactly the same order was obtained for the same heavy metals by Jiang *et al.*, (2014) from their analysis of soils of coal gangue dump of north eastern China. In this study conducted in Whein Town community, Cadmium with mean value of 601.73mg/kg was the key factor influencing the ecological risk to the environment.

All the sampling points have strong E^i_R of Cadmium, whereas other metals only showed slight potential ecological risk (Table 4.13). Therefore there is the need to further investigate Cadmium pollution in the studied catchment. The scope of comprehensive potential ecological risk (RI) was 555.147mg/kg – 651.063mg/kg (Table 4.13) and this indicates the degree of ecological pollution and damage is very strong. The very strong pollution and damaged to the ecosystem are attributed to cadmium high (E^i_R) concentration values obtained (Table 4.13).

Table 4.13: Grading and interpretations of E^i_R and RI

Ecological risk index (E^i_R) of a single metal	
Scope of Ecological risk index (E^i_R)	Interpretations
$E^i_R < 30$,	indicates slight level of pollution
$E^i_R \geq 30$ but < 60	Indicates medium or average degree of pollution
$E^i_R \geq 60$ but < 120	indicates strong level of pollution
$E^i_R \geq 120 < 240$ and	indicates strong level of pollution
$E^i_R \geq 240$	Indicates extremely strong level of pollution
Comprehensive Potential Ecological Risk index (RI)	
Scope of Potential Ecological Risk index (RI)	Interpretations
RI < 40	indicates slight level of pollution
RI ≥ 40 but < 80	indicates medium level of pollution
RI ≥ 80 but < 160 and	indicate strong level of pollution
RI ≥ 160 but < 320	indicates very strong level of pollution

Source: Hakanson, L. (1980) and Jiang *et al.*, (2014)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The objectives of the study were to ascertain citizens' perceptions on the effect of the landfill activities and to evaluate real time health hazards the landfill pose to community dwellers; to determine some Physico-Chemical parameters, as well as the concentrations of selected heavy metals such as Zn, Cu, Pb, Cd, Cr and Fe in soils, leachates and water sources; in addition, to evaluate the contamination status of the soils and potential ecological risk the soils pose in the study catchment.

The inhabitants in the study catchment entirely depended on hand dug-well as their source of drinking water, followed by sachet and borehole waters. Generally, the study established that residents in the catchment believed their water sources were polluted from leachates, and other contaminants released from the landfill into the community through the stream (drainage) that conveyed storm water from the landfill compound and adjacent areas into the nearby streams and groundwater sources.

Consumption of water from these sources, therefore leads to the incidence of illnesses and diseases such as diarrhea, typhoid, cholera, fever, asthma, and stomachache. These were attributed to inadequate management or the failure to implement a sound environmental waste management system.

The site itself is a breeding ground of parasites and disease vectors such as mosquitoes and houseflies and the permanent stench emanating from the wastes has become a daily nuisance and possible hazard for the occurrence of upper respiratory diseases.

Health reports from two medical centres in the study area listed malaria, typhoid and diarrhea as the top three diseases reported at the out patients department (OPD). This therefore lends credence to their perceptions.

Laboratory analysis of their potable water sources showed that BOD and TDS levels were higher than WHO permissible limits while the studied heavy metals (Zn, Cu, Cr, Cd, Pb and Fe) all had appreciable levels to constitute contamination.

The leachates and stream waters had the levels of these parameters persistently above the WHO standards. It was inferred that leachates discharges were responsible for the contamination of the water sources.

The results of heavy metal pollution assessment indicated that the mean Cf values recorded for all the elements had a range of 0.0219mg/kg – 19.9506mg/kg and follows the descending order of: Cd > Pb > Cu > Zn > Cr. The degree of contamination (CD) index was 20.12mg/kg which indicate that there was considerable contamination by the heavy metals.

The potential ecological risk assessment indices of single elements was in the descending order of Cd > Pb > Cu > Cr > Zn. Cadmium was the key influence factor causing the risk; its mean value was as high as 601.73mg/kg.

All the sampling sites showed a strong potential ecological risk of Cadmium while all other heavy metals in the sampled soils of the study area showed only slight potential ecological risk. The range of comprehensive potential ecological risk (RI) was 555.147mg/kg – 651.063mg/kg which indicated that the degree of ecological pollution and damage is very strong.

In reference to Earthtime INC (2008) declaration which states “Proper operations of the Whein Town Sanitary Landfill and its facilities are expected to reduce health risks associated with the opened unsanitary disposal of wastes that promotes the breeding of disease vectors and pests as well as the contamination of groundwater, surface water and soil which all lead to an increase in the incidences of parasitic infections, hepatitis, malaria, plague along with gastrointestinal diseases including cholera and typhoid".

Previously with an integrated solid wastes management motive, on the contrary this research established that the lack of sound environmental solid wastes management or integrated solid waste management implementation at the Whein Town Sanitary Landfill resulted to illnesses, diseases, pollutions of soil and waters sources and other nuisance in the studied catchment.

Therefore, the conclusive results demonstrate that both the water resources and agricultural soils in Whein town of Liberia have been contaminated by discharges from the landfill that has been cited within the community. Furthermore, quality of life has been greatly affected by atmospheric pollution from the waste dump as well as consumption of water of poor quality.

5.2 RECOMMENDATIONS

- A full scale physico-chemical and biological analysis should be conducted to evaluate heavy metals' concentrations on soil and in drinking water sources in the studied catchment and its environs by EPAL and other relevant authorities
- The EPAL, the National Environmental and Occupational Health (NEOH) and Ministry of Health (MOH) should conduct a full analysis on the vegetables and fruits growing in the soil surrounding the landfill compound to evaluate the level to which these crops have been contaminated.
- Similarly, there is the urgent need for Ministry of Commerce, the EPAL and NEOH to carry out physic–chemical and microbiological analysis on aquatic fauna such as fish and crabs to determine their suitability for consumption.
- There is the need for EPAL, NEOH, Ministry of Public Works (MPW) and the MCC to critically assess the performance of the landfill and possibly decommission its use as a matter of urgency since it has over-lived its useful life span.
- The Liberia Water and Sewer Corporation (LWSC) and MPW should supply Safe pipe borne water to the community to discourage the inhabitants from harvesting from their present sources of drinking water, and
- A blood analysis (medical) should be conducted by MOH to evaluate the concentration of heavy metals that may have already accumulated in some of the inhabitants of the study area and its environs.

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APPENDICES

Appendix 1: Pictures showing leachates spillage from the WSPs into adjoining lands and stream




Appendix 2: pictorials of plot of agricultural lands and stream used for farming and fishing purposes in studied catchment





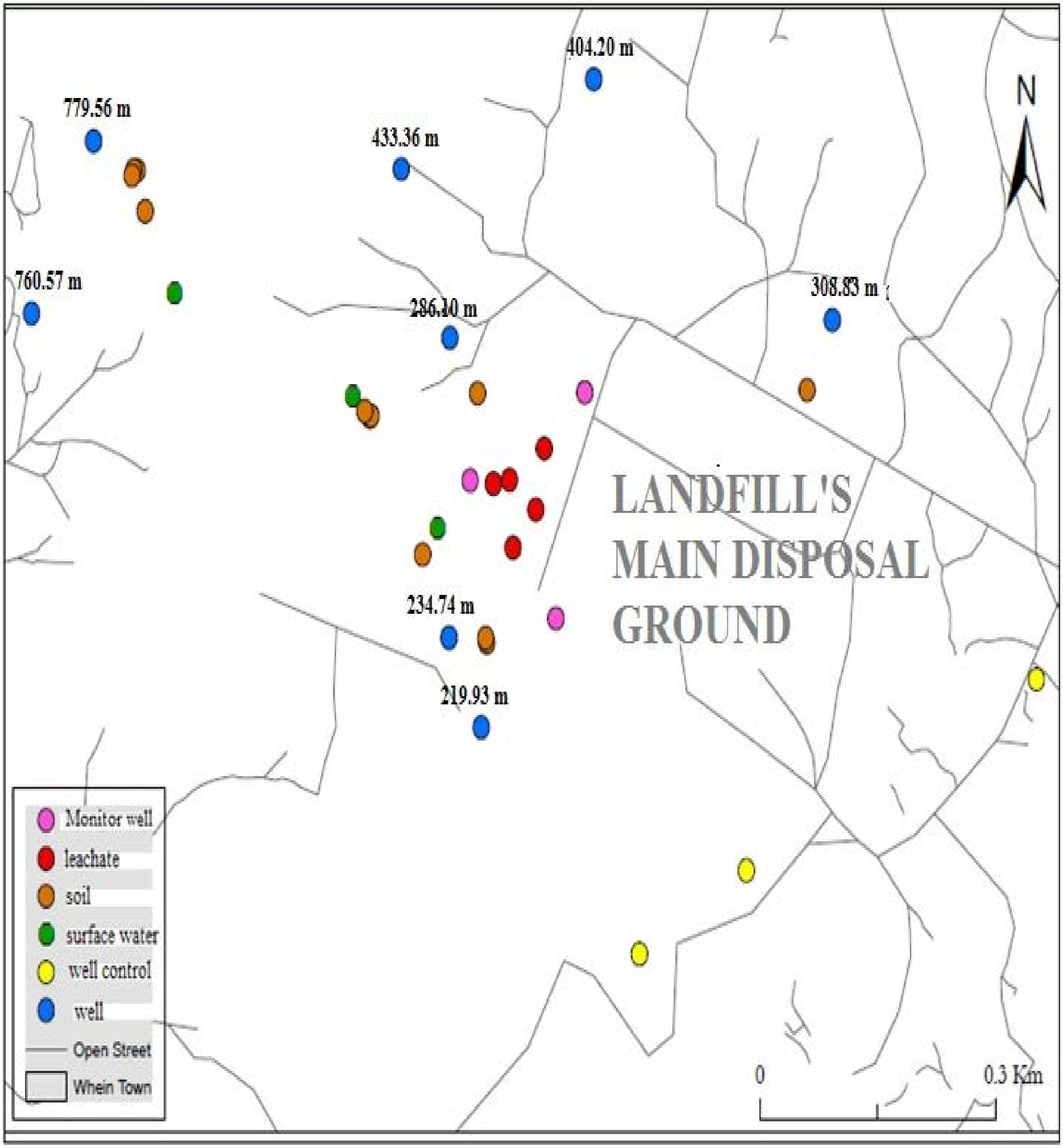
A local fishing method used to catch crab, frogs and fishes in liberia especially in rural communities

APPENDIX 3: GPS COORDINATES OF SAMPLING SITES

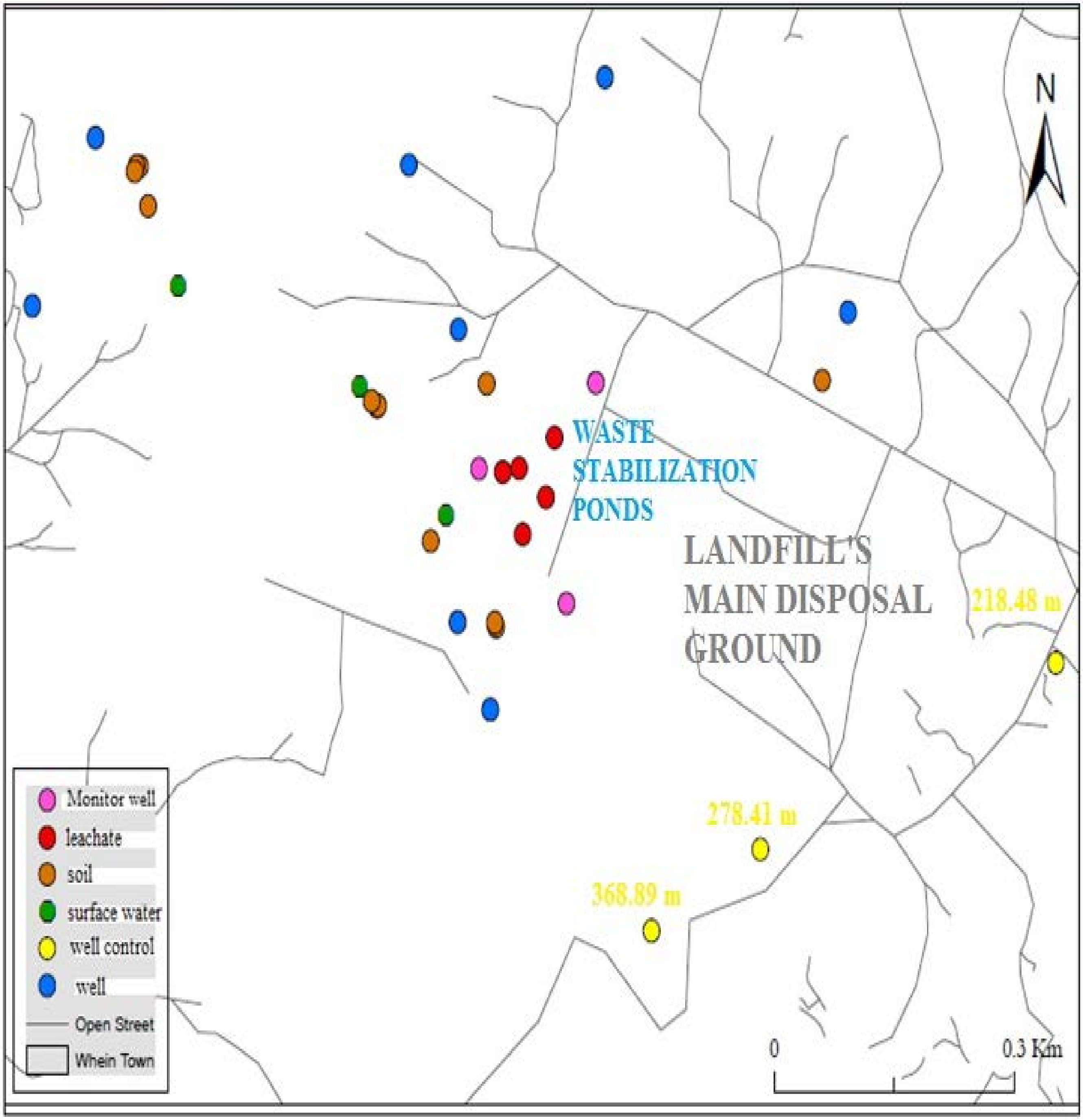
Sampling points	Latitude	Longitude	Elevation
MW1	6.322805	-10.6755	9.233852
MW 02	6.3221	-10.6768	7.605865
MW 03	6.320987	-10.6758	8.696114
L 1	6.322354	-10.676	8.432983
L 2	6.322071	-10.6766	9.7104
L 3	6.322103	-10.6764	10.171728
L 4	6.321865	-10.17173	9.193016
L 5	6.321556	-10.676331	10.905298
S 1	6.322824	-10.672961	12.830345
S 2	6.322798	-10.6767	11.907068
S 3	6.322611	-10.678	7.388077
S 4	6.322618	-10.678	8.974628
S 5	6.322657	-10.678	9.092203
S 6	6.324261	-10.6805	8.539371
S 7	6.324587	-10.6806	6.483852
S 8	6.324591	-10.6807	6.760975
S 9	6.324546	-10.6807	9.217251
S 10	6.320798	-10.6766	10.276197
S 11	6.320833	-106.766	12.348087
S 12	6.321503	-10.6774	5.562307
SW 01	6.322781	-10.6782	9.168316
SW 02	6.3221719	-10.6802	5.985014
SW 03	6.321719	-10.6772	7.360584
W 01	6.323384	-10.6727	15.714653
W 02	6.323608	-10.6754	10.457962
W 03	6.323244	-10.6771	13.723694
W 04	6.324597	-10.6776	7.27335
W 05	6.320835	-10.6771	9.641186
W 06	6.320116	-10.6767	11.202501
W 07	6.32482	-10.6811	7.571503
W 08	6.323436	-10.6818	8.662842
WC 01	6.318966	-10.6737	18.653269
WC 02	6.318297	-10.6749	13.327913
WC 03	6.320497	-10.6703	20.456692

Appendix 4: Collection of water and leachate samples for laboratory analyses

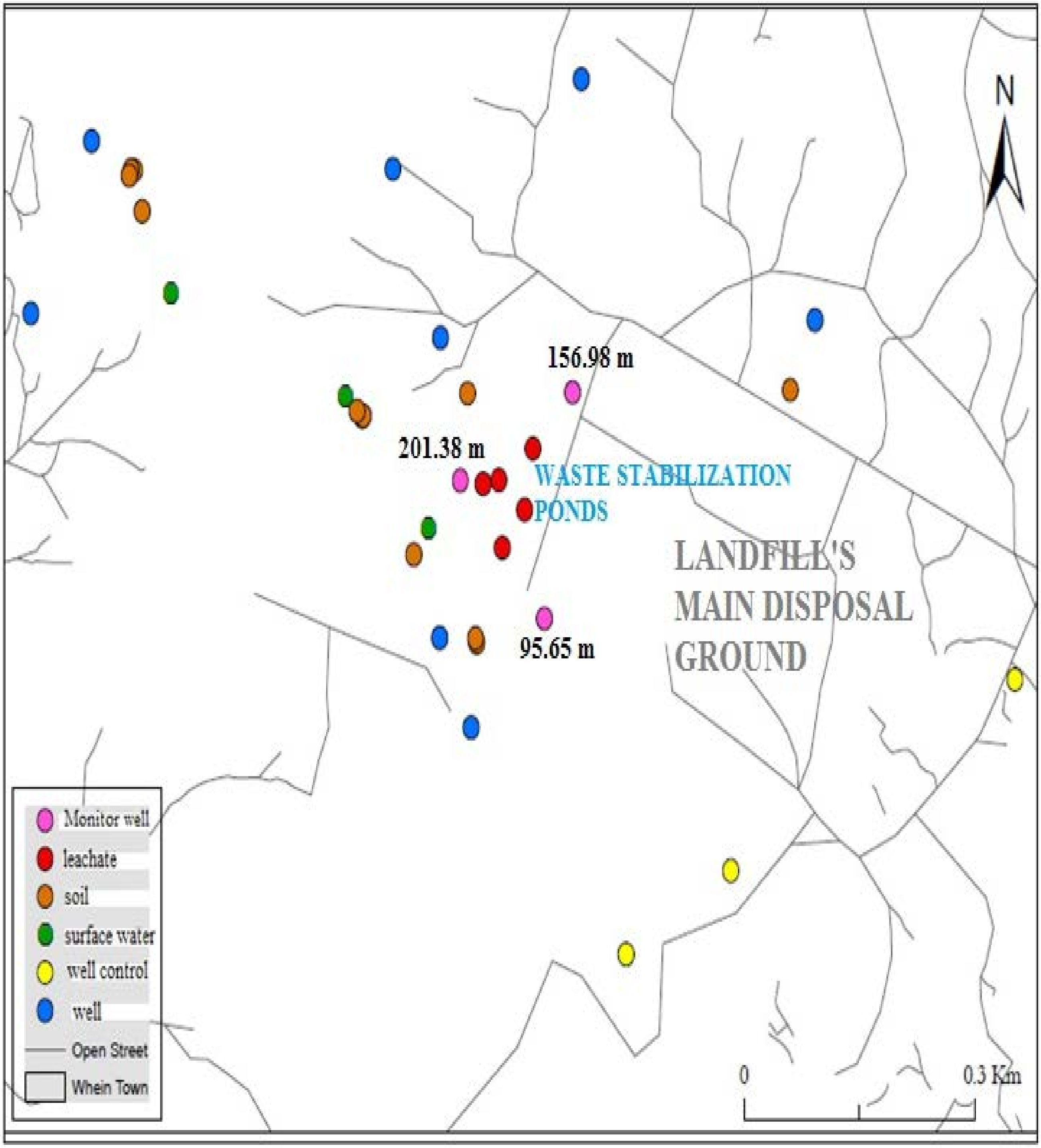
Appendix 5: Distances of potable water sources from the landfill



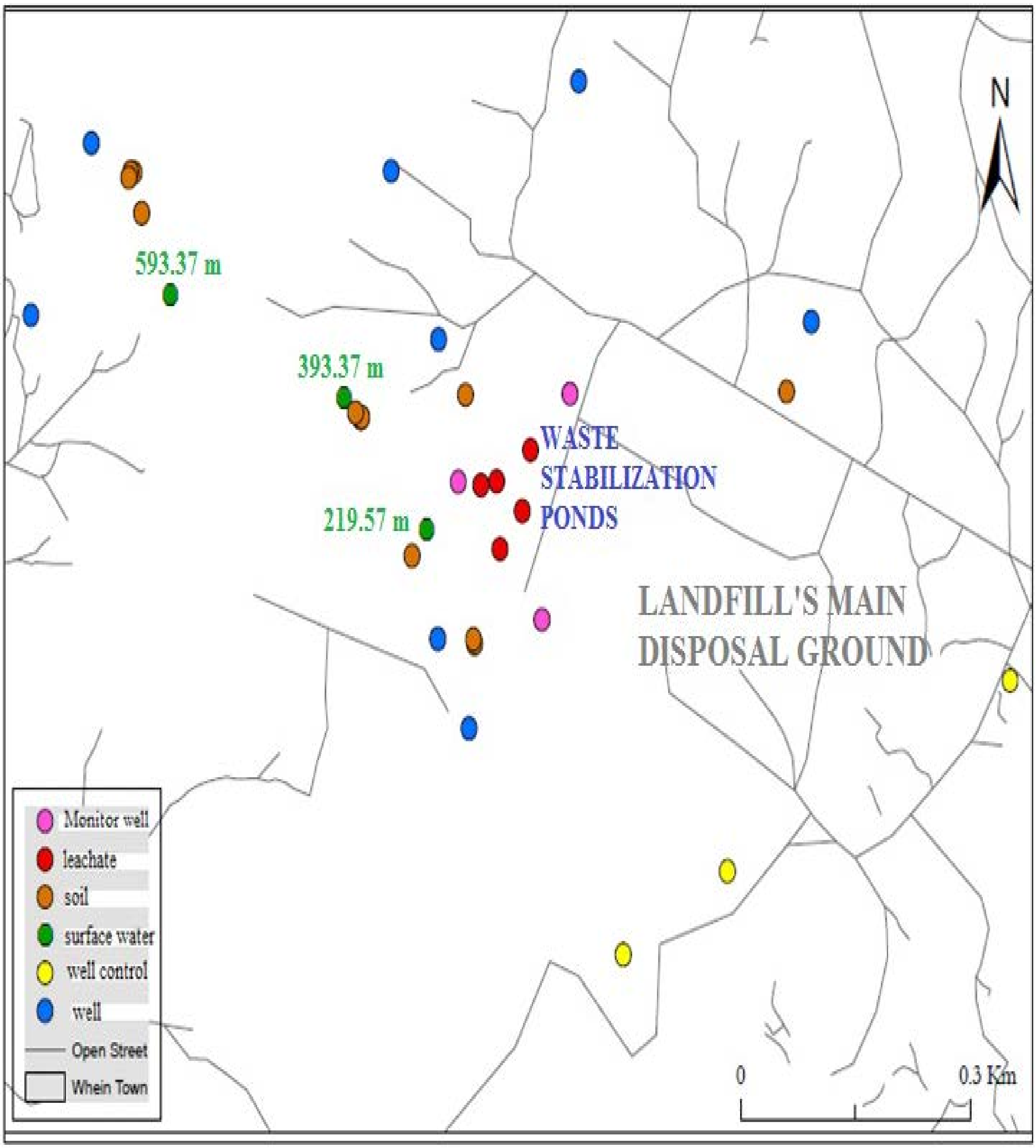
Appendix 6: Distances of sampled well controls (hand dug-well) from landfill



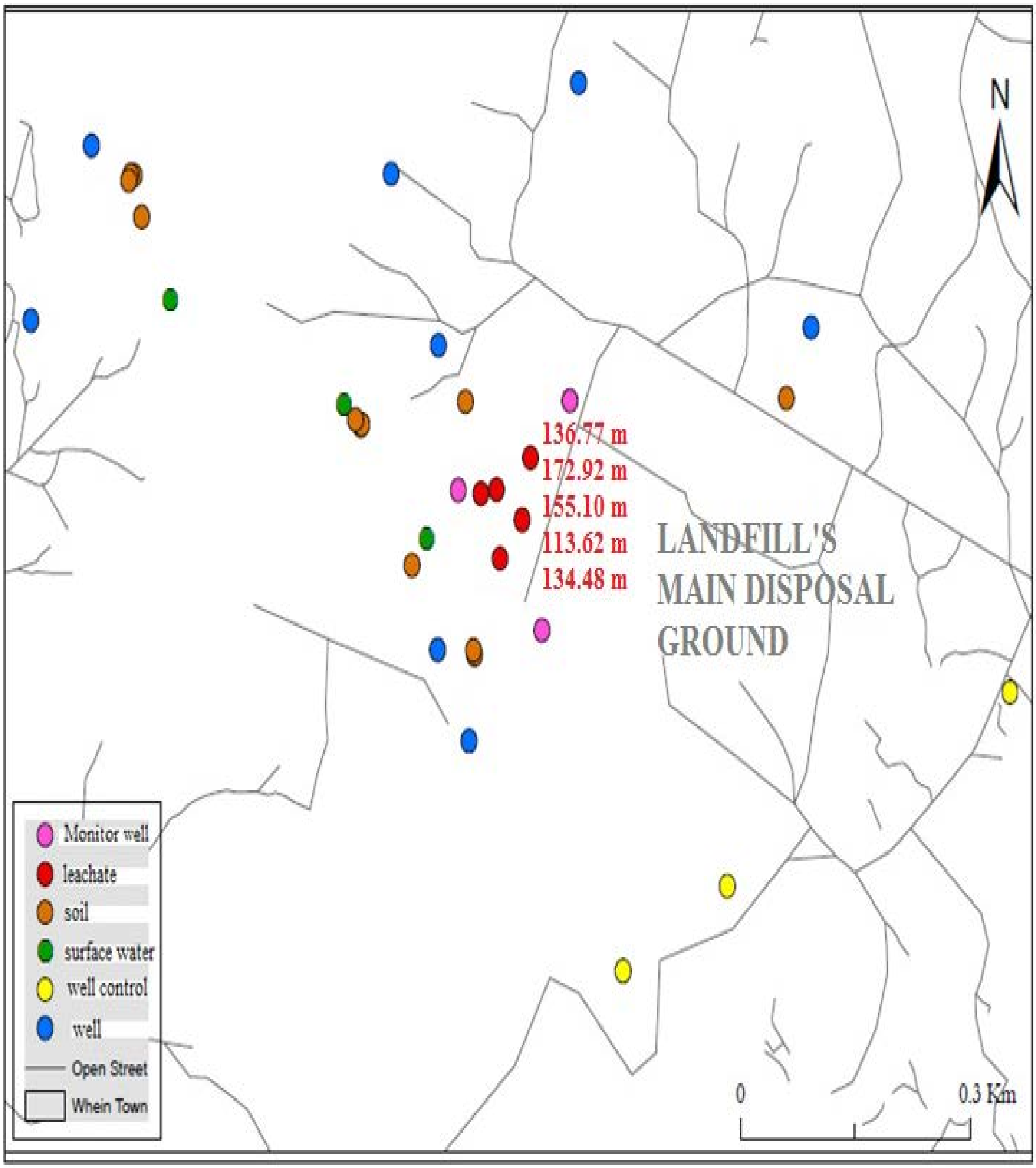
Appendix 7: Distances of the monitor wells from the landfill



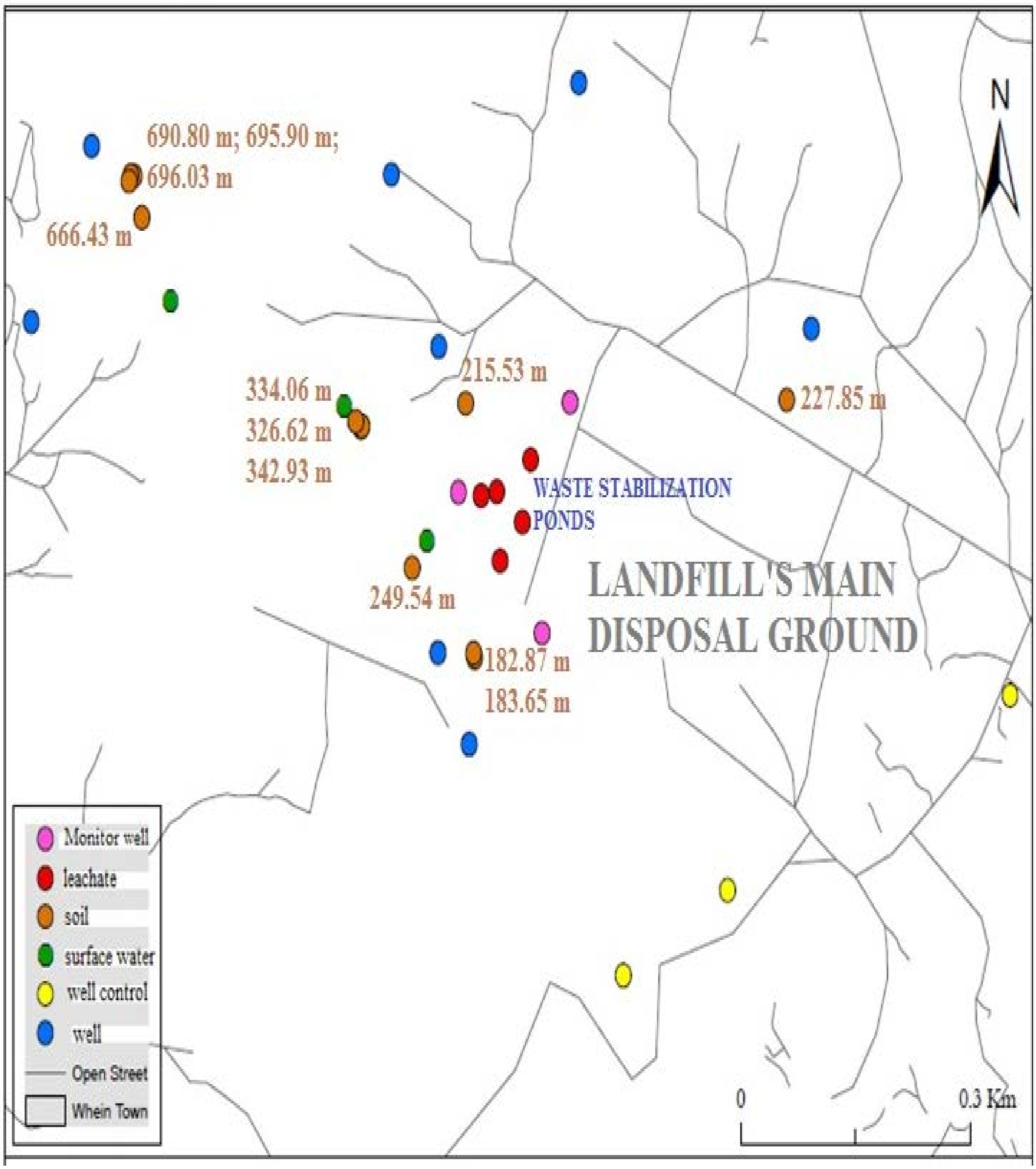
Appendix 8: Distances of stream waters from the landfill



Appendix 9: Distances of leachates sampling points from the landfill



Appendix 10: Distances of soils sampling points from the landfill



APPENDIX 11: Questionnaires

Date received __________________

Dear Respondent,

My name is Stephen M. Gibson; I am a student studying Environmental Science at the Institute for Environment and Sanitation Studies, University of Ghana. I am conducting a research into **"Evaluation of Landfill Effects on Soil And Water Sources, a Case Study of The Whein Town Sanitary Land Fill, Montserrado County-Liberia"**

The objectives of the study is to ascertain citizens' perceptions on the effect of landfill's activities and to evaluate health hazards it poses to community dwellers; to determine some Physico-Chemical parameters, as well as the concentrations of trace metals (Zn, Cu, Pb, Cd, Cr and Fe) in soil and water sources. In addition, to evaluate the contamination status of the soil and potential ecological risk heavy metal pose on soil and microbes in the study catchment. I am therefore soliciting your time and cooperation to enable me achieves the goals of the questionnaire. Information provided will be treated with utmost confidentiality and anonymously; and will be used for academic purposes only.

A: Demographic characteristics of respondents

1. Sex of Respondent: a) Male [ ] b) Female [ ]
2. Marital Status: a) Single [ ] b) Married [ ] c) Divorced [ ]
3. Age of Respondent: a) 11-20 [ ] b) 21-30 [ ] c) 31-40 [ ] d) 41-50[ ] e) 50 and above [ ]
4. Religion: a) Christianity [ ] b) Islam [ ] c) Traditional [ ]

d) Other__________________

5. Level of Education: a) Primary [ ] b) Junior High [ ] c) Senior High [ ]
   d) University [ ] e) Never Schooled [ ]

6. Occupational Status: a) Employed [ ] b) Unemployed [ ] c) Self Employed
   d) Business [ ] e) Other____________________________

7. Total members of the household or number of people in the house:
   ____

8. Are you a head of a household in the community? a) Yes [ ] b) No [ ]

B: Landfill-related problems

9. In your view is the landfill being properly managed? a) Yes [ ] b) No [ ]

10. If Yes or No, kindly briefly explain your reasons:

……………………………………………………………………………………………

……………………………………………………………………………………………

11. Please identify some of the nuisance (Sanitation and health issues) associated with the current solid waste management at the Whein town landfill site: ***(Tick as many as are applicable)***

a) Odor [ ], b) Rats [ ] c) House flies [ ] d) Mosquitoes [ ]

e) Refuse lying around [ ] f) Respiratory problems [ ]

g) Parked refuse eroding [ ]

h) Leachate flowing through community and polluting water bodies [ ]

12. What is the distance between your house and the dumpsite? ………………. meters / feet

13. What predominant sicknesses/disease conditions do you suffer from?
    a) Malaria [ ] b) Fever [ ] c) Headache [ ] d) asthma [ ] e) Cough [ ]

    f) Others ……………………………………………………………………………….

14. In your opinion, what is responsible for the disease(s)?

……………………………………………………………………………………………

……………………………………………………………………………

15. Do you frequently or sometimes hear explosive noise from the landfill site?

a)Yes [ ] b) No [ ]

16. What other concerns do you have about the landfill site? ***(Tick as many as are applicable)***

a) Water pollution [ ] b) Waste pollution [ ] c) Noise pollution [ ]

d) Air pollution [ ] e) Constant noise from scavengers

f) others:………………………………………………………………………

C: Water-related problems

17. What is the source of your drinking water? ***(Tick as many as are applicable)***
a) Hand dug well [ ] **b)** Borehole [ ] **c)** spring water [ ] **d)** stream [ ]
e) Pond [ ] **f)** government water tank [ ] **g)** pipe water [ ] **h)** sachet water [ ]

18. Which of the above is more reliable in terms of water availability?

19. Which of the above do you mostly depend on and why?
……………………………………………………………………………………
……………………………………………………………………………………

20. Do you use the borehole and hand-dug wells? Yes [ ] No [ ]

21. Identify the problems with the quality of your potable water sources
i) Well/Borehole: a) taste [ ] b) smell / odor [ ] c) color [ ] d) others

ii) Stream/pond: : a) taste [ ] b) smell / odor [ ] c) color [ ] d) others

22. Why do you still use water from the borehole/hand-dug wells and streams in spite of the quality challenges/issues?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

23. In your estimation, what is responsible for the water quality problems you observed in (21) above?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

24. Do you have any health problem when you drink from:
    i. **Borehole/well:** a) Diarrhea [ ] b) Typhoid [ ] c) Ringworm [ ]
    d) Scabies [ ] e) Cholera [ ] f) Skin disease [ ] g) Nausea [ ]
    h) Stomach upset [ ] i) other ……………………………………………

    ii. **Stream/spring/pond:** a) Diarrhea [ ] b) Typhoid [ ] c) Ringworm [ ]
    d) Scabies [ ] e) Cholera [ ] f) Skin disease [ ] g) Nausea [ ]
    h) Stomach upset [ ] i) other ……………………………………………

25. Do you treat water from stream, pond, borehole, and hand-dug well before using?
    Yes [ ] No [ ]

26. If yes, how?
    a) Boiling [ ] b) filtering [ ] c) Chlorination [ ] d) Other …………………

27. If No (to question. 25), why do you not treat it?
    ………………………………………………………………………………………….

28. Has there been regular monitoring of your well water by the appropriate authorities/inspectors?
    Yes [ ] No [ ]

29. Do the inspectors provide you with regular updates on the results of the monitoring??
    Yes [ ] No [ ]

30. Are there other problems you like to mention, if yes please do………………………………………………………………………………….

Appendix 12: Challenged water with colour problem

Appendix 13: Seasonal Concentration of pH in leachates and water sources

	pH concentration levels		Mean	
Samples	**Dry**	**Wet**	**Dry**	**Wet**
MW1	**7.39**	**7.19**		
MW 2	**7.21**	**6.93**		
MW 3	**7.87**	**7.29**	**7.49**	**7.13667**
L 1	**8.1**	**7.94**		
L 2	**8.04**	**7.93**		
L 3	**8.09**	**8.03**		
L4	**7.94**	**7.5**		
L5	**8.19**	**7.93**	**8.072**	**7.866**
SW 1	**7.39**	**6.74**		
SW 2	**7.29**	**6.77**		
SW 3	**7.39**	**6.59**	**7.35667**	**6.7**
W 1	**7.49**	**7.06**		
W 2	**7.83**	**6.93**		
W 3	**7.81**	**6.96**		
W 4	**7.87**	**6.87**		
W 5	**7.29**	**6.93**		
W 6	**7.47**	**7.19**		
W 7	**7.39**	**7.03**		
W 8	**7.42**	**7.16**	**7.57125**	**7.01625**
WC 1	**6.74**	**6.71**		
WC 2	**6.93**	**6.73**		
WC 3	**6.73**	**6.7**	**6.8**	**6.71**

Appendix 14: Seasonal Concentration of BOD in leachates and water sources

	BOD concentration levels		Mean (mg/L)	
Samples	**Dry**	**Wet**	**Dry**	**Wet**
MW 1	297.9	312.6		
MW 2	302.3	337.1		
MW 3	310.4	356.8	303.533	335.5
L 1	843.9	879.9		
L 2	838.7	865.6		
L 3	809.6	818.3		
L4	764.8	791.7		
L5	739.4	791.3	799.28	829.36
SW 1	181.3	197.9		
SW 2	167.4	181.4		
SW 3	207.3	235.7	185.333	205
W 1	106.4	117.3		
W 2	139.1	161.7		
W 3	157.8	178.5		
W 4	131.6	153.4		
W 5	167.3	183.7		
W 6	171.9	205.2		
W 7	151.5	174.7		
W 8	101.6	132.5	140.9	163.375
WC 1	35.2	41.8		
WC 2	34.5	38.3		
WC3	25.4	31.9	31.7	37.333

Appendix 15: Seasonal concentration of TDS in leachates and water sources

	TDS Concentration level		Mean (mg/L)	
Samples	**Dry**	**Wet**	**Dry**	**Wet**
MW 1	3712.2	3657.3		
MW 2	3599.5	3489.6		
MW 3	3792.1	3675.1	3701.27	3607.33
L 1	4791.8	4473.5		
L 2	4621.5	4291.8		
L 3	4398.6	4013.1		
L4	3898.7	3379.4		
L5	3819.6	3495.2	4306.04	3930.6
SW 1	2212.3	1924.5		
SW 2	2029.7	1839		
SW 3	2241.8	2116.1	2161.27	1959.87
W 1	995.6	958.87		
W 2	1090.4	1042.4		
W 3	1128.2	1019.8		
W 4	1196.1	1164.5		
W 5	1201.3	1149.7		
W 6	1289.7	1120.3		
W 7	993.5	891.4		
W 8	975.1	931.4	1108.74	1034.83
WC 1	112.3	101.7		
WC 2	107.7	96.5		
WC3	98.4	81.3	106.133	93.166

Appendix 16: Seasonal Concentration of EC in leachates and water sources

	EC concentration levels		Mean (µS/cm)	
Samples	Dry	Wet	Dry	Wet
MW 1	417.9	434.8		
MW 2	401.5	419.7		
MW 3	429.3	443.2	416.233	432.567
L 1	505.9	592.3		
L 2	498.4	579.7		
L 3	442.5	559.9		
L4	421.3	453.2		
L5	304.7	329.8	434.56	502.98
SW 1	355.2	368.3		
SW 2	334.3	356.2		
SW 3	359.7	371.3	349.733	365.267
W 1	234.3	242.1		
W 2	256.7	262.9		
W 3	287.9	298.4		
W 4	257.9	278.7		
W 5	237.3	259.5		
W 6	271.7	292.7		
W 7	213.1	229.9		
W 8	221.5	239.5	247.55	262.963
WC 1	113.1	120.1		
WC 2	109.6	119.8		
WC3	99.3	109.5	107.333	116.466

Appendix 17: Seasonal Concentration of Heavy Metals in leachates and water sources (mg/L)

	Zinc		Copper		Lead		Cadmium		Chromium		Iron	
Samples	**Dry**	**Wet**	**Dry**	**Wet**	**dry**	**wet**	**dry**	**Wet**	**Dry**	**wet**	**dry**	**wet**
MW1	3.793	4.604	3.108	3.214	3.719	3.897	1.953	2.186	2.764	2.919	4.241	4..463
MW 2	3.508	4.319	2.991	3.112	3.643	3.798	1.839	1.988	2.793	2.874	4.102	4.251
MW 3	3.819	4.096	3.292	3.471	3.893	3.985	2.207	2.391	2.829	2.969	4.219	4.489
L 1	4.763	5.108	4.611	4.958	4.389	4.737	2.579	2.845	3.399	3.673	4.829	5.187
L 2	4.431	5.096	4.593	4.777	4.321	4.473	2.553	2.774	3.351	3.497	4.788	4.913
L 3	4.192	4.811	4.214	4.345	3.884	3.992	2.422	2.538	3.132	3.184	4.437	5.083
L4	3.251	4.199	4.173	4.189	3.762	3.811	2.381	2.409	3.011	3.097	4.341	4.549
L5	3.339	3.871	4.115	4.171	3.733	3.845	2.373	2.97	2.89	2.484	4.439	4.617
SW 1	2.721	2.893	3.571	4.893	2.261	2.473	1.379	1.525	1.771	1.963	3.663	3.889
SW 2	2.543	2.649	3.237	3.509	2.077	2.211	1.331	1.456	1.652	1.775	3.367	3.528
SW 3	2.839	2.961	3.723	3.942	2.307	2.503	1.419	1.593	1.864	2.084	3.771	3.981
W 1	1.621	1.793	1.103	1.121	0.016	0.021	<0.01	<0.01	0.039	0.043	2.011	2.121
W 2	1.597	1.637	1.027	1.079	0.013	0.018	<0.01	<0.01	0.034	0.039	1.963	1.998
W 3	1.829	1.945	1.619	1.863	0.019	0,024	0.021	0.29	0.056	0.085	2.839	2.974
W 4	1,583	1.729	1.123	1.189	0.014	0.021	0.014	0.019	0.04	0.049	2.501	2.653
W 5	1.913	1.995	1.744	1.829	0.018	0.022	0.019	0.029	0.045	0.068	2.871	2.997
W 6	1.647	1.718	1.819	1.992	0.017	0.021	0.017	0.024	0.049	0.073	2.939	3.151
W 7	1.423	1.449	1.01	1.112	0.012	0.015	0.012	0.017	0.13	0.019	1.678	1.726
W 8	1.409	1.418	1.019	1.125	<0.01	0.11	0.011	0.013	0.011	0.013	1.621	1.669
WC 1	0.052	0.064	0.311	0.353	0.011	0.011	<0.01	<0.01	0.012	0.013	0.077	0.081
WC 2	0.033	0.039	0.227	0.229	<0.01	<0.01	<0.01	<0.01	<0.01	0.012	0.084	0.089
WC 3	0.021	0.029	0.213	0.227	<0.01	<0.01	<0.01	<0.01	<001	0,01	0.061	0.077

Appendix 18: Seasonal Concentration of Heavy Metals in soils (mg/kg)

	Zinc		Copper		Lead		Cadmium		Chromium		Iron		pH	
Samples	dry	wet	dry	wet	dry	wet	dry	wet	dry	Wet	dry	Wet		
S1	1.412	1.416	1.21	1.127	1.212	1.217	1.111	1.118	1.509	1.518	1.313	1.321	5.93	5.83
S2	3.237	3.359	1.357	1.386	1.303	1.331	1.295	1.306	1.541	1.593	1.379	1.398	5.83	5.76
S3	1.755	1.869	1.201	1.219	1.288	1.297	1.203	1.219	1.519	1.578	1.356	1.412	5.63	5.59
S4	1.712	1.791	1.219	1.233	1.295	1.299	1.209	1.222	1.527	1.562	1.592	1.713	5.93	5.87
S5	1.7	1.753	1.215	1.237	1.273	1.285	1.221	1.289	1.514	1.527	1.416	1.421	5.86	5.82
S6	1.603	1.729	1.147	1.159	1.229	1.287	1.119	1.228	1.508	1.519	1.334	1.374	5.73	5.59
S7	1.539	1.825	1.139	1.155	1.218	1.222	1.112	1.119	1.502	1.508	1.327	1.358	5.83	5.73
S8	1.521	1.539	1.117	1.143	1.209	1.218	1.108	1.114	1.506	1.517	1.542	1.584	5.72	5.58
S9	1.473	1.491	1.112	1.129	1.202	1.231	1.101	1.117	1.503	1.5111	1.612	1.678	5.82	5.79
S10	2.461	2.516	1.309	1.318	1.269	1.277	1,271	1.296	1.589	1.601	1.776	1.824	5.84	5.48
S11	2.543	2.651	1.317	1.329	1.281	1.295	1.179	1.192	1.592	1.615	1.771	1.782	5.71	5.59
S12	3.369	3.587	1.419	1.465	1.3	1.327	1.283	1.297	1.819	1.838	1.918	1.979	5.83	5.58

Appendix 19: pictorial view of the wastes stabilization ponds and main wastes dumpsite