ENVIRONMENTAL IMPACTS OF ACTIVE AND DECOMMISSIONED LANDFILL SITES IN THE ACCRA METROPOLIS: A CASE STUDY OF THE PANTANG AND MALLAM LANDFILL SITES

BY

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Rebecca Annorbah towards the award of Mphil Environmental Science Degree in the Institute of Environment and Sanitation Studies, Department of Science, University of Ghana.

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ABSTRACT

The study investigated the impacts of the Pantang and Mallam landfill sites in the Greater Accra Region on the surrounding environment. The Pantang landfill site is an active site that still receives waste of all kinds from various parts of Accra. The Mallam landfill, on the other hand, was decommissioned over a decade ago. Samples of leachate from the two landfill sites and air in the vicinity of the respective sites were taken over a period of three months and analysed. Soil samples were also taken from locations upslope and down slope of the Pantang landfill site and ground water was sampled from two wells, one about 30 metres from the Pantang landfill and the other about 150 metres away from the Pantang landfill site. The leachate, air, soil and groundwater samples were analysed in the laboratory for their physical and chemical constituents. Leachate, air, soil and groundwater samples from the Pantang landfill were coded PL, PA, PS and PG, respectively, and leachate and air from the Mallam landfill were coded M1L, MA.

The pH of leachate from Pantang landfill ranged from 8.00-8.9 pH units (mean 8.35). The highest pH of leachate from the Pantang landfill was measured in March and the least in April. The turbidity of leachate from the Pantang landfill ranged from 93-309 NTU (mean 213.97). The highest turbidity of leachate from the Pantang landfill was measured in March and the least in February. The PM_{10} in air sampled from the vicinity of the Pantang landfill a ranged from 250.00 - 680.56 ug/m^3 (mean 527.78). The highest PM_{10} of air sampled from the vicinity of the Pantang landfill was recorded in April and the least in March. The TSP in air sampled from the vicinity of the Pantang landfill a ranged from ranged from 291.67 - 875.00 ug/m^3 (mean 665.56). The highest TSP of air sampled from the vicinity of the Pantang landfill was recorded in April and the least in March.

The pH of soil sampled from the vicinity of the Pantang landfill ranged from 8.07 - 8.97 pH units (mean of 8.51) and the soil organic matter content from 4.243- 10.659 mg/kg (mean 7.523 mg/kg). The highest pH of soil sampled from the vicinity of the Pantang landfill was measured in February and the least in March. The highest soil organic matter content was measured in March and the least also in March but at different sampling locations. The pH of groundwater sampled from the Pantang landfill ranged of 6.84-7.4 pH units (mean 7.180) for well one and 7.56-8.6 (mean 8.06) for well two. The turbidity of groundwater sampled from the Pantang landfill ranged from 3.1- 4.6NTU (mean 4.0) for well one and 31.4-35 (mean 33.70) for well two.

The pH of the leachate sampled from the Mallam landfill ranged from 8.15 -8.90 (mean 8.39). The highest pH of the leachate sampled from the Mallam landfill was measured in February and the least in March. The turbidity of the leachate sampled from the Mallam landfill ranged from 194 – 127 NTU (mean 152). The highest turbidity of the leachate sampled from the Mallam landfill was measured in March and the least in February and April. The PM_{10} of the air sampled from the vicinity of the Mallam landfill ranged from 13.89 - 27.78 (mean 23.15). The highest PM_{10} of the air sampled from the vicinity of the Mallam landfill was recorded in April and the least in March. The TSP of the air sampled from the vicinity of the Mallam landfill ranged from ranged from 27.78 - 41.67 ug/m^3 (mean 37.04). The highest TSP of the air sampled from the vicinity of the Mallam landfill was recorded in April and the least in March. The assessments from the study showed that leachates from both landfills are polluted and may be impacting on the surrounding environment possibly especially on the soil and groundwater system.

DEDICATION

I dedicate this thesis to the glory of the Lord and to my family.

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CHAPTER ONE

INTRODUCTION

1.1. Background

Population growth, industrialization, economic development and increased consumption have led to increase in world waste generation. As of July 2013, world population was estimated to be 7.149 billion (United States Census Bureau, 2013). The population of the world is estimated to increase to 8.3 billion in 2025 and 10.9 billion by 2050 (UN, 2012). The world generated a total of 1.3 billion tonnes of waste in 2010 and this is expected to increase to approximately 2.2 billion tonnes per year by 2025 in response to population growth. The increase in world waste to approximately 2.2 billion tonnes per year by 2025 would mean an increase in per capita waste generation rate from 1.2 to 1.42 kg per person per day in the next fifteen years. Accra, the capital town of Ghana had a population of 1,695,136 million in 2000 (Ghana Statistical Services, 2012).

In a time span of ten years, this increased to a population of 1,848,614 million (Ghana Statistical Services, 2012). This population growth has been accompanied by very little improvement in waste management and sanitation facilities. The implications are that more people are exposed to health hazards and diseases associated with poor sanitation conditions. Ghana generates thirteen thousand tonnes of waste daily, with Accra alone contributing two thousand five hundred (2,500) tonnes to that total. Out of the two thousand five hundred (2,500) tonnes of waste Accra generates per day, an average of 1,250 tonnes is collected daily and hauled to Pantang dump site and Tema landfill site (Accra Metropolitan Assembly, 2013). Four hundred (400) tonnes of waste is left uncollected every day representing a total tonnage of one hundred and forty six thousand (146,000) waste per year. The increase in population growth and waste generated has being accompanied by little improvement in waste management especially in developing and third world countries.

Waste management is the collection, transportation, processing or disposal, management and monitoring of waste materials (Kaluli, et al., 2011). Solid waste collection and disposal is a major problem of urban environment in the world today. The lack of appropriate solid waste management has led to significant soil, water, air and aesthetic pollution, associated human health problems, as well as an increase in greenhouse gas emissions. The world's current waste generation rate has called for the need to put into action the Integrated Waste Management Approach where the objective is waste prevention, reduction, reuse and recycling, and energy recovery. The aim of the Integrated Waste Management Approach is to extract the maximum practical benefits from products and to generate the minimum amount of waste (Stegmann, 2006). In this post-industrial age, technology is being widely employed to attenuate environmental problems aiming at minimizing, if not gradually abolishing, waste disposal, using pollution prevention methods (Stegmann, 2006).

Waste disposal methods have over the years evolved from land filling to incineration to recycling. A landfill site is also referred to as a tip or dump (Kaluli, et al., 2011). Land filling is the deposition of waste in a series of compacted layers on the surface of the land or into excavations in the land surface (Elliott et al., 2009). Based on the design, a landfill site may be classified as a conventional landfill where abandoned quarry sites are used or as an engineered site referred to as sanitary landfill site.

It may also be classified as hazardous, non- hazardous and inert landfill sites based on the toxicity of the waste it receives (Elliott et al., 2009). Historically land filling is the most common and oldest method of organized waste disposal and remains so in many places around the world including Ghana (Elliott et al., 2009). The amount of municipal solid waste generated in the U.S. and which was disposed of in 1,908 landfills in 2011 was reported to be 53.6% (U.S.EPA, 2013). England had forty four percent (44%) of its 68 million tonnes of waste produced in 2002/2003 being land filled (U.S.EPA, 2013). India and China landfills seventy to eighty percent (70-80%) of the waste they generate. Canada landfills eighty percent of its waste (U.S.EPA, 2013). Developing countries like Senegal, Mali, Ghana and Nigeria still have most of their waste ending up in open dump systems unlike the US, Canada and England that have their waste being sent to sanitary landfills.

Land filling in most developing countries including Ghana as a waste management option has been nothing more than uncontrolled dumping and discharge into riverbeds, marshy lands, wetlands and old quarry sites. Land filling as a method of waste disposal has its advantages and disadvantages. The advantages are that well planned landfills can be monitored and reclaimed, waste going into it can be processed to remove all recyclable materials before tipping and methane produced by decomposing organic materials captured (Elliott et al., 2009). The disadvantage is that compared to modern and current waste management methods, land filling as a means of waste management still remains the method most likely to pose environmental and health threats.

Air Pollution, ground and surface water pollution, soil pollution and loose waste are the main challenges of landfills around the globe (Afzal et al., 2000). Degradation of the organic component of waste by microbial activities releases leachate and gases into the environment. Landfills especially those lacking liners, leachate and gas monitoring systems have their surrounding environs being often heavily polluted. Landfills may have the leachate and gases emanating from them polluting surface and ground water bodies and air respectively.

The gaseous substances emitted during the biodegradation of the organic component in waste pollute the ambient air in the vicinity of landfills. Methane which is produced by anaerobic decomposition is a major land fill gas which is a more potent greenhouse gas than carbon dioxide. The flaring of gases especially methane, carbon dioxide and sulphur compounds from landfills have the possibility of reducing ambient air quality and also enhancing greenhouse effects (U.S.EPA, 2013).

In the US, landfills are the third largest source of anthropogenic methane (U.S.EPA, 2013). According to Lee and Jones, (1991) approximately seventy five percent (75%) of the estimated 75,000 sanitary landfills in the United States pollute adjacent groundwater with leachate. Soil pollution may also be observed as leachate migrates through the soil to join ground water. Soil pollution may be observed as acidification, loss of soil fertility, loss of soil flora and fauna and reduced microbial activity caused by the deposition of chemical contaminants. Loss of general aesthetics through littering and choking of gutters results in reduced property value. Poorly covered landfill waste gets exposed and attracts vectors and disease carrying vermin of all type.

1.2. Problem statement

Many Metropolitan, Municipal and District Assemblies in Ghana face huge challenges on the management of waste, especially of waste disposal. In Accra, for example, the Metropolitan Assembly has had serious conflicts with residents and communities within areas intended or earmarked for waste disposal (Accra Metropolitan Assembly, 2013). Many residents confront the Assembly and often vehemently prevent dumping of waste near their areas of residence due to the perception of adverse environmental impacts on land, soil, air and water especially when dumping is close to residential areas.

Areas surrounding or close to active or abandoned landfill sites have also been encroached upon and many now serve as residential areas for some low to middle income dwellers. Two such landfills in the Accra Metropolis are the Mallam landfill site which was decommissioned in May 2001 and the Pantang landfill site which at present is the only active landfill in Accra (Accra Metropolitan Assembly, 2013).

Several studies have been undertaken to assess the impact of landfills on the environment in Ghana. Osei et al. (2011) assessed and evaluated the extent of contamination of the surrounding environment by leachate from the Oblogo landfill. Nyame et al. (2012) studied the decommissioned Mallam landfill site to assess the hydrochemistry of leachate from the site. Akiti et al. (2012) studied the possible impact of the percolation of leachate from the Oblogo landfill on unsaturated zone water quality.

Most of these studies did not, however, compare likely impacts of decommissioned or abandoned landfills with active or existing landfills that still receive huge volumes of mostly heterogeneous waste. Since factors such as the age, waste stream, climate, rate of dumping and degradation of landfill material could potentially influence its environmental impacts, a study that involves both an existing or active landfill and a decommissioned or abandoned landfill could help provide invaluable information for the management of landfills in a rapidly urbanizing city such as Accra. This study was therefore undertaken to acquire data in order to assess the environmental impacts of the active Pantang landfill and decommissioned Mallam landfill sites in the Accra metropolis.

1.3. Broad and specific objectives

The broad objective of the study was to assess the impacts of the active Pantang landfill and decommissioned Mallam landfill sites on the environment by determining the physico-chemical properties of leachate, soil, groundwater and air sampled from the Pantang landfill and leachate and air sampled from the Mallam landfill.

To achieve the above broad objective, the following specific objectives were addressed:

i. determining the composition of leachates generated at the research sites.
ii. assessing the quality of the ambient air, soil and groundwater at the sites.
iii. comparing the possible extents of pollution at or around the two landfill sites.

CHAPTER TWO

LITERATURE REVIEW

2.1. Definitions of waste and classification of waste

Waste refers to any material that is of no further use to the owner use in terms of his/her own purposes of production, transformation or consumption and for that reason is discarded (Taylor and Allen, 2013). The United Nations Environment Programme according to the Basel Convention defined waste as substances or objects which are disposed of or are intended to be disposed of.

The type of waste generated has evolved over the years with development of technology. Waste generated in recent times has high components of less biodegradable materials with the introduction of rubbers and plastics. Wastes generated by humans range from relatively innocuous substances such as food and paper waste to toxic substances such as paint, batteries, asbestos, healthcare waste, sewage sludge derived from wastewater treatment and radioactive waste in the form of spent nuclear fuel rods. Waste generated by human activities can be classified into commercial and non-hazardous industrial wastes, hazardous (toxic) industrial wastes, construction and demolition waste and municipal solid waste based on its origin and risk to human and environmental health (Taylor and Allen, 2013). Waste can also be classified based on its nature and state as solid, liquid and gaseous; and based on the type, waste is classified as organic and inorganic (Taylor and Allen, 2013).

Municipal Solid Waste refers to trash or garbage created when everyday items are used and discarded by the public (US.EPA, 2013). The UN Conference on Environment and

Development; defines municipal solid waste to includes all domestic and non-hazardous waste such as commercial or institutional waste, street sweeping and construction debris. According to the European Union (1999), municipal solid waste refers to waste from households as well as other waste which because of its nature and composition is similar to waste from households.

Municipal solid waste consist mostly of household or domestic waste, sanitation waste and demolition debris collected by or on behalf of municipal authorities and disposed through the waste management system. The sources of municipal solid waste include homes, offices, municipalities, markets, institutions and industries that generate non-hazardous waste (Thomas and Hoomwey, 1999). The amount of Municipal Solid Waste generated and its composition is influenced by urbanization, changing lifestyle and food habits.

2.2. Municipal solid waste management

Waste Management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid waste in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics and environmental consideration (Kumar et al., 2002). Waste management also includes all administrative, financial, legal, planning and engineering functions involved in the spectrum of solutions to problems of solid waste (Tchobanaglous et al., 1997). Waste management is undertaken to reduce waste effect on health, the environment and its aesthetics. Waste management involves waste sorting and storage, collection, handling and transportation, processing and disposal.

2.2.1. Waste sorting and storage

Waste sorting involves the separation of waste into various components such as organic and inorganic materials or ferrous and non-ferrous metals. Sorting may be at the household, community bin, transfer station or centralized sorting facility, processing site or the Landfill site. In Ghana, waste sorting is not properly incorporated in the waste management stream. It is only in recent times that individuals have made the collections of plastic water sachets as their work. The plastic water sachets are sold to industries to produce plastic chairs, dust pans, waste bins etc. Sorting operations can be carried out manually, semi-mechanised or fully mechanised (Benneh et al., 1993).

Waste storage is the temporal holding of waste at the household or community before final disposal. Open ground storage was very common in the past. Wastes are now stored in waste bins of various sizes. The waste bins may be made of plastic or metal. Storage of wastes is done at the source, community level and transfer stations (Benneh et al., 1993).

2.2.2. Waste collection, handling and transportation

Waste collection involves gathering solid waste and recycling materials and transferring them to either a processing or disposal site. Domestic waste collection services are often provided by local government authorities, or by private companies in the industry (Benneh et al., 1993). In Accra, waste collection is the responsibilities of the Accra

Metropolitan Assembly. Through public private partnership, companies such as Zoomlion, Asadu, etc collect waste on behalf of the Accra Metropolitan Assembly

Waste collection methods include:

i. Community bins where waste containers are placed at specific points where members of a community carry their waste to.

ii. Door-to-Door Collection where waste is placed at the doorstep at a set day/time when the waste collector arrives.

iii. Block collection where the collection vehicles arrive at a particular place or a set day and time to collect waste from the households. Households bring their waste containers and empty directly into the vehicle.

iv. Curbside collection where the homeowner is responsible for placing the containers to be emptied at the curb on the collection day and for returning the empty containers to their storage location until the next collection (Tchobanoglous et al., 1993)

v. Waste handling and transportation involves the transfer of wastes from smaller collection vehicles to larger transport vehicles and, the subsequent transport of the wastes over long distances, to a processing or disposal site.

2.2.3. Waste processing and disposal

Solid waste processing reduces the amount of material requiring disposal and, in some cases produces a useful product. Waste processing may be done at the source of waste generation or at a waste processing plant away from the source. The primary goal is to achieve maximum recovery of waste materials. Waste processing techniques include the following:

Recycling and reuse which is a practice where materials destined for disposal are collected, reused, reprocessed or remanufactured. The materials from which the items are made can be reprocessed into new products. The most common consumer products recycled include aluminium, copper, polyethylene and glass.

Composting of waste is the biological process of decomposition where organic waste is acted upon by bacteria under controlled ventilation, temperature and moisture (Kumar et al., 2002). The resulting humus is used for agricultural or landscaping purposes and the methane gas generated is captured and used for generating electricity and heat.

Energy recovery is where waste can be processed to recover the energy in it. This can be done through biochemical conversion where organic matter is decomposed by microbial bacteria action to release energy or by thermo- chemical conversion where organic matter is decomposed by heat. The potential of recovery of energy from waste is determined by the quantity of waste, and the physical and chemical characteristic of the waste. The physical characteristics considered are the size of the waste constituents, waste density and moisture content. Smaller sized waste constituents aid in faster decomposition of the waste. Waste of high density reflects a high proportion of biodegradable organic matter and moisture. High moisture content causes biodegradable waste fraction to decompose more rapidly than in dry conditions.

The bio-chemical conversion process is based on the enzymatic decomposition of organic matter by microbial action to produce methane gas. It is preferred for wastes having high percentage of organic biodegradable matter and high level of moisture content, which aids microbial activity. Biogasification also called biomethanisation is a bio-chemical conversion process of decomposing biomass with anaerobic bacteria to produce biogas. This process produces biogas containing approximately 60:40 mixtures of methane (CH_4), and carbon dioxide (CO_2) and simultaneously generating an enriched sludge fertilizer- with an energy content of 22.5 MJ/m^3. Anaerobic digestion of the organic fraction of municipal solid waste offers the advantage of both a net energy gain by producing methane as well as the production of a fertilizer from the residuals (Edelman et al., 2000).

Incineration is one of the most effective means of dealing with many wastes, which reduces their harmful potential, and often convert them to energy form (Tchobanoglous et al., 2002). Incineration is a thermo-chemical conversion that involves the controlled burning of waste in a purposely built facility. It involves the process of direct burning of wastes in the presence of excess air at the temperatures of about 800°C and above (above (Knox, 2005). The process sterilizes and stabilises the waste. Incineration reduces the volume of waste to less than a quarter of the original and the combustible material is converted into ash and carbon dioxide (Kumar et al., 2002). About 65-80 % of the energy content of the organic matter is recovered as heat energy and utilised either for direct thermal applications, or for producing power.

Pyrolysis also referred to as destructive distillation or carbonisation is the thermal decomposition of organic matter at high temperature of about 900°C in an inert environment. Pyrolysis produces a pyroligenous liquid having high heat value and is a feasible substitute for industrial fuel oil.

Gasification is the thermal decomposition of organic matter at high temperatures in the presence of limited amounts of air producing a mixture of combustible and noncombustible gas (carbon monoxide, hydrogen and carbon dioxide). Waste disposal takes two forms, which are non-engineered landfill disposal and sanitary landfill disposal. Non-engineered disposal is the most common method of disposal in low-income countries, which have no control, or with only slight or moderate controls.

2.3. Waste degradation

Waste degradation is the breakdown of the organic component of waste by microbial organisms especially bacteria. The degradation of the organic component of waste undergoes the following phases.

2.3.1. Initial adjustment, transition and acid formation phase

This phase is associated with initial placement of solid waste and accumulation of moisture within the landfill. An initial lag time is observed until sufficient moisture develops and supports an active microbial community (Tapas, 2014).

In the transition phase, the field capacity is exceeded, and a transformation from an aerobic to anaerobic environment occurs. This is evidenced by the depletion of oxygen trapped within the landfill media. A reducing condition is established with shifting of electron acceptors from oxygen to nitrates and sulphates, and the displacement of oxygen by carbon dioxide. By the end of this phase, measurable concentrations of chemical oxygen demand (COD) and volatile organic acids (VOA) can be detected in the leachate (Tapas, 2014).

The third phase is the acid formation stage where the organic materials are acted upon. Microbial conversion of the biodegradable organic content results in the production of intermediate VOAs at high concentrations throughout this phase. It is characterized by reduced pH and metal mobilization (Tapas, 2014).

2.3.2. Methane fermentation and maturation

In this phase, intermediate acids are consumed by methanogenic bacteria and converted into methane and carbon dioxide. Sulphates and nitrates are reduced to sulphides and ammonia, respectively. The pH value is elevated and this supports the growth of methanogenic bacteria. The pH at this phase is controlled by the bicarbonate buffering system. Heavy metals are removed by complexation and precipitation at this stage (Tapas, 2014).

This is the final state of landfill stabilization. At this stage, nutrients and available substrate become limited, and the biological activity shifts to relative dormancy. Gas production drops dramatically and leachate strength stays steady at much lower concentrations. Reappearance of oxygen and oxidized species is observed slowly (Tapas, 2014). The slow degradation of resistant organic fractions continues with the production of humic like substances.

The progress towards final stabilization of landfill solid waste depends on the physical, chemical and biological factors within the landfill environment, the age and characteristics of land filled waste, the operational and management controls applied, and the site-specific external conditions. Environmental conditions which impact significantly on biodegradation in landfills include pH, temperature, nutrients, absence of toxins, moisture content, particle size and oxidation-reduction potential.

2.4. Leachate and landfill gas production

Leachate formation occurs when soluble components are dissolved out of solid waste material by percolating water. Landfill leachate is a potentially polluting liquid, which unless returned to the environment in a carefully controlled manner may cause harmful effects on groundwater and surface water surrounding the landfill site. The generation of leachate is caused principally by precipitation percolating through waste deposited in a landfill resulting in the extraction of the water-soluble compounds and particulate matter of the waste (Henry and Heinke, 1996). Leachate may also carry insoluble liquids (such as oils) and small particles in the form of suspended solids. Depending on the waste types, further contaminants may be introduced as a result of biodegradation of the wastes. Leachate from a landfill varies widely in composition depending on the age of the landfill and the type of waste it contains (Henry and Heinke, 1996).

2.4.1. Factors that influence leachate and landfill gas production

The quality and quantity of leachate and landfill gas produced is related to factors such as waste type and composition, local climate (precipitation, humidity, and temperature), age of landfill, degree of waste compaction, method of land filling moisture content and type of bacteria. The quality of leachate is determined primarily by the composition and solubility of the waste constituents. The climate has also a great influence on leachate production because it affects the input of precipitation (P) and losses through evaporation (EV). Finally, leachate production depends on the nature of the waste itself, namely its water content and its degree of compaction. The production is generally greater whenever the waste is less compacted, since compaction reduces filtration rate. The composition of landfill leachates also varies greatly depending on the age of the landfill (Welander et al., 1997). In young landfills, containing large amounts of biodegradable organic matter, a rapid anaerobic fermentation takes place, resulting in volatile fatty acids (VFA) as the main fermentation products. Acid fermentation is enhanced by a high moisture content or water content in the solid waste (Wang et al., 2003).

2.4.2. Leachate composition and characteristics

Leachate composition varies relative to the site construction and operational practice, age of the dumpsite, amount of precipitation and; the quantity and type of wastes disposed (Campbell, 1993). Landfill leachate is a water-based solution consisting of water, organic, inorganic and bacterial compounds together with solid. The organic compounds include alcohols, acids, aldehydes, short chain sugars. The organic content of leachates is often measured through analyses of parameters such as COD, BOD (biochemical oxygen demand) and TOC and dissolved organic carbon (Thomas et al., 2009).. Inorganic compounds in landfill leachate include salts (e.g., sodium and chloride), and an abundance of common anions and cations (e.g., bicarbonate and sulfate).

Landfill leachate also contains dissolved heavy metals (e.g. Fe, Mn, Pb, Ni, Cu, Hg) (Welander et al., 1997). The biotoxicity of leachate is generally determined based on its physico-chemical properties, with ammonia, chemical oxygen demand (COD), and heavy metals being identified as the major contributors (Thomas et al., 2009).

The physical, chemical and biological characteristics of leachate are discussed below:

The colour of leachate is orange brown or dark brown (Bertazzoli and Pelegrini, 2002). The chroma is around 2000 to 4000. Leachate is associated with a malodorous smell, due mainly to the presence of organic acids which result from the decomposition of organic matter in the waste (Williams, 2004). The dark color and malodor disappear slowly with increasing age of landfill. Change in colour and smell is also related to the nature of precipitation and the quantity and quality of the waste.

Leachate is generally found to have pH between 4.5 and 9 (Christensen et al., 2001).The pH of leachate at the early stage of formation has a pH lower than 6.5, making the leachate acidic and this is due to high concentration of volatile fatty acids (VFAs) (Bohdziewicz and Kwarciak, 2008). As time progresses and the landfill ages; the pH rises up to pH higher than 7.5, making the leachate alkaline (Abbas et al., 2009). The pH of the leachate is also affected by the nature of precipitation and the quantity and quality of waste.

BOD and COD of leachate is a measure of the oxygen demand of the leachate. In the initial acidogenic biodegradation stage, the leachate is characterized by high BOD5 and COD. Young landfill leachate is characterized by high BOD5 (4000–13,000 mg/L) and COD (30,000–60,000 mg/L) (Foo and Hameed, 2009). According to Tatsi et al. (2003), young leachate may have BOD5 as high as 81,000 mg/L. A decrease in BOD5 and COD is often reported with the increase in age of the landfill. As the organic and inorganic components of the waste decrease, oxygen demand for microbial activity also decreases. The BOD is at its maximum concentration from 6 months to 2.5 years. Finally, the BOD index begins to reduce from3-6 years and reaches a steady concentration from 6-15 years (Svenolof, 1992). For stabilized leachates, COD generally ranges between 5000–20,000 mg/l (Li and Zhao, 2002).

The concentration of TOC is normally in the range 265-2800mg/l. The BOD/ TOC reflect the oxidation of organic carbon in leachate. The value of BOD and TOC is high in the initial stages of landfills. The oxidation of organic carbon in leachate reduces with landfill age hence BOD and TOC values are reduced (Svenolof, 1992).

TDS consists mainly of inorganic salts and dissolved organics. The amount of TDS reflects the extent of mineralization and a higher TDS concentration can change the physical and chemical characteristics of the receiving water (Al-Yaqout and Hamoda, 2003). Changes in TDS value of leachate relate to the age of the landfill. In the initial stages of landfills, the concentration of TDS is high and contains sodium, calcium, chloride, sulphate and iron. As the landfill ages, the concentration of inorganic matter reduces.

Suspended solid refers to solid matter in the leachate. It consists of organic matter, inorganic matter, clay and microorganism. Leachate from landfills normally contains only small amounts of suspended solids. Leachate has high concentration of salts. The predominant salt in leachate is chloride (100-4000mg/l) and phosphate (91600mg/l), which are more serious when the rainfall is less (Tyre and Michele, 1997).

Nitrogen and Phosphorus are the main components of the inorganic pollutant in leachate. The concentrations of Nitrogen (N) and Phosphorus (P) are high when the land filling is in progress. However, when the landfill is closed, P reduces slowly and N increase because of the decomposition of waste under the anaerobic condition (Tyre and Michele, 1997).

The concentration of ammonia nitrogen increases with the increase in age of the landfill which is due to hydrolysis and fermentation of nitrogenous fractions of biodegradable refuse substrates (Abbas et al., 2009). The concentration of ammonia nitrogen increases with land filling. According to Li and Zhao (2002) ammonia nitrogen in stabilized leachate might range between 3000–5000 mg/L. Ammonia nitrogen is ranked as a major toxicant to living organisms, as established by various toxicity analyses using bioassays and various test organisms such as *Salmo gairdnieri* and *Oncorhynchus nerka* (Kurniawann et al., 2006).The main component of ammonia nitrogen is ammonia. Ammonia is considered as a major long-term pollutant because of its stability under anaerobic conditions. The mean concentration of ammonia in leachate ranges between 500–1500 mg/L after a period of 3–8 years of waste placement and continues to be within this range over 50 years (Kulikowska and Klimiuk, 2008). Higher concentrations of ammonia are also known to enhance algal growth, promote eutrophication due to decreased dissolved oxygen (Kurniawann et al., 2006). Due to its toxicity, it can also disrupt biological leachate treatment operations (Deng and Englehardt, 2007).

In general, the concentration of heavy metals in landfill leachate is fairly low (Christensen et al., 2001). Concentration of heavy metals in a landfill is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids (Kulikowska and Klimiuk, 2008). As a result of decreased pH at later stages, a decrease in metal solubility occurs resulting in rapid decrease in the concentration of heavy metals except lead because lead is known to produce very heavy complex with humic acids (Harmsen, 1983). A lower concentration of Cd (0.006 mg/L), Ni (0.13mg/L), Zn (0.61 mg/L), Cu (0.07mg/L), Pb (0.07 mg/L), and Cr (0.08 mg/L) were found in 106 Danish landfills by Kjeldsen and Christophersen (2001). The high dissolved organic carbon (DOC) concentration in leachate renders the metals non-toxic because only the free metals are known to exhibit toxicity (Vigneault and Campbell, 2005., Koukal et al., 2003).

However, the solubility and mobility of metals may increase in the presence of natural and synthetic complexing ligands such as EDTA and humic substances (Williamson and Owen, 2006). Further, colloids have great affinity for heavy metals and a significant but highly variable fraction of heavy metals is associated with colloidal matter Christensen et al., (2001) and; Jensen and Christensen (1999) found that10–60% of Ni, 30–100% Cu and 0–95% Zn were constituted in colloidal fractions. The solubility of the metals can also increase because of the reducing condition of the leachate which changes the ionic state of the metals (i.e., Cr (VI)→Cr (III), and As (V) → As (III) (Williamson, and Owen, 2006., Sierra-Alvarez et al., 2005., Halim et al., 2004., Li, et al., 2007). The amount of heavy metals in leachate is related to the industrial level of the community and how much industrial waste is land filled. Domestic waste has low levels of heavy metals compared to industrial waste. Industrial waste accounts for most part of heavy metals in leachate.

2.4.3. Landfill leachate and gas generation stages

Mechanisms regulating mass transfer from wastes to leaching water, from which leachate originates, can be divided into two groups; namely aerobic and anaerobic digestions. Waste deposited in landfills is not inert thus containing organically degradable materials. Percolating rainwater provides a medium in which the waste, particularly the organics, can undergo degradation by micro-organisms, primarily bacteria into simpler substances (Salem et al., 2007). Leachate produced in the early stages of decomposition of waste is typically generated under aerobic conditions. Initially, organic matter, in the form of proteins, carbohydrates and fats, is decomposed under aerobic conditions (i.e. oxidised), through a series of hydrolysis reactions, to form carbon dioxide and water together with nitrates and sulphates via a number of intermediate products such as amino acids, fatty acids and glycerol (Salem et al., 2007).

Such oxidation reactions are exothermic, causing temperatures in the landfill become elevated to as high as 80–90^{o}C. This heat is retained and enhances the subsequent stages of gas and leachate production. Carbon dioxide is released as a gas or is dissolved in water to form carbonic acid which subsequently dissociates to yield the bicarbonate anion (HCO_3^-) at near neutral pH (Taylor and Allen, 2013). Aerobic decomposition of organic matter depletes the waste deposit of oxygen as buried waste in the landfill or refuse dump becomes compacted and circulation of air is inhibited.

As oxygen becomes depleted, it is replaced as the oxidising agent by in succession, nitrate (NO_3^-), manganese (as MnO_2), iron as $Fe(OH)_3$ and sulphate (SO_4^{2-}) (Taylor and Allen, 2013). The solubility of metals in the leachate is enhanced through complexation by dissolved organic matter In general, the aerobic stage is short, no substantial volumes of leachate are produced, and aerobic conditions are rapidly replaced by anaerobic conditions.

The main stages of anaerobic digestion are (i) acetogenic (acid) fermentation, (ii) intermediate anaerobiosis, and (iii) methanogenic fermentation, all three of which can be operating simultaneously in different parts of the landfill. Acetogenic fermentation brings about a decrease in leachate pH, high concentrations of volatile acids, high concentrations of soluble degradable organic compounds and considerable concentrations of inorganic ions (e.g. Cl^-, $SO4^{2-}$, Ca^{2+}, Mg^{2+}, and Na^+). As the redox potential drops, sulphate is slowly reduced; generating sulphides, which may precipitate iron, manganese and heavy metals that were dissolved by the acid fermentation stage (Taylor and Allen, 2013). Decrease in pH is due to production of volatile fatty acids (VFAs) and to high partial pressures of carbon dioxide (CO_2), whilst the increased concentrations of anions and cations results from leaching (lixiviation) of easily soluble organic material present in the waste mass. Breakdown of organic materials reduces the redox potential to lesser than 330mV, which allows the next stage of the process to become initiated.

Leachate from this phase is characterised by high values of biochemical oxygen demand (BOD) commonly greater than 10,000 mg/L, high BOD5/COD (biochemical oxygen demand /chemical oxygen demand) ratios commonly greater than 0.7, acidic pH values typically 5-6 and ammonia (NH_3) due to hydrolysis, and fermentation in particular of proteins.

Intermediate anaerobiosis commences with a gradual increase in the methane (CH_4) concentration in the gas, coupled with a decrease in H_2, CO_2 and volatile fatty acids. Conversion of the volatile fatty acids leads to an increase in pH values and to alkalinity, with a consequent decrease in the solubility of calcium, iron manganese and the heavy metals, which are probably precipitated as sulphides. Ammonia is released but is not converted to nitrate in such an anaerobic environment.

Methanogenic fermentation is the final stage in the degradation of organic wastes (Taylor and Allen, 2013). It operates within the extremely limited pH range of 6-8 making the leachate produced neutral or slightly alkaline. At this stage in the degradation process, the composition of leachate is characterised by low concentrations of volatile acids and total dissolved solids (TDS), indicating that solubilisation of the majority of organic components is almost complete, although waste stabilisation will continue for several decades. The biogas being produced at this stage has a methane content of generally greater than 50 per cent. Leachate produced at this stage is characterised by relatively low BOD values, and low ratios of BOD/COD. As biodegradation near completion, aerobic conditions may return, and leachates will eventually cease to be hazardous to the environment.

2.4.4. Leachate treatment techniques

The techniques of leachate treatment can be divided into biological, physical and chemical methods. Leachate treatment techniques include aerobic biological treatment, anaerobic biological treatment, spray irrigation to land, reed bed treatment, ammonia stripping, reverse osmosis and ozonation (Abdulhussain, et al., 2009).

The biological leachate treatment method is grouped into aerobic and anaerobic technique. The advantage of anaerobic process is that it allows heavy metals to be removed from the leachate by precipitation as carbonates (Callander and Barford, 1983). The anaerobic treatment system includes the complex organic compounds that are transferred to CH_4 and CO_2, and also produces excess sludge that does not need so much management. The energy consumption of anaerobic process is lower than aerobic processes.

However, the high NH4+N concentration within the leachate is often not completely reduced through the anaerobic process (Callander and Barford, 1983). Aerobic biological processes have been identified as the most successful and reliable treatment for the landfill leachate (Robinson, 1995). This treatment readily reduces the high organic loading present in leachates during the early stages of waste decomposition and also nitrifies high concentrations of ammoniacal-nitrogen (Tattersall, 2004). The aerobic processes can be carried out over a wide range of temperatures and also the rate of degradation is higher in the aerobic process than in the anaerobic processes. The success aerobic leachate treatment is greater with the use of non-attached growth processes in aerated lagoons or tanks.

Aeration encourages the formation and growth of suspended biological flocs, which break down and metabolise the polluting components of the leachate. The efficiency of the method is connected with the stabilization of the landfill. The aerobic process or anaerobic process should be used together with physical pre-treatment to improve the efficiency of the biological treatment. Leachates continue to contain many pollutants such as heavy metals and some persistent organic compounds after bio-degradation. These compounds are only removed through the physical and chemical processes of leachate treatment. The aim of physical and chemical treatment is to remove heavy metal ions and

NH_3-N (ammonia nitrogen). Methods like ammonia stripping, spray irrigation to land, reed bed treatment, ammonia stripping, reverse osmosis and ozonation belong to the physical and chemical treatment and, they could be used as pre-treatments to help the biological treatment process (Abdulhussain, et al., 2009).

2.5. Landfill sites

A landfill site is a facility for the disposal of solid waste by burial. It is the oldest form of waste disposal. A landfill site is also referred to as a tip or dump (Zurbrugg et al., 2003). Land filling is pre-dominantly used in low income countries due to its economic advantages (Elliott et al., 2009).The disadvantages of landfills are that, landfills and their surrounding areas are often heavily polluted. This leads to water, air and soil pollution through the spread of dangerous chemicals into the water table or into waterways (Akaeze, 2001).

Landfills without gas collection systems can also enhance the chances of global warming by releasing methane a greenhouse gas into the atmosphere. Landfill sites are classified as engineered and conventional landfill sites. Engineered landfill sites are also referred to as sanitary landfills. Sanitary landfills are specially built landfills, which reduces the harmful effects of dumping. A sanitary landfill is a disposal site designed, constructed, operated and maintained to minimize potential environmental impact of deposited waste. Engineered landfills have appropriate liners for groundwater protection, sumps for leachate collection, leachate treatment system, groundwater monitoring wells, Landfill gas collection systems and appropriate final cover design.

The conventional land filling method involves the use of abandoned quarry sites and open grounds as dump sites. Open ground dumping also occurs in low lying marshy areas leading to the destruction of wetlands. Conventional land filling has the lowest initial capital investment and operating cost (Elliott et al., 2009). Conventional land filling sites are unplanned. There is also no control over waste inputs and pollution emissions. Conventional land filling leads to the contamination of surface and groundwater, loss of environmental aesthetics and property value; and also serve as breeding places of vermin and disease vectors.

In the Accra Metropolis, no engineered landfill site has been set up. The Accra Metropolitan Assembly has always made use of pits created as a result of quarry activities. The Oblogo and Mallam landfills are examples of this practice. The Pantang landfill is also located on a marshy ground which would have served as a wet land for flood control. These sites where selected for dumping without leachate treatment facility; groundwater monitory plan or landfill gas monitory plan.

The Accra Metropolitan Assembly and EPA only relied on the underground bed rock to protect the underground water regime.

2.5.1. Landfill site selection, design and operation

Selection of land for landfill site construction is a major problem because public acceptance is often lacking. In many cases local societies revolt against landfill placement in their community and this may be attributed to the Not-In-My-Backyard Syndrome (NIMBY). For landfill, site selection to be efficient, serious environmental threats and nuisance as well as lack of social acceptance associated with them should be adequately considered. Economically, the cost of construction, operation and maintenance, waste transport and the cost of impacts alleviation must be known (Dooley, 1993).

Other factors that are considered are location - landfills are to be located at distances from residential areas, industrial units, archaeological sites, airports, military establishments, forest or reforested areas, protected areas or areas of ecological importance, environmental criteria- landfills are to be sited away from flood plains and wet lands to prevent contamination of the underground water system, social criteria-under this criteria authorities are to consider issues relating to social acceptance, residential pressure, property status, farming and animal-raising activity, use of groundwater by residents and current aesthetic status.

Hydro-geological criteria that should also be considered are those relating to aquifer characteristics that is the depth and top soil and subsoil conditions. The site should be away from groundwater recharge areas. The site should have a deep water table to prevent leakage of leachate into ground water. Soil of site should have a low permeability and thick impermeable subsoil layer. Functional criteria concerns the availability of cover material, transportation networks and accessibility, and climatic conditions including rainfall height, intensity and frequency (Kent et al., 2003)

Landfill designing entails the use of liners, leachate collection, treatment and disposal system, ground water monitoring wells and landfill gas collection systems. Liners are provided in a landfill to protect ground water and underline soil from leachate releases. Clay or synthetic liners are used to line the sides and bottom to prevent leachate seepage.

The leachate collection and removal system is usually located on top of the liners to remove leachate for treatment and disposal. Ground water monitoring wells are constructed to collect ground water for testing in the laboratory for contamination level assessment. Gas collection systems are built to monitor landfill gas migration, odour, and air quality

2.5.2. Landfill site operation and decommissioning

Operation of the landfill involves covering waste frequently after compaction by heavy duty vehicles with soil or other materials to control odour, blowing litter, fire, disease vectors, and scavenging. During the operation, ground and surface water monitoring to access water contamination is carried out to establish corrective actions.

Decommissioning refers to steps beyond closure of a waste disposal site which have been taken to minimize and monitor potential adverse environmental impacts. Poorly decommissioned landfill sites tend to violate sustainability principles by passing along to future generations significant environmental problems. Landfill site decommissioning entails closure and Post closure activities.

Landfill closure is done when a landfill reaches its capacity to receive any more waste. Landfill closure is done to ensure long term protection of the environment. This involves the installation of a final cover. Land fill closure involves capping and grading where landfill site is covered with a layer of clay and graded to positive drainage. Post Closure which is the long term care of the closed landfill is necessary to minimize environmental impact. Post closure steps include maintenance of the integrity and effectiveness of the final cover, regrading of cover material after settling of waste, revegetation, leachate collection and treatment, landfill gas migration monitoring, surface and ground water quality monitoring, odour and vermin control and improvement of general aesthetics.

2.6. Environmental problems associated with landfills

Poorly covered landfill waste gets exposed and attracts disease carrying vermin of all types. Vermin and insects pests are attracted to the landfill by the ready availability of food (Afzal et al., 2000). They breed, multiply and move from the landfill to spread diseases. Invertebrates found in this habitat include members of the phyla Nematoda (flat worms), Annelida (segmented worms), and Arthropoda (including isopods, insects and arachnids such as spiders, harvestmen and mites). Many of these contribute to the decomposition processes. Among the insects, these can include crickets and grasshoppers.

Flies are a group of specific concern as they act as disease vectors and their population growth is also encouraged by the heat generated through decomposition. Birds including members of the gull and crow families are also quite common. The principal vermin species associated with landfills which are problematic are flies, wild birds (especially gulls and members of the crow family) and rodents (Afzal et al., 2000). Vermin have the ability to carry disease vectors (bacteria, viruses, fungi) and chemical contaminants out of the site, either directly or through the spread of litter. Potentially, pathogenic bacteria are primarily hazards for site operators (Eduljee, 1995). Distributed litter can also find themselves been carried away from the site in breeze causing visual and physical hazards such as fire, choking of domestic animals, blockage of drains and watercourses.

Ground and surface water pollution from leachates is one of the key environmental problems of landfills. Unlined and poorly managed landfills are assumed to cause pollution through leachate seepage into ground and surface waters (Afzal et al., 2000). The seepage tends to increase the nutrient loads affecting the trophic status of water bodies and resources leading to eutrophication. Acidification from leachate increases the potential for solubilising trace metals from trace metal ores in the water (Harsem, 1983).

Landfill gases produced as a result of organic matter degradation by anaerobic bacteria includes methane, carbon dioxide, volatile organic compounds, oxides of sulphur and nitrogen and other non-methane organic compounds (Gendebien et al., 1992). These gaseous pollutants have significant effects on plants, animals and the entire ecosystem. Some air pollutants do not always disperse effectively and may remain together at quite high concentrations, causing unexpected damage some distance from the source.

The methane and carbon dioxide components are green house gases (GHG) contributing to global warming. Methane, carbon monoxide and carbon dioxide all act as greenhouse gases of global significance, with methane being by far the most active but carbon dioxide being produced in the greatest quantities (Krupa, 1997). Both methane and carbon monoxide react with hydroxyl radicals and oxygen in the atmosphere to generate carbon dioxide within a period of days to a few years (Clarke 1986., O'Neill, 1993., Wellburn, 1994., Yunus et al., 1996). Small amounts of methane are also consumed through absorption by soils. Methane is also inflammable and explosive causing fires on landfill sites (Gendebien et al., 1992). The volatile organic compounds and non-methane organic compounds are the component characterized as toxic to the environment and as such to human health. Volatile organic compounds particularly esters; organosulphur, hydrogen sulphide and ammonia cause odour emissions on landfills (Yunus and Iqbal, 1996).

The acidic gaseous constituents (HCl, SO_x, NO_x and HF) are all of global significance since they contribute to the acid rain phenomenon and its secondary effects on the acidification of soils and ecosystems (Gendebien et al., 1992). Ammonia is a secondary acidifying agent following its atmospheric oxidation to nitric acid. These acidic constituents are all potentially noxious. They have similar general effects on plants, causing loss of stomata control, a reduction in photosynthesis, enzyme inhibition, changes in synthetic pathways, and depressed growth and yields (Gendebien et al., 1992).

Ammonia is also liberated in leachate (Yunus and Iqbal, 1996). When leachate is exposed to air, the ammonia volatilises and contributes to potential problems of acid rain. Ammonia generated from leachate within landfills migrates through the soil horizons where it is nitrified (oxidised) to nitrite and nitrate and subsequently causes eutrophication problems. Nitrous oxide (N_2O) is also a greenhouse gas. Nitrogen dioxide participates in the formation photochemical smog. NO_2 is also a plant growth retardant and can cause decreases in agricultural yields. Oxides of sulphur (SO_2 and SO_3) mainly enter plants through the stomatal pores. Low concentrations may increase photosynthetic rates in the short term, but higher exposure decreases photosynthesis and ultimate yield (Yunus and Iqbal, 1996).

All green plant species are adversely affected by dust deposition, which limits photosynthesis by reducing sunlight and carbon dioxide penetration to leaves. This is alleviated by rainfall, but some dusts can form a permanent foliar crust, which is particularly problematic for evergreen foliage, which has a long replacement cycle. Air pollution may lead to respiratory tract infections, nervous system diseases and eye irritation in humans.

Land filling also affects soil quality through the creation of physical pressure within the soil resulting in reduced soil stability and drainage. The movement of heavy machinery during general waste management operations leads to excessive compaction of the top and sub soils. Soils found close to landfills can become contaminated with a range of substances, including acidifying agents, metals, organic pollutants and pathogenic microorganisms.

Contamination can arise through direct migration from landfills, through water pollution or by indirect deposition from air. The deposition of chemical contaminants including metals, the wet deposition of gases, and the seepage of gases from landfills can all suppress microbial activity throughout the soil ecosystem ecosystem (Finnecy & Pearce, 1986). Soil acidification is caused by sulphur dioxide, oxides of nitrogen and ammonia. These gases are either deposited directly onto the soil (dry deposition) or washed out of the air by rain (wet deposition).

Soil acidification can slow down soil processes and populations of soil microorganisms may change with a shift towards acid-tolerant species. Acidification alters the solubility and mobility of a number of soil minerals. Soil acidification tends to favour the release of various forms of aluminium that may damage plants by affecting plant roots and mycorrhizae (root /fungal relationships).The supply of nutrients within the soil is governed by cycles that depend on the activities of soil organisms ranging from bacteria and fungi (micro-flora) to small invertebrates (micro-fauna) and earthworms. The actions of all these organisms are affected by physical and chemical disturbance of the soil during waste management operations. Also, essential root activities can be adversely affected by changes in soil pH and lateral seepage of leachate or gaseous contaminants such as methane or hydrogen sulphide (Finnecy & Pearce, 1986).

CHAPTER THREE

STUDY SITE, MATERIALS AND METHODS

3.1. Study sites

The study sites were the decommissioned landfill site at Mallam and the active landfill site at Pantang, Abloradjei. The decommissioned landfill site is an old disused quarry pit. It was used as a landfill site between July1991and May 2001 under the management of the Accra Metropolitan Assembly. The total land area of the decommissioned landfill site is 16.06 acres with an average depth of 20.06 m (Accra Metropolitan Assembly, 2013).

The estimated amount of waste that was deposited was 2,698,570 metric tons at a density of 1.045 tons/ m^3 (Accra Metropolitan Assembly, 2013). The entire surface of the decommissioned landfill site was covered with gravels but with time erosion has washed some away. The Pantang landfill is sited on a marshy ground. The bottom and sides of the Mallam and Pantang landfills are not lined. The sites also lack leachate collection and gas monitoring systems. The compaction method for the Mallam landfill site was the vehicular method (bulldozer) and this same method is being used on the Pantang landfill site, with soils as the cover material for both sites.

The Pantang Active landfill site is located in the Ga East Municipal Assembly which is located at the northern part of the Greater Accra Region and covers a land Area of 166 sq km. It is bordered on the west by the Ga West Municipal Assembly, on the east by the Adentan Municipal Assembly, the south by Accra Metropolitan Assembly and the north by the Akwapim South District Assembly (Ga East Municipal Assembly, 2012). The decommissioned landfill site at Mallam is located in the Ga South Municipal Assembly formerly Weija Municipal Assembly. It lies within latitude 5^{o} 48 North 5^{o} 29 North and Latitude $0^{o}8^{'}$ West and $0^{o}30^{'}$ West. The Ga south municipality shares boundaries with the Accra Metropolitan to the South-East, Akwapim South to the North-East, Ga West to the East, West Akim to the North, Awutu-Effutu Senya to the West, Gomoa to the South-West and the Gulf of Guinea to the South. It occupies a land area of approximately 517.2 sq km with about 362 communities (Ga South Municipal Assembly, 2012).

3.1.1. Demographic characteristics, climate and vegetation

The Ga East Municipality's population after the 2010 National Population and Housing Census was at 259,668. The municipality has about 65 settlements with Abokobi, a well known Presbyterian community as the capital (Ga East Municipal Assembly, 2012). According to the 2010 National Population and Housing Census, the population of the Ga South Municipal Assembly was estimated at 485,643. Gbawe is the Administrative capital of the Ga South Municipal assembly (Ga South Municipal Assembly, 2012).

The Ga East Municipality is located in the savannah agro-ecological zone. The Ga East Municipality also has a bi-modal rainfall pattern with the average annual temperature ranging between 25.1ºC in August and 28.4ºC in February and March. February and March are normally the hottest months. The Municipality has two main vegetations namely shrub lands and grassland. The shrub lands occur mostly in the western outskirts and in the north towards the Aburi hills and consist of dense cluster of small trees and shrubs that grow to an average height of about five meters. The grassland which occurred to the southern parts of the district has now been encroached upon by human activities including settlements (Ga East Municipal Assembly, 2012).

The Ga South Municipality lies wholly in the coastal savanna agro-ecological zone with secondary forest in the hinterlands where rainfall is high. The rainfall pattern is bi-modal with an annual mean varying between 790 mm on the coast to about 1270 mm in the extreme north. The first rainy season begins in May and ends in mid-July while the second begins in mid-August and ends in October. Rainfall is usually characterized by thick cloudy conditions and high intensive storms. The annual average temperature ranges between 25.1ºC in August and 28.4ºC in February and March are the hottest months. It has a relative humidity of about 75% with an average duration figures of about 94% and 69% at 6:00 and 15:00 respectively (Ga South Municipal Assembly.2012).

3.1.2. Soil and agricultural land use

The land area of the Ga South Municipality is underlined by shallow rocky soils and is extensively developed on the steep slopes of the Weija hills as well as basic gneiss inselbergs. On the Weija hills, the soils are mainly pale and sandy with bushy quartzite occurring to the surface in most places. These soils are rich in sand stone and lime stone that are good source of material for the construction industry. The red earth is usually developed in old and thoroughly weathered parent materials. They are typically loamy in texture near the surface becoming more clay below. The red soils are porous and well drained and support road development and also provide ample moisture storage at depth for deep rooting plants. Nutrients supplies are concentrated in the humus top soil.

The main type of soil in this area is the Coastal Savannah Ochrosols. The coastal sands are pale yellow in colour and without humus or organic matter. These soils are suitable for coconut and shallots cultivation. On the Akwapim range, the soils are mainly pale and sandy with brushy quartzite occurring to the surface in most places. These soils are rich in sandstone and limestone that are good source of material for the construction industry.

The land is mostly owned by families who have the sole responsibility to lease or sell out right (Ga South Municipal Assembly, 2012). The Ga East Municipality is made up of a number of soil types located at various parts of the municipality. The Fete Consociation type of soil is located at Gonten, Abokobi, Bobomase, Akporman, Adenkrebi, and Kponkpo. The Fete Consociation type of soil is very shallow, excessively well drained, pale coloured sandy loam contains small pieces of rock on steep slopes. The soil is suitable for permanent forestry. The Nyigbenya, Hatso Complex Association type of soil is located at Oshiyie, Frafraha, Agbogba, Haatso, Kwabenya, Taifa, and Dome. The Nyigbenya, Hatso Complex Association type of soil is well drained, red, sandy clay loam to clay with abundant rough stone concretions and quartz gravels. The soil is suitable for permanent forestry. The Oyarifa-Manfe Complex Association type of soil is located at Ayimensah, Manmomon, Adoteiman, Otinibi, and Oyarifa. The Oyarifa-Manfe Complex Association type of soil is deep, orange brown to bright red, sandy clay loam containing abundant ironstone concretions and gravels. The soil is suitable for maize, yam, cassava, groundnut, sweet potato, vegetables, etc. The Danfa-Dome Association type of soil is located from Danfa to Dome.

The Danfa-Dome Association type of soil is red well drained concretionary clay; yellowish brown with lime concretions; deep black, calcareous cracking clays. The soil is suitable for irrigated rice, cotton, sugarcane, vegetables. The Fete Bediesi Complex Association type of soil is located at Taboadidi, Berekuso, Sesemi, and Ayim. The Fete Bediesi Complex Association type of soil Consist of yellow brown and alluvial sand; red, well drained sandy clay loam. The soil is good for forestry, maize, cassava, yams, pineapple, cowpea, soyabean, sisal, sunflower and tree crops like cashew, mongo, citrus, teak, etc. (Ga East Municipal Assembly, 2012). Land in the District is owned by chiefs, clan or family heads who hold them in trust for their subjects. However, land could also be acquired through direct purchase, rented, leasehold and share cropping.

3.1.3. Relief and drainage

The land area of Ga south consists of gentle slopes interspersed with plains in most parts and generally undulating at less than 76m above sea level. The slopes are mostly formed over the clay soils of the Dahomeyan gneiss with alluvial areas surrounding the low lying coastal lagoons. The Akwapim range and the Weija hills rise steeply above the western edge. The crest of the Akwapim range lies generally at 300m southwards. This line of hills continues through to the Weija hills with the highest point reaching 192m near Weija.

There are two main rivers namely, the Densu and Ponpon River, which drain the Municipality. The larger of the two is the Densu which drains down from the Eastern region through the western portion of the Municipality to Weija where it enters the sea. It is the source of water supply for over half of the entire population of Accra Metropolis. Other water bodies mostly tributaries of the Adaiso, Doblo, Ntafafa and the Ponpon rivers (Ga South Municipal Assembly, 2012)

3.1.4. Waste management

The four landfill sites in the Ga South Municipality are the Oblogo, Mallam (State Construction Corporation), Mallam Number One and Mallam Number Two landfill sites. Until they were reclaimed, the sites, which served as dumping sites for refuse from all parts of Accra for years, emitted overpowering stench which became a nuisance and posed health challenges to adjoining communities. The rehabilitation of the landfill sites was carried out as part of the Accra Metropolitan Assembly's (AMA's) solid waste management component of the Government of Ghana and the World Bank urban environmental sanitation project, phase two.

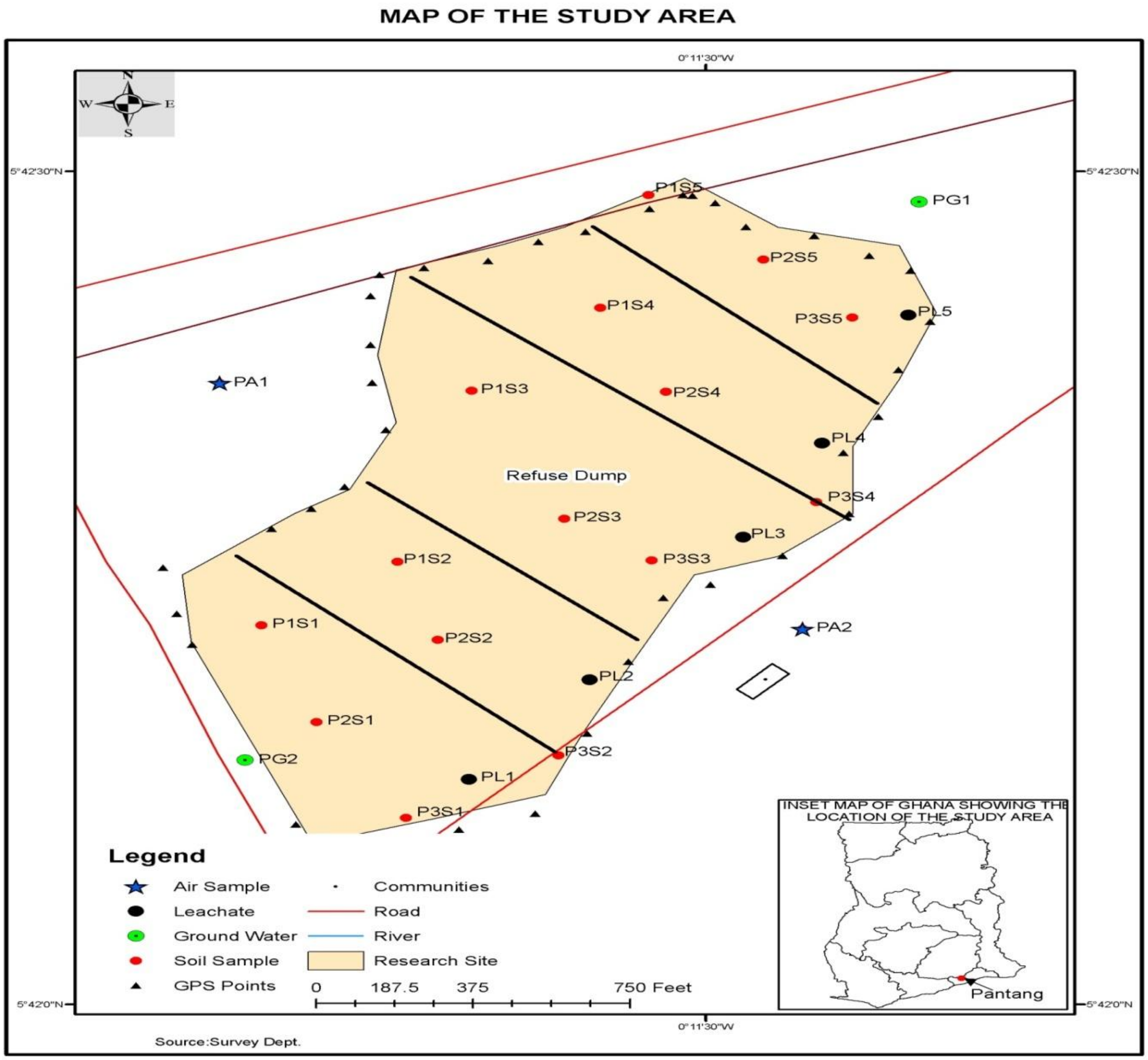
The World Bank released $1.4 million to Ghana for the capping of the four landfill sites, which cover 158 acres, by Zoomlion and Malson Company Limited. Capping of these sites, especially Mallam One and Two has been washed away over the years through erosion by rain water. Peripheral drains to carry leachates were poorly constructed. The drains are shallow, narrow and lack covers.

Currently the Pantang landfill site in the Ga East Municipality is the only active land fill in Accra and it receives solid waste brought from neighboring Assemblies- Adenta Municipal, Accra Metropolitan and Ga West Municipal. Concerns have been raised by the communities living close to the landfill over environmental and health risks posed by the landfill (Ga East Municipal Assembly, 2012).

3.2. Reconnaissance survey

Visits were made to the Mallam and Pantang research areas to determine the most appropriate sampling protocol and survey strategies to use. The research locations for the

Pantang landfill site (Figure 3.1) were coded as follows: PL for leachate, PA for air samples, PS for soil and PG for groundwater samples. The research locations for the Mallam landfill site (Figure 3.2) were coded as follows: M1L for leachate and MA for air samples.



Source:Survey Dept.

Figure 3.1: Research locations at the Pantang landfill.

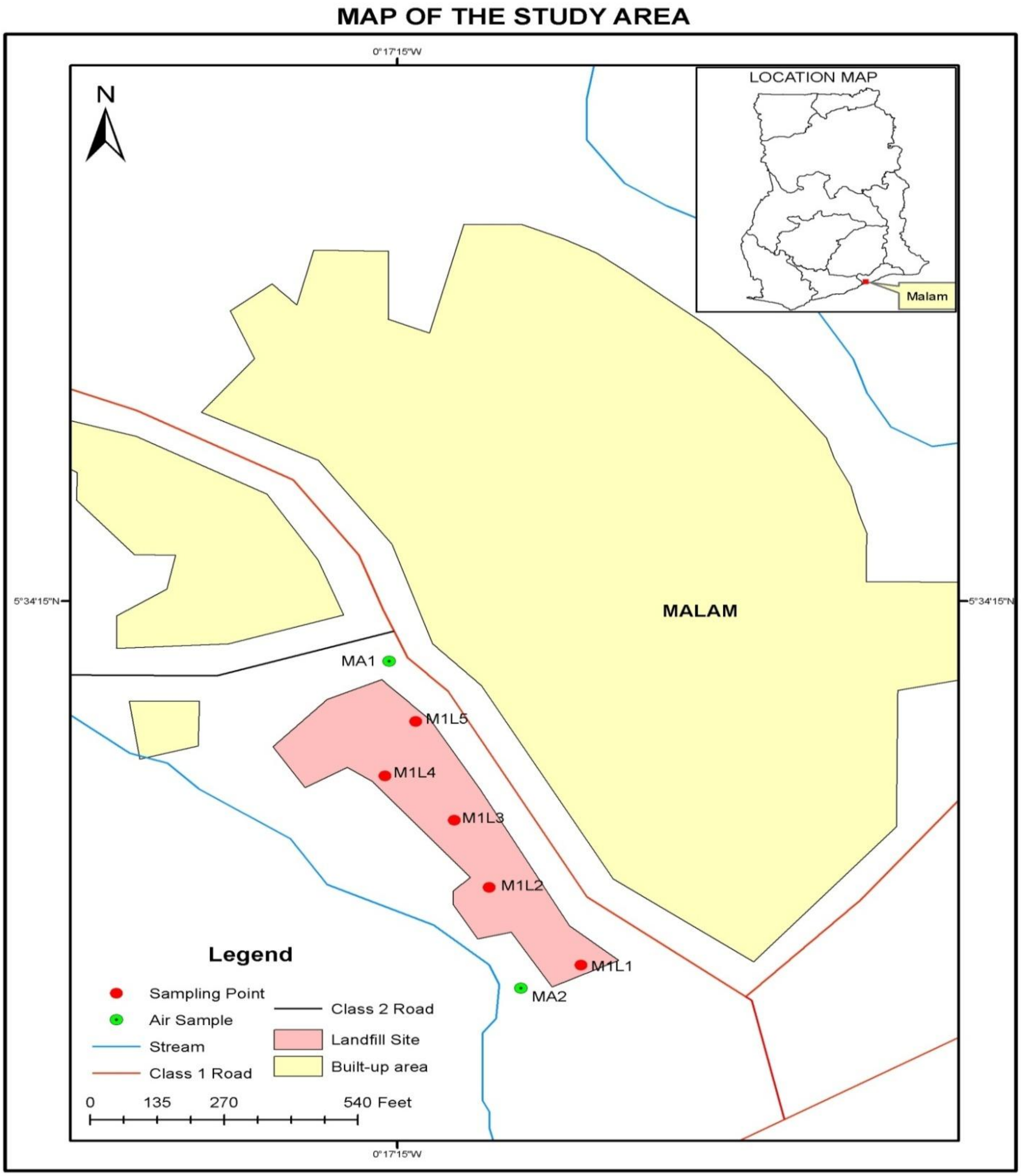


Figure 3.2: Research locations at the Mallam landfill.

3.3. Sampling and analytical methods

3.3.1. Leachate and groundwater

Leachate from each of the study areas was sampled up slope and down slope of the landfill sites. Leachate from the Pantang landfill site was sampled from five research locations coded PL1, PL2, PL3, PL4 and PL5. Leachate from the Mallam landfill site was sampled from five research locations coded M1L1, M1L2, M1L3, M1L4 and M1L5. Groundwater samples were collected from two wells, one very close to the landfill site coded PG2 and the other about 150 metres away from landfill site coded PG1.

Samples of leachates and groundwater for ex-situ analysis in the laboratory were collected into 1.5-liter polyethylene and 500ml PVC bottles. The bottles were previously cleaned by washing in non-ionic detergent, rinsed with tap water and finally rinsed with de-ionized water prior to usage. During sampling, the bottles were rinsed 2-3 times with leachate and groundwater being collected. Samples were filtered to remove all residues and the bottles filled to the brim. Samples in the 500ml PVC bottles for metal analysis were acidified with 2ml of concentrated nitric acid (HNO_3) to adjust the pH to less than two, to arrest microbial activities and prevent loss of the metals by precipitation and absorption. Samples were stored in ice chest at a temperature lower than 4.0^{o}C and transported to the laboratory. Samples that were not analyzed immediately were stored in a refrigerator.

All the laboratory analyses to determine the levels of pollutants in the leachate and groundwater, unless otherwise stated, were carried out following standard methods of the American Public Health Association (APHA). Analyses determined physical, chemical, oxygen demand and heavy metals parameters. With the exception of heavy metals which were determined in the Ecological laboratory of the University of Ghana, all other parameters were measured in the laboratory of the Environmental Protection Agency.

The physical parameters determined on the leachate and groundwater were pH, electrical conductivity, total dissolved solids, total suspended solids and turbidity. The pH, electrical conductivity and total dissolved solids were measure in-situ. The pH was determined using the Wagtech Potalab pH meter that employs the electro-chemistry technique. The electrical conductivity (EC) and total dissolved solids (TDS) were measured using the Wagtech Potalab conductivity/TDS meter that employs the electrochemistry technique. The total suspended solid (TSS) of the samples was determined using the Wagtech Potalab Photometer. The turbidity (TUR) of the samples was determined using a portable turbidimeter (Wagtech Potalab turbidimeter) which uses the Nephelometric principle.

The oxygen demand parameters determined for the leachate and groundwater were Dissolved Oxygen, Biological Oxygen Demand and Chemical Oxygen Demand. The Dissolved Oxygen (DO) was measured in-situ for with the DO metre (Wagtech system of probes) that employs the Electrochemistry Technique.

Biological Oxygen Demand (BOD) measures the amount of oxygen consumed by microorganisms in decomposing organic matter in water. Respirometry technique was used to measure the amount of oxygen consumed by these organisms during a specified period of time (5 days at 20^{o}C). The BOD bottle was filled with the sample and incubated for 5 days at 20^{o}C. Dissolved oxygen was measured initially and after incubation, and the

BOD was computed from the difference between the initial and final DO (Equation1) (APHA, 1995).

Calculation: BOD_5 mg/l = [(d_1 - d_2) / P] ____________________ Equation1

Where;

d_1= initial DO of sample, mg/l

d_2= DO of sample after 5 days incubation at 20^0 C, mg/l

p=decimal volumetric fraction of sample used

Chemical Oxygen Demand (COD) is a measure of the amount of oxygen in water consumed for chemical oxidation of pollutants. The COD content of the leachate and groundwater was determined using the Wagtech COD test which is a colour absorbance or transmittance technique. Two ml of the leachate and groundwater were measured into two test tubes respectively. The COD nutrient was added, shaken vigorously and heated for 2 hours. The solution was cooled and the COD of the sample was measured using the Wagtech Potalab Photometer, which was earlier blanked using the COD nutrient.

The nutrients parameters determined on the leacahte and groundwater were sulphate (SO_4), sulphite (SO_3), Total phosphorus (TP), nitrate (NO_3), nitrite (NO_2) and ammonia (NH_3).

The sulphate content of the leachate and groundwater was determined using the Wagtech sulphate test which is a colour absorbance or transmittance technique. It is based on a single tablet reagent containing barium chloride in a slightly acidic formation. The barium salts react with sulphate to form insoluble barium sulphate which is turbid. The degree of turbidity is proportional to the sulphate concentration and measured using the photometer. Two test tubes were filled with leachate and groundwater samples respectively to the 10ml mark. One sulphate turb tablet was added, crushed and mixed to dissolve. A cloudy solution was formed indicating the presence of sulphate. The solution was allowed to stand for five minutes then mixed again to ensure uniformity. Phot 32 was selected on the photometer. Photometer reading was taken and displayed as mg/l SO_4.

The Total phosphorus concentrations of the leachate and groundwater samples were determined using the palintest tubetests total phosphorus/12 test which is a simple two stage procedure based on a colour absorbance or transmittance technique. The sample is first digested with acid persulphate to break down polyphosphates and organic phosphorus compounds and convert them to orthophosphate. The resulting orthophosphate together with the original present in the sample is then determined by reaction with ammonium molybdate and ascorbic acid to form the intensely colored molybdenum blue complex. In this way, the Total phosphorus content of the sample can be determined.

A catalyst is incorporated to ensure complete and rapid colour development and an inhibitor to prevent interference from silica. The intensity of the colour produced in the test is proportional to the total phosphorus concentration and is measured using the photometer. Procedure for total phosphorus determination in the laboratory: Tubetest heater was turned on, control set to 100-105^{0}C (212-221) and allowed to heat up to temperature. The cap of two tubetest total phosphorus/ 12 tubes were removed and 2.0ml of leachate and groundwater samples added respectively using a pipette. Two digest ox tablets were added, crushed and mixed to dissolve. The cap was tightly replaced and tube inverted gently to mix. The tube was labeled and placed in the tubetests heater and digested for one hour. The tube was carefully removed, transferred to a test tube rack and allowed to cool to room temperature.

The cap was carefully removed from the cooled tube and 2.0ml of phosneut solution was added using a pipette. One tubetests phos NO.1 tablet was added, crushed and mixed to dissolve. One tubetests phos NO.2 tablet was also added, crushed and mixed to dissolve. The Tube was capped and gently inverted several times to mix. Tube with content was allowed to stand for 10 minutes to allow colour development. Phot 92 was selected on the photometer. Tubetest tube containing deionised water only was used to set the blank on the photometer. Photometer reading was taken and displayed as mg/l P.

The Nitrite concentrations of the leachate and groundwater samples were determined using the Wagtech Nitricol method which is a colour absorbance or transmittance technique. Two test tubes were filled with leachate and groundwater samples respectively to the 10ml mark. One niticol tablet was added, crushed and mixed to dissolve. The solution was allowed to stand for 10 minutes to allow full colour development. Phot 64 was selected on photometer and result displayed as mg/lNO_3.

The sulphite concentrations of the leachate and groundwater samples were determined using the Wagtech sulphitest method based on a colorimetric procedure involving the reduction of an indicator dye. Two test tubes were filled with leachate and groundwater samples respectively to the 10ml mark. One sulphitest NO1 tablet was added, crushed and mixed to dissolve. One sulphitest NO2 tablet was added to solution in tube, crushed and mixed to dissolve. Tube was capped immediately. The solution was allowed to stand for two minutes to allow full colour reduction to take place. Phot 34 was selected on the photometer and photometer reading taken. The result was displayed as mg/lSO_3.

The ammonia concentrations of the leachate and groundwater samples were determined using the Wagtech Ammonia test based on an Indophenol method. Two test tubes were filled with leachate and groundwater samples respectively to the 10ml mark. One ammonia NO.1 tablet and one ammonia NO.2 tablet were added, crushed and mixed to dissolve. The solution was allowed to stand for ten minutes to allow colour development. Phot 4 was selected on the photometer and photometer reading taken. The result was displayed as mg/l.

The nitrate concentrations of the leachate and groundwater samples were determined using the Wagtech Nitrate test which is a colour absorbance or transmittance technique. Twenty ml each of the leachate and groundwater was taken. One spoon of nitratest powder was added to the sample and swirled to mix. One nitratest tablet was added to the mixed sample, shake to dissolved and allowed to stand for 3mins. 10ml of the solution was decanted into a covert and one nitricol tablet added, crushed and allowed to stand for 10mins. Phot 24 was selected on the photometer and photometer reading taken. The result was displayed as mg/l.

The heavy metals determined on the leacahte and groundwater samples were Chromium (Cr), Lead(Pb), Cadmium(Cd), Iron (Fe), Copper(Cu), Nickel(Ni), Manganese(Mn) and Zinc(Zn). Hundred ml each of leachate and groundwater samples was transferred into Pyrex beakers containing 10ml of aqua regia and 1 ml of perchloric acid. The solution was then incubated at 80°C in a water bath, allowed to cool and filtered. The filtrates were transferred to 100ml volumetric flasks and diluted to the mark with distilled water and analyzed for heavy metals using Atomic Absorption Spectrophotometry.

3.3.2. Air

The particulate matter parameters determined for air were particulate matter (PM_{10}) and total suspended particles (TSP). The particulate matter was sampled using a MiniVol Sampler set to a flow rate of 5.0L/min at the designated site. Samples were taken at a minimum height of 5 meters above the ground level to prevent the collection of ground level dust temporarily made airborne. The sampler was oriented in the direction of wind flow. Pumped air was siphoned through a filter paper, mounted in a sampling unit and sampling undertaken for 24 hours. The filter paper was stabilised before and after sampling in a desicator. The filter paper was pre-weighed and post-weighed before and after sampling. Starting time was noted. Initial and final elapse times were noted, and the difference should be 24hrs to indicate sampling has taken place.

For total suspended particle sampling, the impactor was removed from the filter holder assembly (head) and for PM_{10} sampling the impactor was placed in the filter holder assembly. Selected filter was removed from the labeled petrislide. The filter cassette was open with the cassette separator. With the forceps, the filter was placed in the filter cassette, cassette placed in the filter holder (head), labeled and kept in plastic bags. Samplers were carefully transported to the field. Sampler was placed firmly on a level surface with the intake upward and at least 30cm from any obstacle. Inlet tube compression nuts were loosened and inlet tube extended to the maximum height and nut retightened. Filter holder with impactor for Pm sampling and filter holder without impactor for TSP sampling were attached to the top of two separate sampler inlet tubes and tightened. Sampler case was opened and turned on, flow rate; start time and initial elapse time were noted. Sampler was set to auto mode and case closed.

After sampling final elapse time was noted, head was removed and Inlet tube compression nuts loosened and Inlet tube pushed back in. In the lab, head was unscrewed and cassette removed. Petrislide with ID which matches ID on head was located and using the cassette separator the top half of the cassette was removed, exposed filters were removed from the cassette and placed in its original petrislide. The exposed filters conditioned in the desicator for 48 hr to minimize the effect of moisture on the filters after taking air samples and weighed afterwards.

The amount of the PM_{10} and TSP was estimated by taking the difference in the weight of the filter paper before and after air sampling by gravimetric estimation. The results were expressed as micrograms of PM_{10} per cubic meter of air and micrograms of TSP per cubic meter of air. To express the amount of PM_{10} and TSP in mg/m3, the mass of the PM_{10} and TSP in micrograms is divided by the product of the flow rate set and the sampling duration (Equation 2).

$$PM_{10} \text{ or TSP (ug/m3)} = \frac{\text{(mass sampled (ug)}}{\text{((Flow Rate (m}^3\text{/min) x sampling duration (mins))}} \quad \text{Equation 2}$$

The heavy metals determined for the air sampled were Chromium (Cr), Lead(Pb), Cadmium(Cd), Iron (Fe), Copper(Cu), Nickel(Ni), Manganese(Mn) and Zinc(Zn). Exposed filter papers were composited and acid digested using aqua regia (1:3 HNO_3 and HCl) for total metal ion extraction. After digestion, the extract was filtered and diluted with distilled water.

The diluted extract was used to quantify heavy metals using atomic absorption spectrophotometer (Model AAnalyst 800, Perkin–Elmer, USA).The gases sampled were the carbon monoxide, nitrogen dioxide, ammonia and sulphur dioxide. The Accuro gas detector pump and the Drager tube were used for gas sampling. The appropriate Dradger tube for the gas concern was selected. Both tips of tube were opened with Drager tube opener. Drager tube with both ends opened was inserted into the Accuro pump with arrow facing pump. Pump was held with end- of-stroke indicator and stroke counter facing user. Pump was squeezed until it stopped. Pump was released after squeezing until bellows were fully expanded.

Pump was squeezed again when the end-of-stroke indicator appeared. It was repeated until the number of stokes for concerned tube was reached. The entire length of discoloration in the tube was read by matching the color developed with the color comparison chart and noting the nearest corresponding matching value and recording in parts per million (PPM). Used tube was removed and pump was flushed with clean air. The number of strokes for CO was five and measuring time 150 seconds. The number of strokes for SO_2 was ten and measuring time 3 minutes. The number of strokes for Ammonia was ten and measuring time one Minute. The gaseous sample in PPM was converted to ug/m^3 using the formula below (Equation 3):

Gaseous concentration (ug/m^3) = field reading (ppm) x cf x f x1000 ______(Equation 3)

Where f is atmospheric pressure correction and cf is conversion factor

3.3.3. Soil

Soil samples were taken from the Pantang landfill site only. A control site was selected away from the landfill site. The landfill site was divided into five research sections. The first section was coded PS1, the second PS2, the third PS3, the forth PS4 and the fifth PS5. In each section, three research locations were identified and surface soils taken by the hand auger at a depth of 0-15 cm.

The sampling points in the first section (PS1) were coded P1S1, P2S1 and P3S1and those of the second section (PS2) were coded P1S2, P2S2 and P3S2. P1S3, P2S3 and P3S3 were the sampling points of the third section (PS3) and those of the forth section (PS4) were coded P1S4, P2S4 and P3S4. The fifth section (PS5) had it sampling points being coded P1S5, P2S5 and P3S5. The cores of soil sampled with the auger from the three points in each section were mixed thoroughly for a composite sample. The composite soil for each section was transferred into plastic bags and labeled PS1, PS2, PS3, PS4 and PS5. The soil samples were transported to the laboratory, dried at room temperature, ground and sieved through a sieve with a 2 mm mesh.

The parameters determined for soil samples were pH, electrical conductivity, percentage organic carbon (%OC), percentage organic matter (%OM), Ammonia, Nitrate and metals (Cd, Mn, Pb, Fe, Cu, Cr, Ni and Zn). To determine pH and electrical conductivity, 10 grams of the soil sample was weighed into an extraction cup. Ten ml of distilled water was dispensed into the cup with soil and allowed to stand for fifteen minutes. Solution was shaken on the mechanical shaker for thirty minutes at one hundred and fifty revolutions per minute and allowed to stand for ten minutes. The solution was filtered and the pH and EC were determined on the filtrate using a pH/EC multimeter.

Organic carbon was determined by the wet oxidation method (Walkley-Black method). Procedure- 0.100g of the soil sample weighed into 250mls conical flask and 10mls of 1.0m $K_2C_2O_7$ solution was added. Twenty milliliters (mls) of concentrated H_2SO_4 was also added. Solution was vigorously swirled for 1 minute and allowed to stand for 30 minutes. Two hundred milliliters (mls) of distilled water, 10ml H_3PO_4 and 1.0mls of barium diphenylamine sulphonate indicator were added to the solution in the conical flask and stirred. Solution in the conical flask was titrated against $FeSO_4$ until a green coloration indicating the end point was formed. The ferrous sulphate solution was standardized by titrating against 10ml of 1m $K_2C_2O_7$ solution. Organic carbon percentage was calculated using Equation 4 below.

$$\%\ OC = (2.394\ (3.4 - T \times 0.0333)\ )\ /\ (\text{Weight of soil}) \qquad \underline{\qquad\qquad\qquad \text{Equation 4}}$$

%OC value was multiplied by 1.724 to obtain the % organic matter.

To determine Ammonia and Nitrate, Ten grams of the soil samples was weighed, transferred into a plastic shaking bottle. Fifty milliliters (mls) of 2M KCL extraction solution was added, corked and content shake for one hour. After shaking, the sample was allowed to stand for 30 minutes. The sample was filtered into Buchner funnels using filter papers Whatman NO. 42. A steam distillation apparatus was set up using NH_3 free distilled water. Filtrate was steamed through the apparatus for 30 minutes and 50ml distillate collected and titrated with 0.01 HCL.

The heavy metals Cd, Mn, Pb, Fe, Cu, Cr, Ni and Zn were analysed using the Atomic Absorption Spectrophotometer (AAS). Dried homogenized powdered soil sample weighing 0.5g was taken and digested in a Teflon beaker with a mixture of HNO_3, $HClO_4$ and HF in the ratio 4:1:4 respectively. The mixture was placed on a hot plate for three hours at 85ºC, the digest was filtered into 100mlstandard flask and made up to mark with deionized water. The resultant solution was analysed for the interested heavy metals using the Atomic Absorption Spectrophotometer.

3.3.4. Pollution indexes

The pollution indexes of leachate, air and soil were determined on the Mallam and Pantang landfill sites. The leachate pollution was determined using the Leachate Pollution Index (LPI) by Kumar and Alappat (2003). Air pollution was determined using the Air Quality Index formula by Rao and Rao (1989). Soil pollution was measured using the Pollution load index by Tomlinson et al (1980). Leachate migration was assessed using the formula by Kerndorff et al. (1992).

The LPI developed by Kumar and Alappat (2003) was used determine the extent of pollution by leachate generated on the Pantang and Mallam landfill sites. LPI determination was focused on the following pollutants for the two sites: Chromium, Iron, Total Dissolved Solids, Biochemical Oxygen Demand, Chemical Oxygen Demand, Copper, Nickel, Zinc, and Lead. The LPI value represents the level of leachate contamination potential of a given landfill at a given time and ranges from 5 to 100.

It is an increasing scale index, where a higher value indicates a poor environmental condition. The LPI was determined firstly by testing for the concentration of pollutants in the leachate by analytical procedures. The concentrations of the pollutants were noted as Ci. The pre-determined variable weight factors which constants are indicating the importance of each pollutant variable to the overall leachate pollution was noted. The Variable weight factors of the pollutants were noted Wi.

The pollutants and their variable weight factors are as follows pH: 0.055, chromium: 0.064, iron 0.045. Total Dissolved Solids: 0.050; Biochemical Oxygen Demand: 0.061; Chemical Oxygen Demand: 0.062; Copper: 0.050; Nickel: 0.052; Zinc: 0.056; Lead: 0.063. the ‘p' values or sub-index values for all the parameters were computed from the sub-index curves based on the concentration of the leachate pollutants obtained during the tests.

The ‘p’ values were obtained by locating the concentration of the leachate pollutant on the horizontal axis of the sub index curve for the pollutant in question and the leachate pollution sub-index value was noted where it intersects the curve. The ‘p' values or sub-index values for the parameters were noted as Pi. The ‘p’ values obtained above for all the parameters are multiplied by their respective weights assigned to each parameter. The equation below was used to calculate the LPI since the concentrations of only nine parameters were used (Equation 5).

$$LPI = (\Sigma WiPi) \div (\Sigma Wi) \qquad \text{Equation 5}$$

The Air Quality Index (AQI) was calculated by the formula given by Rao and Rao (1989). The Air Quality Index (AQI) is a measure of the ratio of the pollutant concentration in ambient air to the national standards of the pollutants (Equation 6).

$$API = 1/n\,(P\,C_{ith}/NSC_{ith} + \ldots + PC_{nth}/NSC_{nth})\ x100 \qquad \text{Equation 6}$$

where,

PC_{ith} is the pollutant concentration of the ith pollutant,

NSC_{ith} is the National Standard concentration value of the ith pollutant,

PC_{nth} is the pollutant concentration of the nth pollutant,

NSC_{nth} is the National Standard Concentration value of the nth pollutant

n is the number of pollutant determined. For this study, the Air Quality Index (AQI) was calculated using only the PM_{10} and TSP concentrations and calculated as (Equation 7).

$API=1/2\ (PM_{10}\ C/\ PM_{10}NSC) + (TSP\ C/\ TSP\ NSC)\ x100$ ______________ Equation 7

The Air Quality Index (AQI) scale is divided into five categories as follows (0-25) Clean air, (26-50) Light air pollution, (51-75) moderate air pollution, (76-100) heavy air pollution and (Above 100) severe air pollution.

The Pollution Load Index by Tomlinson et al. (1980) was used to determine the extent of soil pollution. To obtain the Pollution Load Index (PLI) the concentration Factors (CF) was first computed by dividing the concentration of the metals obtained for the soil sampled (C metal) by the world average concentrations (C background value) for the metals reported for shale by Turekian and Wedepohl (1961).

$CF = (C\ metal) / (C\ background\ value)$ __________________________ Equation 8

The PLI was calculated by obtaining the n-root from the n-CFs' that were obtained for all the metals (Equation 9).

$PLI=n\sqrt{}(CF1xCF2xCF3x\ldots x\ CFn)$ __________________________ Equation 9

Where,

CF = contamination factor,

n = number of metals C metal = metal concentration in polluted sediments

C Background value = background value of that metal.

The PLI value of > 1 is polluted, whereas <1 indicates no pollution Harikumar et al., 2009).

The Kerndorff Formula was used to assess leachate migration by analysing the concentrations of parameters in groundwater down-gradient from the landfill and the concentrations in groundwater sampled sufficiently where it is not influenced by the landfill derived contaminants. The well coded PG1 on the Pantang landfill was used for this analysis since it is located down slope of the landfill site.

The impact on groundwater by the leachate migrating from the landfill was determined using the Kerndorff contamination factor which represents the ratio of the measured concentration in the groundwater down gradient of the landfill to the concentration in the uncontaminated groundwater up-gradient of the site. A ratio value greater than 1.0 means the parameter is leaking from the site and a ratio of 1.0 or lower indicates that the parameter in not leaking; thus, the greater the leakage event, the greater the Kerndorff contamination factor.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. LEACHATE

4.1.1. pH

Leachate is generally found to have pH value of between 4.5- 9 (Christensen et al., 2001). The pH of the leachate from the Pantang landfill ranged from 8.00-8.9 with a mean of 8.345 pH units and standard deviation of 0.263 (Appendix 2). The leachate from the research location (coded PL4) on the Pantang landfill recorded the highest pH value of 8.9 in March and the research location (coded PL3) recorded the lowest pH of 8.0 in April (Appendix 3). The pH of the leachate from the Mallam landfill ranged from 8.15 - 8.90 with a mean of 8.388 and standard deviation of 0.224.

The leachate from the research location coded M1L4 on the Mallam landfill recorded the highest pH of 8.90 in February and M1L2 recorded the lowest pH of 8.15 in March (Appendix 4). pH of the leachate from the Pantang and Mallam landfills lies within the EPA guideline value of 6-9 (Appendix 2). Adeolu (2011) also recorded a pH value of 8.1. Kulikowska and klimiuk (2008) and Tatsi and Zouboulis (2002) reported a range of pH 7.46–8.61 and 7.3–8.8 respectively, from old landfill sites.

The alkaline nature of the leachate from the Pantang and Mallam landfill sites is typical of leachate from aged landfill sites (Aluko et al., 2003; Abbas et al., 2009). Precipitation and the quantity and quality of waste may have also affected the pH recorded. The high alkalinity may be a result of high organic strength of the leachate. Osei et al (2011) also reported a pH range of 7.52 – 8.5 at the Oblogo dumpsite. Akiti (2012) reported a similar pH range of 8.4 – 8.6 at the Oblogo landfill site. The high pH is an indication that the waste decomposition is at the methanogenic phase. The sampling points PL5 and PL3; and M1L4 showed decreasing trend with sampling period and the other sampling points exhibited fluctuating trend with time. An analysis of variance for pH showed an insignificant difference ($P=0.636$, $P > 0.05$) between recorded values.

4.1.2. Dissolved oxygen (DO)

DO of the leachate from the Pantang landfill ranged from 1-3.7 with a mean of 2.226 and standard deviation of 0.894 (Appendix 2). The leachate from the research location (coded PL3) on the Pantang landfill recorded the highest DO of 3.7 in February and the research location (coded PL5) recorded the lowest value of 1.0 in February and April (Appendix 3, Figure 4.1). DO of the leachate from the Mallam landfill ranged from 0.941 to 3.6 with a mean of 2.184 mg/l and standard deviation of 0.822 (Appendix 2). The leachate from the research location (coded M1L1) on the Mallam landfill recorded the highest DO of 3.6 in April and the research location (coded M1L2) recorded the lowest of 0.941 in March (Appendix 4, Figure 4.1). The DO for the leachate from the Pantang landfill showed decreasing trend for PL1 and PL3 which indicates an increase in organic materials with time thus causing the depletion in oxygen level as a result of decomposition, the remaining sampling points showed fluctuating trend with time.

The DO of the leachate from the Mallam landfill showed increasing trend for M1L1, M1L3 and M1L5 which indicates a decrease in organic materials with time resulting in low decomposition hence less oxygen depletion with time, the remaining sampling points showed fluctuating trend with time. The leachate from the Mallam site recorded a higher DO because there are fewer amounts of organic and inorganic materials to be decomposed hence less oxygen demand for microbial activities since it no longer receives waste unlike the Pantang site which is still active. An analysis of variance for DO 0.895 showed an insignificant difference (P=0.895, P > 0.05) between recorded values.

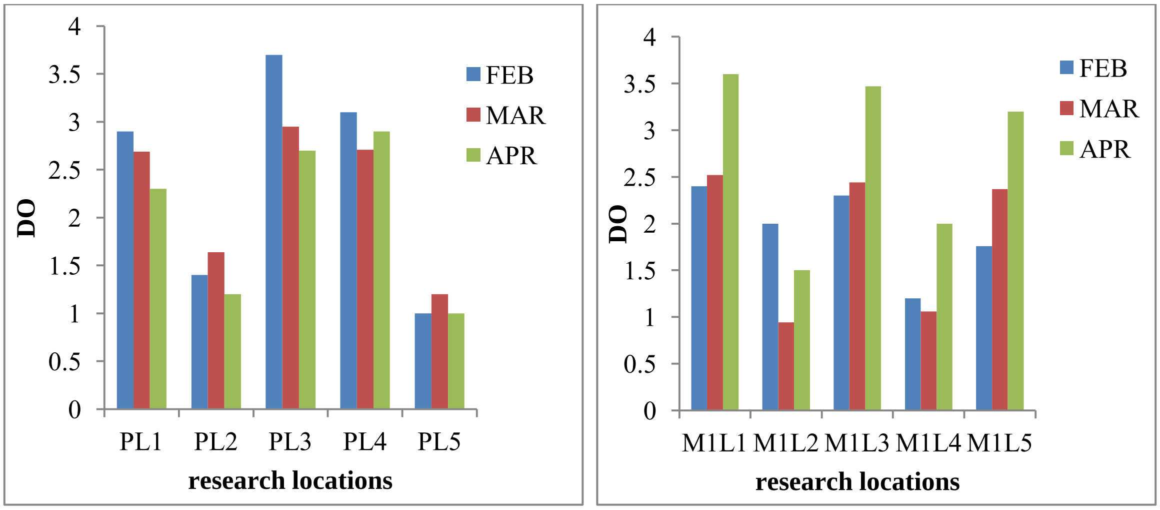


Figure 4.1: Plot of dissolved oxygen (DO) for leachate from the Pantang and Mallam landfill sites

4.1.3. Total suspended solids (TSS)

The leachate from the Pantang landfill had a TSS ranging from 1320-1723 with a mean of 1582 and standard deviation of 91.418 (Appendix 2). The leachate from the research location (coded PL2) on the Pantang landfill recorded the highest TSS of 1723 mg/l in the month of February and the research location (coded PL3) recorded the lowest value of

320 mg/l in February (Appendix 3). TSS of the leachate from the Mallam landfill ranged from 209-391 mg/l with a mean of 266.467 mg/l and standard deviation of 49.492 (Appendix 2). The leachate coded M1L5 from the Mallam landfill recorded the highest Total Suspended Solids (TSS) of 391mg/l in March and M1L2 recorded the lowest of 209 mg/l in February (Appendix 4). The TSS measured for the leachates from the Pantang and Mallam landfills were above the EPA guideline of 50mg/l for effluent discharge into the environment (Appendix 2). The high TSS concentration indicates the presence of large amounts of organic and inorganic materials in the leachate.

The research locations (coded PL5) and (coded M1L3) exhibited increasing trend with time; the other points showed fluctuating trend across the sampling period and this may be due to uneven distribution of organic and inorganic substances across the sampling points. The leachate from the Mallam landfill recorded a lower TSS concentration compared to that of Pantang because of aging. An analysis of variance for TSS showed a significant difference ($P=0.000 \quad P< 0.05$) between recorded values.

4.1.4. Turbidity (Tur)

The turbidity of the leachate from the Pantang landfill ranged from 93-309 with a mean of 213.973 and standard deviation of 85.581 (Appendix 2). The leachate from the research location (coded PL4) on the Pantang landfill recorded the highest turbidity of 309 NTU in the march and the research location (coded PL3) recorded the lowest of 93 NTU in February (Appendix 3). Turbidity of the leachate from the Mallam landfill ranged from 127-194 NTU with a mean of 152.507 and standard deviation of 18.771

(Appendix 2). The research location coded M1L2 from the Mallam landfill recorded the highest turbidity of 194 NTU in March and M1L5 recorded the lowest of 127 NTU in February and April (Appendix 4).

The turbidity of the leachate from the Pantang and Mallam landfills were above the EPA guideline value of 75 NTU for effluent discharge into the environment (Appendix 2). Osei et al (2011) reported a turbidity of 750 – 1490 NTU at the Oblogo dumpsite. The high turbidity may be due to the presence of dissolved organic substances. The high turbidity recorded for the leachate from Pantang in March may be due to rainfall which dissolved organic and inorganic materials into the leachate and also caused a disturbance in the leachate column leading to suspension of materials in solution. The leachate from the Mallam landfill recorded a lower turbidity compared to that of Pantang because of aging. An analysis of variance for turbidity showed a significant difference ($P=0.011$ $P< 0.05$) between recorded values.

4.1.5. Electrical conductivity (EC)

EC of the leachate from the Pantang landfill ranged from 50163-74830 with a mean of 63463 and standard deviation of 8543.705 (Appendix 2). The leachate from the research location (coded PL3) on the Pantang landfill recorded the highest EC of 74830µS/cm in April and the research location (coded PL3) recorded the lowest 50163µS/cm in March (Appendix 3). The EC of the leachate from the Mallam landfill ranged from 10150 – 36490 with a mean of 19232.267µS/cm and standard deviation (9066.951) (Appendix 2). The leachate from the research location (coded M1L1) on the Mallam landfill recorded the highest electrical conductivity (EC) of 36490µS/cm in March and the research location M1L1 recorded the lowest of 10150µS/cm February (Appendix 4).

The electrical conductivity of the leachates from the Pantang and Mallam landfills were above the EPA guideline value of 1500µS/cm for effluent discharge into the environment (Appendix 2). Adeolu et al. (2011) recorded an EC value of 12400. Nyame et al. (2012) reported a value of 7960 – 24890 at Oblogo. The high EC indicates the presence of dissolved materials in the leachate.

The leachate from the Mallam landfill recorded a lower electrical conductivity compared to that of Pantang because of aging. The leacahte sampling points for Pantang showed fluctuating trend with time indicating uneven distribution of dissolved materials in time and space. The research locations coded M1L2, M1L3 and M1L4 showed decreasing trend with time and this may be due to increasing age. An analysis of variance for EC showed a significant difference ($P=0.000 \quad P< 0.05$) between recorded values

4.1.6. Total dissolved solids (TDS)

TDS of the leachate from the Pantang landfill ranged from 20134-48141 with a mean of 32923.933 and standard deviation of 7274.217 (Appendix 2). The leachate from the research location (coded PL1) on the Pantang landfill recorded the highest TDS of 48141mg/l in March and the research location (coded PL5) recorded the lowest 20134mg/l in February (Appendix 3, Figure 4.2). The TDS of the leachate from the Mallam landfill ranged from 1649-4325 mg/l with a mean of 3135.667 mg/l and standard deviation of 990.548 (Appendix 2). The leachate from the research location (coded

M1L4) on the Mallam landfill recorded the highest Total Dissolved Solids (TDS) of 4325mg/l in March and the research location M1L1recorded the lowest of 1649mg/l in March (Appendix 4, Figure 4.2). The TDS of the leachate from the Pantang and Mallam landfills were above the EPA guideline of 1000mg/l.

A similar result was reported by Adeolu (2011) as 6200 mg/l. Akiti (2012) reported of a similar range of 1239.33 - 4088.33 mg/l. The leachate from the Mallam landfill recorded a lower TDS concentration compared to that of Pantang because of aging. The high TDS indicates that both sites have huge amounts of organic and inorganic materials undergoing decomposition. TDS showed a fluctuating trend over the sampling period. An analysis of variance for TDS showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

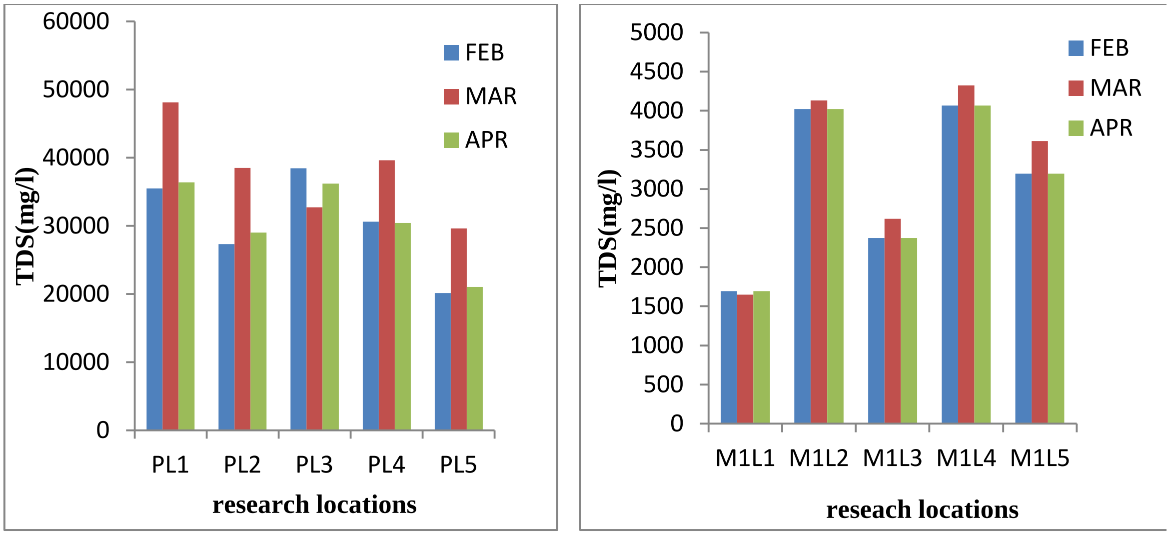


Figure 4.2: Plot of total dissolved solid (TDS) for leachate from the Pantang and Mallam landfill sites

4.1.7. Biological oxygen demand (BOD)

The BOD of Pantang leachate ranged from 124-293 with a mean of 192.133 and standard deviation of 51.017 (Appendix 2). The leachate from the research location (coded PL5) on the Pantang landfill recorded the highest BOD of 293mg/l February and the research location coded PL3 recorded the lowest 124mg/l in February (Appendix 3). The BOD of the leachate from the Mallam landfill ranged from 123 – 207 with a mean of 160.6 mg/l and standard deviation of 28.623 (Appendix 2). The leachate from the research location (coded M1L2) on the Mallam landfill recorded the highest Biological Oxygen Demand (BOD) of 207mg/l in April and the research location coded M1L1 recorded the lowest 123 mg/l in April (Appendix 4). The BOD of the leachate from the Pantang and Mallam landfills were above the EPA guideline of 50mg/l which indicates the high organic strength of the leachate. The leachate from the Mallam landfill recorded a lower BOD because of aging.

A BOD of 152.10 was reported by Osei et al (2011) also reported a BOD of 66.7 – 100. The leachate from the Pantang landfill recorded a higher BOD over that of Mallam because it is still an active site whilst the Mallam is not. The concentration of BOD of the leachate from the Pantang landfill increased across the research locations from (PL1) to (PL4) with time and decreased at PL5 with time. For leachate from the Mallam site, the concentration of BOD decreased at the research locations (M1L1), (M1L3) and (M1L5); and increased at (M1L2) and (M1l4). An analysis of variance for BOD showed a significant difference ($P=0.046 \quad P< 0.05$) between recorded values.

4.1.8. Chemical oxygen demand (COD)

The COD of the leachate from the Pantang landfill ranged from 583 -829mg/l with a mean 719.133mg/l and standard deviation of 91.818 (Appendix 2). The leachate from the research location (coded PL3) 0n the Pantang landfill recorded the highest COD of 829mg/l in February and the research location (coded PL4) recorded the lowest 583mg/l in February (Appendix 3, Figure 4.3). COD of the leachate from the Mallam landfill range from 760 -1520 with a mean of 1122.533 mg/l and standard deviation of 229.880. The leachate from the research location (coded M1L3) on the Mallam landfill recorded the highest Chemical Oxygen demand (COD) of 1520mg/l in February and (coded M1L2) recorded the lowest of 760mg/l in February (Appendix 4, Figure 4.3). The COD of the leachate from the Pantang and Mallam landfills were above the EPA guideline of 50mg/l which indicates the high organic strength of the leachate. A much higher value of COD (70,900 mg/L) was reported in leachate obtained from Thessaloniki Greater Area (Greece) by Tatsi and Zouboulis (2002).

The research locations (PL4, PL5, M1L1, M1L2, M1L4 and M1L5) showed increasing trend with time indicating increase in organic waste with time. The leachate from the Mallam landfill recorded a higher COD over that of Pantang because of the discharge of domestic waste water especially those containing detergents by residents leaving very close to the decommissioned landfill site. An analysis of variance for COD showed a significant difference ($P= 0.000 \quad P< 0.05$) between recorded values.

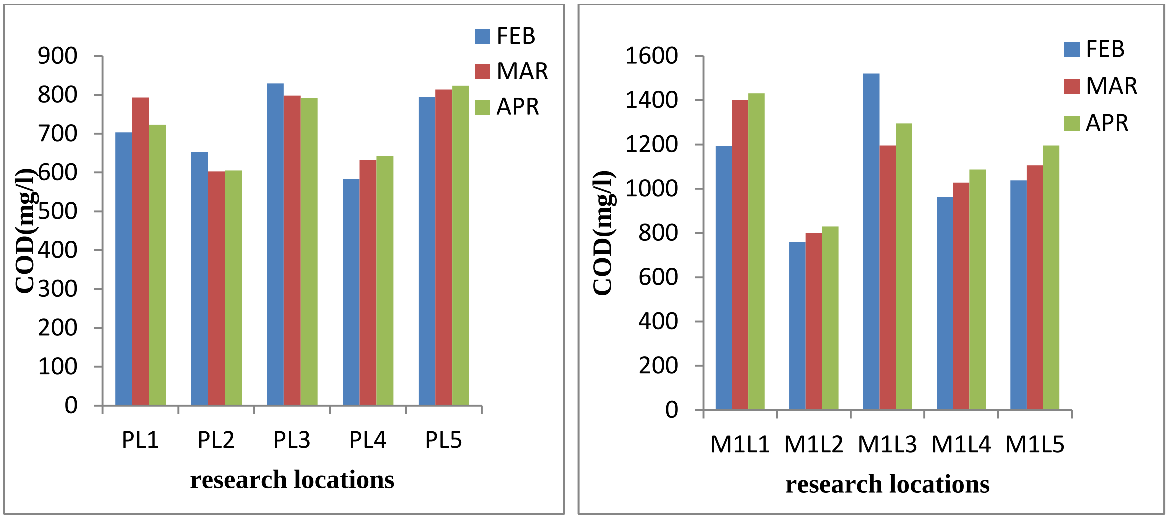


Figure 4.3: Plot of chemical oxygen demand (COD) for leachate from the Pantang and Mallam landfill sites

4.1.9. Nitrate (NO_3)

The nitrate of the leachate from the Pantang landfill ranged from 24.3- 57.3 with a mean of 37.038 mg/l and standard deviation of 10.907 (Appendix 2). The leachate from the research location (coded PL5) on the Pantang landfill recorded the highest nitrate of 57.3 mg/l in February and the research location (coded PL5) recorded the lowest 24.3mg/l in March (Appendix 3). The low concentration in March is due to dilution. The nitrate of the leachate from the Mallam landfill ranged from 34.2 -79 mg/l with a mean of 59.613 mg/l and standard deviation of 10.972 (Appendix 2). The leachate from the research location (coded M1L3) on the Mallam landfill recorded the highest nitrate of 79mg/l in March and the research location (coded M1L2) recorded the lowest of 34.2 mg/l in March (Appendix 4).

For leachate from Pantang, with the exception of nitrate concentration measured on the sampling point PL5 in February and April, all the other nitrate concentrations were below the EPA guideline of 50mg/l. for leachate from the Mallam landfill site, with the exception of nitrate concentrations measured at M1L2 in march and M1L3 in February, all the other sampling points recorded a concentration above the EPA guideline value. The leachate from the Mallam landfill recorded a higher nitrate over that of Pantang because of the discharge of domestic waste water especially those containing detergents by residents leaving very close to the decommissioned landfill site. An analysis of variance for nitrate showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.10. Nitrite (NO_2)

The nitrite of the leachate from the Pantang landfill ranged from 2.95-6.90 with a mean of 4.741 and standard deviation of 1.165 (Appendix 2). The leachate from the research location (coded PL2) on the Pantang landfill recorded the highest nitrite of 6.9 mg/l in April and the research location (coded PL5) recorded the lowest 2.95 mg/l in February (Appendix 3). The nitrite of the leachate from the Mallam landfill ranged from 0.745 - 2.847 mg/l with a mean of 1.602 mg/l and standard deviation of 0.632.

The leachate from the research location (coded M1L3) on the Mallam landfill recorded the highest nitrite of 2.847 mg/l in March and research the location (coded M1L2) recorded the lowest 0.745 mg/l in April (Appendix 4). The leachate from the Mallam landfill recorded a lower nitrite concentration compared to that of Pantang because of aging An analysis of variance for nitrite showed a significant difference ($P= 0.000 \quad P< 0.05$) between recorded values.

4.1.11. Ammonia (NH_3)

NH_3 of the leachate from the Pantang landfill ranged from 2.5-5.10 with a mean of 3.831 and standard deviation of 0.797 (Appendix 2). The leachate from the research location (coded PL3) on the Pantang landfill recorded the highest ammonia of 5.10 mg/l in February and the research location (coded PL2) recorded the lowest 2.5 mg/l in April (Appendix 3, Figure 4.4). The ammonia of the leachate from the Mallam landfill ranged from 0.58 -1.93 with a mean of 1.169 mg/l and standard deviation of 0.406. The leachate from the research location (coded M1L4) on the Mallam landfill recorded the highest ammonia of 1.93 mg/l in February and the research location (coded M1L1) recorded the lowest 0.58 mg/l in February (Appendix 4, Figure 4.4). The concentration of NH_3 of the leachate from the Pantang and Mallam landfill were higher than the EPA guideline of 1.0mg/l. Adeolu (2011) reported a similar value of 4.5.

The high NH_3 concentration may be due to the deamination of amino acids during the decomposition of organic materials in the waste. The leachate from the Mallam landfill recorded a lower ammonia concentration compared to that of Pantang because of aging and also because it has been decommissioned since ammonia concentration increase with land filling. Ammonia showed a fluctuating trend over the sampling points and this may be due to uneven distribution of organic substances across the sampling points with the exception of PL3, PL4, M1L4 and M1L5 which exhibited decreasing trend with time which may be due to reduction in organic materials with time; and M1L1 and M1L5 which exhibited an increasing trend with time. An analysis of variance for ammonia showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

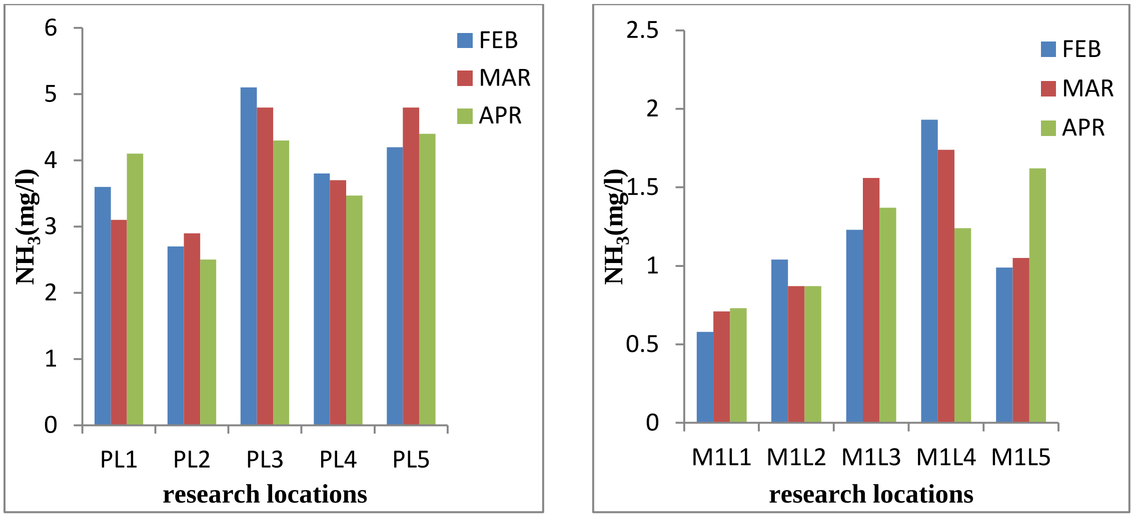


Figure 4.4: Plot of Ammonia (NH_3) for leachate from the Pantang and Mallam landfill sites

4.1.12. Total phosphorus (TP)

Total Phosphorus in the leachate from the Pantang landfill ranged from 5.13-8.94 with a mean of 7.01 and standard deviation of 1.166 (Appendix 2). The leachate from the research location (coded PL3) on the Pantang landfill recorded the highest total phosphorus (TP) of 8.94 mg/l in April and the research location PL2 recorded the lowest 5.13 in April mg/l (Appendix 3). The TP of the leachate from the Mallam landfill ranged from 15.4 -31 mg/l with a mean of 22.373 mg/l and standard deviation of 4.813 (Appendix 2). The leachate from the research location (coded M1L5) on the Mallam landfill recorded the highest total phosphorus (TP) of 31mg/l in April and the research location M1L3 recorded the lowest of 15.4 mg/l in February (Appendix 4).

The total phosphorus of the leachate from the Pantang and Mallam landfills were above the EPA guideline of 2.0 mg/l and this may be due to the presence of organic materials and detergent cans on the landfill site. The concentration of TP showed a fluctuating trend over the sampling period for both landfills. The leachate from the Mallam landfill recorded a higher TP over that of Pantang because of the discharge of domestic waste water especially those containing detergents by residents leaving very close to the decommissioned landfill site. An analysis of variance for total phosphorus showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.13. Sulphate (SO_4)

Sulphate of the leachate from the Pantang landfill ranged from 989-1982 with a mean of 1451.933 and standard deviation of 376.906 (Appendix 2). The leachate from the research location (coded PL1) on the Pantang landfill recorded the highest sulphate of 1982mg/l in February and the research location (coded PL4) recorded the lowest 989mg/l in February (Appendix 3). Sulphate of the leachate from the Mallam landfill ranged from 108 - 290 with a mean of 210.533 mg/l and standard deviation of 53.235. The leachate from the research location (coded M1L2) on the Mallam landfill recorded the highest sulphate of 290mg/l in March and the research location (coded M1L1) recorded the lowest 108 mg/l march (Appendix 4). The concentration of SO_4 of the leachate from the Pantang landfill exceeded the EPA guideline value of 200mg/l for effluent discharge into the environment.

For leachate from the Pantang landfill SO_4 showed a fluctuating trend over the research locations (coded PL2, PL3, and PL4) and this may be due to uneven distribution of organic substances across the sampling points. The sampling points PL1 and PL5 exhibited decreasing and increasing trend respectively. For the leacahte from the Mallam landfill, SO_4 showed fluctuating trend over the research locations M1L1 and M1L2; M1L3 showed a decreasing trend whilst M1L4 and M1L5 showed increasing trend with time. The leachate from the Mallam landfill recorded a lower sulphate concentration compared to that of Pantang because of aging An analysis of variance for sulphate showed a significant difference ($P=0.000$ $P< 0.05$) between recorded values.

4.1.14. Sulphite (SO_3)

Sulphite of the leachate from the Pantang landfill varied from 39-77 mg/l with a mean of 58.16 mg/l and standard deviation of 11.104 (Appendix 2). The leachate from the research location (coded PL3) on the Pantang landfill recorded the highest sulphite of 77mg/l in April and the research location (coded PL5) recorded the lowest 39 mg/l in February (Appendix 3, Figure 4.5). Sulphite of the leachate from the Mallam landfill ranged from 4.30 -8.70 with a mean of 7.434 mg/l and standard deviation of 1.195.

The leachate from the research location (coded M1L1) on the Mallam landfill recorded the highest sulphite of 8.70 mg/l in April and the research location (coded M1L1) recorded the lowest 4.30 mg/l February (Appendix 4, Figure 4.5). The leachate from the Mallam landfill recorded a lower sulphite concentration compared to that of Pantang because of aging. An analysis of variance for sulphite showed a significant difference ($P = 0.000$ $P < 0.05$) between recorded values.

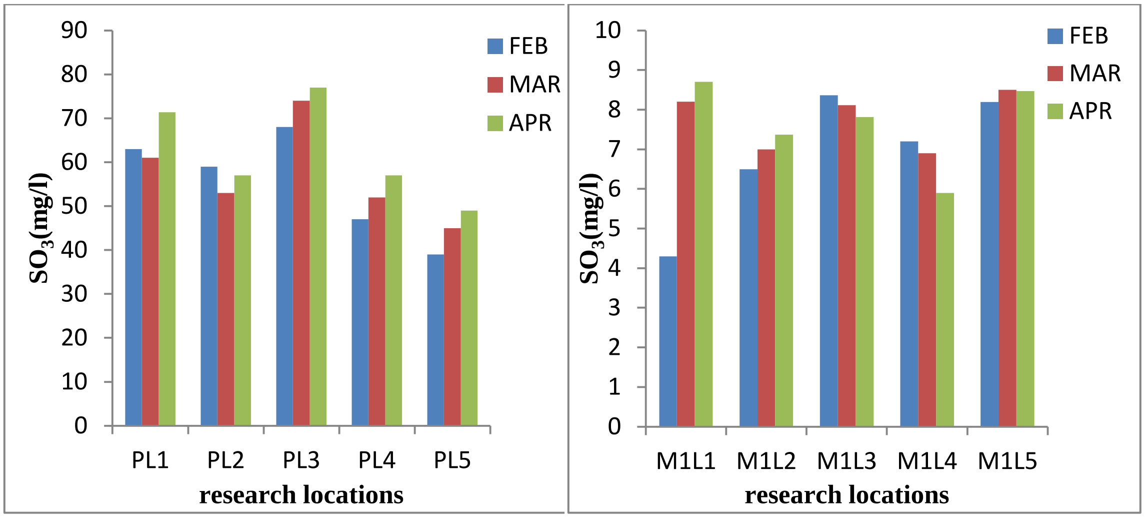


Figure 4.5: Plot of Sulphite (SO_3) for leachate from the Pantang and Mallam landfill sites

4.1.15. Zinc (Zn)

Zinc concentration of leachate from the Pantang landfill ranged from 10.43-23.01 mg/l with a mean of 15.692 mg/l and standard deviation of 3.988 (Appendix 2). The leachate from the research location (coded PL2) on the Pantang landfill recorded the highest Zn of 23.01 mg/l in March and the research location (coded PL5) recorded the lowest concentration of 10.43mg/l in April (Appendix 3). The Zn of the leachate from the Mallam landfill ranged from 0.145 - 0.984 with a mean of 0.549 and standard deviation of 0.237 (Appendix 2). The leachate from the research location (coded M1L1) on the Mallam landfill recorded the highest Zn of 0.984 mg/l in April and the research location (coded M1L2) recorded the lowest 0.145 mg/l in March (Appendix 4). The zinc concentration of the leachate from the Pantang landfill was above the EPA guideline of 5mg/l.

Adeolu (2011) recorded a zinc value of 9.0. The presence of zinc in the leachate is an indication that the landfill receives waste that contains batteries, solders, paints, pigments, alloys, fluorescent tubes and lamps. It also indicates the burning of tyres at the site. The Zn concentration of the leachate from the Mallam landfill was below the EPA guideline value of 5.0mg/l. With the exception of PL4, M1L1, M1L3 and M1L5, the other research locations exhibited fluctuating trend with time. The leachate from the Mallam landfill recorded a lower Zn concentration compared to that of Pantang because of aging. An analysis of variance for Zn showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.16. Copper (Cu)

Copper concentration of leachate from the Pantang landfill ranged from 1.317-2.61 with a mean of 1.978 and standard deviation of 0.461 (Appendix 2). The leachate from the research location (coded PL5) on the Pantang landfill recorded the highest Cu of 2.61 mg/l in April and the research location (coded PL1) recorded the lowest 1.317mg/l in April (Appendix 3). The Cu of the leachate from the Mallam landfill ranged from 0.120 - 0.345 with a mean of 0.224 and standard deviation of 0.064.The leachate from the research location (coded M1L3) on the Mallam landfill recorded the highest Cu of 0.345

mg/l in February and the research location (coded M1L1) recorded the lowest 0.120 mg/l February (Appendix 4).

The Cu concentration of the leachate from the Mallam landfill was below the EPA guideline value of 2.5. The concentration of Copper showed an increasing trend across the research locations M1L1 to M1L5 in February for leachate from Mallam landfill (Appendix 4). Copper concentration of the leachate from the Pantang landfill showed a fluctuating trend across the sampling points and this may be due to uneven distribution of copper contained substances across the sampling points. . The leachate from the Mallam landfill recorded a lower Cu concentration compared to that of Pantang because of aging. An analysis of variance for Cu showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.17. Chromium (Cr)

Chromium of the leachate from the Pantang landfill ranged from 2.73- 5.99 with a mean of 4.386 and standard deviation of 1.143 (Appendix 2). The leachate from the research location (coded PL1) on the Pantang landfill recorded the highest Cr of 5.99 mg/l in February and the research location (coded PL2) recorded the lowest 2.73 mg/l in February (Appendix 3, Figure 4.6). The Cr of the leachate from the Mallam landfill ranged from 0.073 - 0.474 with a mean 0.241 and standard deviation of 1.165.

The leachate from the research location (coded M1L1) on the Mallam landfill recorded the highest Cr of 0.474 mg/l in April and the research location coded M1L5 recorded the lowest 0.073 mg/l April (Appendix 4, Figure 4.6). The mean for the concentrations of chromium in the leachate from the Pantang landfill was above the EPA guideline of 0.5

mg/l and this indicates that the landfill receives waste that contains stainless steel, batteries, solders, paints, pigments, alloys, cement, paper, rubber, fluorescent tubes and lamps. Akiti (2012) reported a range of 0.05 – 0.23 mg/l.

Nyame et al. (2012) reported a range of 2.05 – 18 mg/l for leachate from the Oblogo landfill site. The mean concentration of chromium of the leachate from the Mallam landfill were above the EPA guideline value of 0.5 mg/l and this indicates that the landfill had received waste that contained stainless steel, batteries, solders, paints, pigments, alloys, cement, paper, rubber, fluorescent tubes and lamps before it closure. The concentration of chromium for both sites showed a fluctuating trend across the sampling points and this may be due to uneven distribution of chromium contained substances across the sampling points. The leachate from the Mallam landfill recorded a lower Cr concentration compared to that of Pantang because of aging. An analysis of variance for Cr showed a significant difference (P= 0.000 P< 0.05) between recorded values.

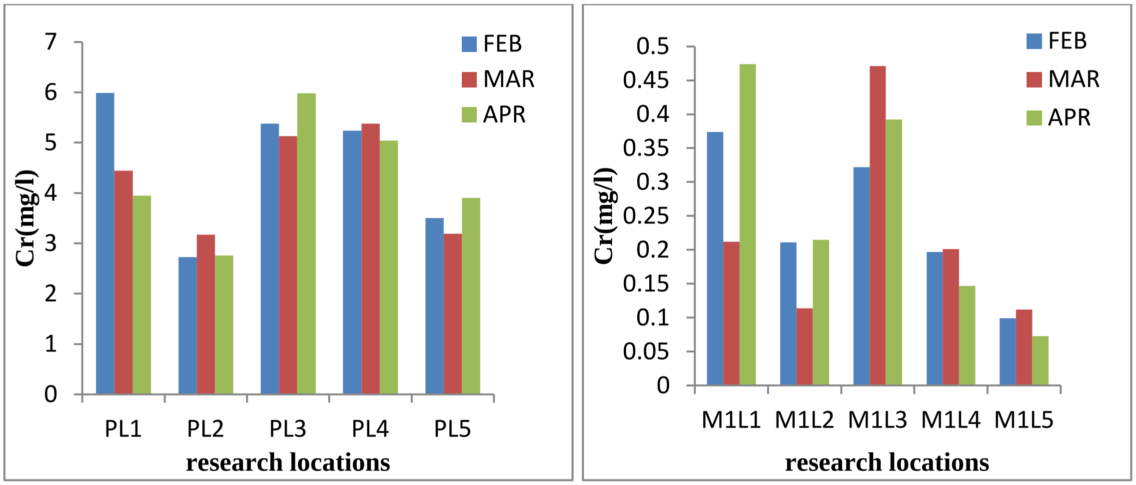


Figure 4.6: Plot of Chromium (Cr) for leachate from the Pantang and Mallam landfill sites

4.1.18. Lead (Pb)

The leachate sampled from Pantang had a lead concentration ranging from 0.267-0.952 with a mean of 0.609 and standard deviation of 0.200 (Appendix 2).The leachate from the research location (coded PL1) on the Pantang landfill recorded the highest Pb of 0.952 mg/l February and the research location (coded PL4) recorded the lowest 0.267 mg/l in March (Appendix 3).

The Pb of the leachate from the Mallam landfill ranged from 0.094 - 0.343 with a mean of 0.186 mg/l and standard deviation of 0.075 (Appendix 2).The leachate from the research location (coded M1L5) on the Mallam landfill recorded the highest Pb of 0.343 mg/l in April and the research location (coded M1L2) recorded the lowest of 0.094 mg/l February. The Lead content of the leachate from the Pantang landfill was higher than the EPA guideline of 0.1.

Said (2012) reported a lead value of 1.55. Aluko et al (2002) reported a mean concentration of lead from1.34-1.639 mg/L. The presence of lead indicates the disposal of lead batteries, chemicals for photograph processing, paints, plastics and lead based paints and pipes at the landfill. For leachate from the Mallam landfill site, all the sampling points recorded a high lead concentration with time with the exception of M1L2 which recorded a lower concentration in February and April. The leachate from the Mallam landfill recorded a lower Pb concentration compared to that of Pantang because of aging. An analysis of variance for Pb showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.19. Manganese (Mn)

Manganese of the leachate from the Pantang landfill ranged from 1.359 -4.51 with a mean of 2.267 and standard deviation of 1.066 (Appendix 2). The leachate from the research location (coded PL5) on the Pantang landfill recorded the highest Mn of 4.51 mg/l in March and the research location coded PL1 recorded the lowest 1.359 mg/l in February (Appendix 3). The Mn of the leachate from the Mallam landfill ranged from 0.110 - 0.793 with a mean of 0.353 and standard deviation of 0.231 (Appendix 2). The leachate from the research location (coded M1L3) on the Mallam landfill recorded the highest Mn of 0.793 mg/l April and the research location coded M1L2 recorded the lowest 0.110 mg/l in March (Appendix 4). The Mn concentration of the leachate from the Pantang landfill was above the EPA guideline of 2.5mg/l. The presence of Mn indicates the disposal of lead batteries, chemicals for photograph processing and paints at the landfill.

The Mn concentration was below the EPA guideline value of 2.5 (Appendix 2). The leachate from the Mallam landfill recorded a lower Mn concentration compared to that of Pantang landfill because of aging. For the leachate from the Mallam landfill, Mn showed a fluctuating trend across the sampling points with time and this may be due to uneven distribution of Mn containing substances across the sampling points. For leachate from the Pantang landfill, the sampling points PL1, PL and PL4 exhibited increasing trend with time. An analysis of variance for Mn showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values

4.1.20. Iron (Fe)

Iron of the leachate from the Pantang landfill ranged from 29.5 -58.3 with an average of 43.19 and standard deviation of 9.070 (Appendix 2). The leachate from the research location (PL3) on the Pantang landfill recorded the highest Fe of 58.3 mg/l in February and the research location coded PL5 recorded the lowest 29.5 mg/l in February (Appendix 3). The Fe of the leachate from the Mallam landfill ranged from 11.62 -18.97 with a mean of 15.734 mg/l and standard deviation of 2.588 (Appendix 2).

The leachate from the research location (coded M1L4) on the Mallam landfill recorded the highest Fe of 18.97 mg/l in April and the research location coded M1L2 recorded the lowest of 11.62 mg/l February (Appendix 4). The concentrations of Fe showed a fluctuating trend with time across the sampling points of both landfills and this may be due to uneven distribution of Fe containing substances across the sampling points.

The leachate from the Mallam landfill recorded a lower Fe concentration compared to that of Pantang because of aging. The high level of Fe in leachate indicates that iron/steel scrap was damped at the site. The oxidation of ferrous Fe to ferric Fe and the foundation of Ferric hydroxide colloids and complexes with humic substances are responsible for the dull colour of leachate (Chu et al 1994). Fe level of 70.62 mg/L was reported by Mor (2006). A mean value of 73.60 was reported by Said (2012). An analysis of variance for Fe showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.21. Cadmium (Cd)

Cd of the leachate from the Pantang landfill ranged from 0.019-0.099 with a mean of 0.077 and standard deviation of 0.020 (Appendix 2). The leachate from the research location (coded PL5) on the Pantang landfill recorded the highest Cd of 0.099 mg/l in April and the research location coded PL1 recorded the lowest 0.019 mg/l march (Appendix 3, Figure 4.7). The Cd of the leachate from the Mallam landfill ranged from 0.014 - 0.097 with a mean of 0.054 and standard deviation of 0.027 (Appendix 2). The leachate from the research location (coded M1L4) on the Mallam landfill recorded the highest Cd of 0.097 mg/l in February and the research location coded M1L2 recorded the lowest 0.014 mg/l in April (Appendix 4, Figure 4.7).

The concentrations of Cd of the leachate from the Pantang and Mallam landfills were observed to be below the EPA guideline of 0.1.with the exception of PL2, M1L2and M1L4 which showed decreasing trend with time ,all the other sampling points for the two landfills exhibited a showed fluctuating trend across the sampling points with time. Azim (2011) observed a similar level of 0.0056mg/l. The leachate from the Mallam landfill recorded a lower Cd concentration compared to that of Pantang because of aging. An analysis of variance for Cd showed a significant difference ($P=0.012$ $P< 0.05$) between recorded values.

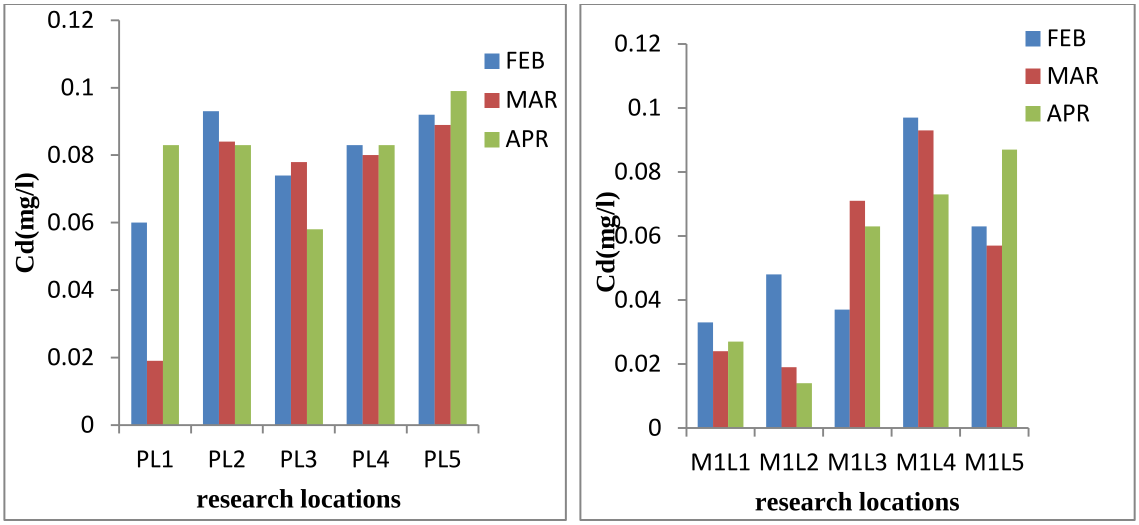


Figure 4.7: Plot of Cadmium (Cd) for leachate from the Pantang and Mallam landfill sites

4.1.22. Nickel (Ni)

Ni of the leachate from the Pantang landfill ranged from 0.169-0.844 with a mean of 0.550 and standard deviation of 0.207 (Appendix 2). The leachate from the research location (coded PL1) on the Pantang landfill recorded the highest Ni of 0.844 mg/l in February and the research location coded PL5 recorded the lowest 0.169 mg/l in February (Appendix 3). The Ni of the leachate from the Mallam landfill ranged from 0.062 - 0.436 with a mean of 0.208 mg/l and standard deviation of 0.118.

The leachate from the research location (coded M1L3) on the Mallam landfill recorded the highest Ni of 0.436 mg/l in February and research location coded M1L2 recorded the lowest 0.062 mg/l April (Appendix 4). The concentration of Ni in the leachate from the Pantang landfill was above the EPA guideline of 0.5mg/l, indicating the disposal of lead batteries, chemicals for photograph processing and paints at the landfill.

The concentration of Ni in the leachate from the Mallam landfill was below the EPA guideline. The leachate from the Mallam landfill recorded a lower sulphite concentration compared to that of Pantang because of aging. An analysis of variance for Ni showed a significant difference ($P= 0.000$ $P< 0.05$) between recorded values.

4.1.23. Leachate pollution indexes (LPI)

The comparison of LPI values for the two landfill sites shows that Pantang leachate (PL) has the highest LPI value of 18.573, whilst Mallam leachate (ML) has the lowest LPI value of 4.799. The high LPI recorded by PL may be due to the fact that the landfill is still operational and is receiving domestic and industrial wastes. Kumar and Alappat (2005) calculated LPI values for two active landfill sites and reported higher LPI (36.4 and 39) than PL (18.573). Kumar and Alappat (2005) calculated LPI value for a closed landfill site and reported higher LPI (15.97) than ML (4.799). The lower LPI value for ML suggests that the landfill leachate is stabilized. Comparing the LPI of both sites to the LPI pollution scale which is 5-100, the leachate from the Mallam dump site had a LPI of 4.799 which is lower than 5 and for that one can say that the leachate is unpolluted and will not pollute the underground water system. The leachate from the Pantang dumpsite may be said to be polluted since the LPI which was 18.573 fell within the LPI pollution scale and leachate may pollute the underground water system.

Table 4.1: LPI for leachates from the Pantang and Mallam landfill sites.

		Pantang leachate			Mallam leachate		
parameters	(Wi)	conc (Ci)	(Pi)	(Wi. Pi)	Conc (ML) (Ci)	(ML) (Pi)	(ML)Aggregation (Wi. Pi)
pH	0.055	8.35	4.97	0.273	8.39	4.99	0.274
TDS(mg/l)	0.050	32923.93	79.02	3.951	3135.7	7.53	0.377
BOD(mg/l)	0.061	192.13	3.95	0.241	160.6	3.29	0.201
COD(mg/l)	0.062	719.13	2.62	0.162	1122.5	4.11	0.255
Zn(mg/l)	0.056	15.69	25.5	1.428	0.241	0.392	0.022
Cu(mg/l)	0.050	1.98	17.24	0.862	0.224	1.95	0.098
Cr(mg/l)	0.064	4.39	25.46	1.629	0.524	3.04	0.195
Pb(mg/l)	0.063	0.609	10.99	0.692	0.186	13.19	0.831
Fe(mg/l)	0.045	43.2	2.6	0.117	15.73	0.948	0.043
Ni(mg/l)	0.052	0.550	19.41	1.009	0.208	7.34	0.382
Total	0.558			10.364			2.678
LPI Value				18.573			4.799

4.2. AIR

4.2.1. Particulate matter (PM_{10})

The PM_{10} of the air sampled from the Pantang landfill ranged from 250.00- 680.56 with a mean of 527.78 and standard deviation of 240.965 (Appendix 5). The highest PM_{10} of 680.56 for air sampled from the Pantang landfill was recorded in the month of April and the least 250.00 in March (Appendix 6, Figure 4.8). The PM_{10} of the air sampled from the Mallam landfill ranged from 13.89 - 27.78 with a mean of 23.15 and standard deviation of 8.019 (Appendix 5). The highest PM_{10} of 27.78 for air sampled from the Mallam landfill was recorded in the month of April and the least 13.89 in March (Appendix 6, Figure 4.8).

The PM_{10} concentration of the air sampled from the Pantang landfill were above the EPA and WHO guidelines. The high PM_{10} concentration may be due to the regular combustion of the waste on the landfill, exhaust of buldozers working on the landfill and dust created as the waste are pushed and compacted. The PM_{10} concentration of the air from the Mallam landfill was below the EPA and WHO guidelines.

The Mallam landfill recorded a low PM_{10} concentration because the landfill has been decommissioned and all activities including burning and compaction is absence. The PM_{10} of both Pantang and Mallam landfills showed a fluctuating trend over sampling period. The low PM_{10} recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for PM_{10} showed a significant difference ($P=0.22$, $P< 0.05$) between recorded values.

4.2.2. Total suspended particles (TSP)

The TSP concentration of the air sampled from the Pantang landfill ranged from 291.67 - 875.00 with a mean of 665.56 standard deviation of 324.576 (Appendix 5). The highest TSP of 875.00 for air sampled from the Pantang landfill was recorded in the month of April and the least 291.67 in March (Appendix 6, Figure 4.8). The TSP concentration of the air sampled from the Mallam landfill ranged from 27.78 - 41.67 with a mean of 37.04 standard deviation of 8.019395 (Appendix 5). The highest TSP concentration of 41.67 for air sampled from the Mallam landfill was recorded in the month of April and the least

27.78 in March (Appendix 6, Figure 4.8). The TSP concentration of the air sampled from the Pantang landfill was above the EPA and WHO guidelines.

The high TSP concentration may be due to the regular combustion of the waste on the landfill, exhaust of buldozers working on the landfill and dust created as the waste are pushed and compacted. The TSP concentration of the air from the Mallam landfill was below the EPA and WHO guidelines. The Mallam landfill recorded a low TSP concentration because the landfill has been decommissioned and all activities including burning and compaction is absent. The TSP concentrations of both Pantang and Mallam landfills showed a fluctuating trend over sampling period. The low TSP concentrations recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for TSP showed a significant difference (P=0.028, P< 0.05) between recorded values.

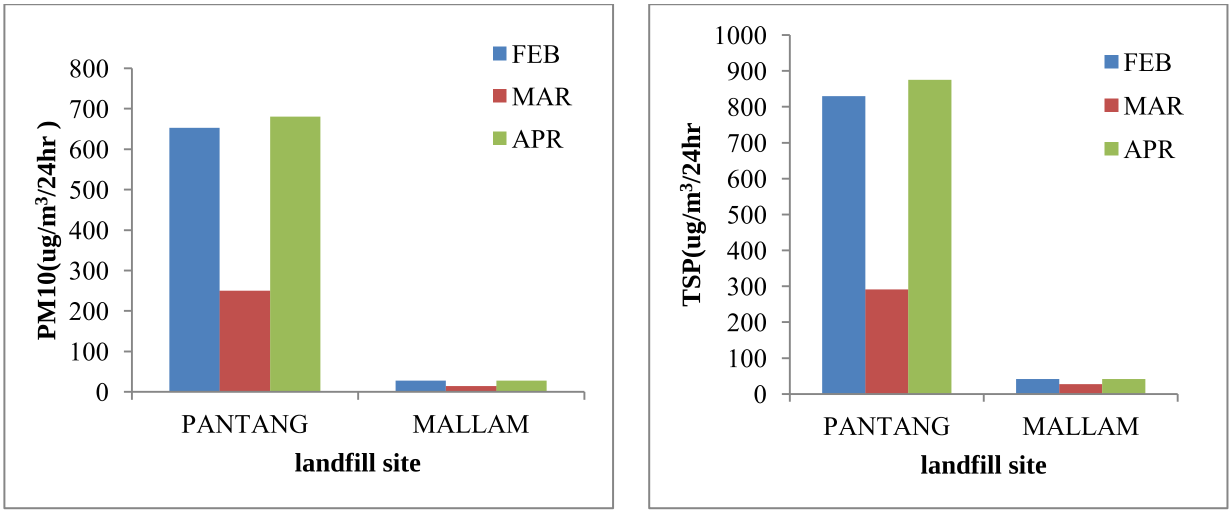


Figure 4.8: Plot of Particulate matter (PM_{10}) and Total suspended particles (TSP) for air sampled from the Pantang and Mallam landfill sites

4.2.3. Carbon monoxide (CO)

The CO concentration of the air sampled from the Pantang landfill ranged from 11000.0 - 20000.0, with a mean of 16433.3 standard deviation of 4781.562 (Appendix 5). The highest CO of 20,000 for air sampled from the Pantang landfill was recorded in the month of February and the least 11000 in March (Appendix 6). CO was not detected in air sampled from the Mallam landfill. The CO concentration of the air sampled from the Pantang landfill was above the EPA and WHO guidelines.

The high CO may be due to regular combustion of the waste on the landfill site, as the Pantang landfill seems to be on fire most of the time. CO was not detected in the air sampled from the Mallam landfill. The low CO concentrations recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for CO showed a significant difference ($P=0.004$, $P< 0.05$) between recorded values.

4.2.4. Ammonia (NH_3)

The NH_3 concentration of the air sampled from the Pantang landfill ranged from 6390-12070, with a mean of 9797 and standard deviation of 3005.007 (Appendix 5). The highest NH3 of 12,070 for air sampled from the Pantang landfill was recorded in the month of February and the least 6390 in March (Appendix 6). The NH_3 concentration of the air sampled from the Mallam landfill ranged from 4970.00 -8520.00, with a mean of 6657.67 and standard deviation of 1781.433786 (Appendix 5).

The highest NH_3 of 8520 for air sampled from Mallam was recorded in the month of February and the least 4970 in March (Appendix 6). The low NH_3 concentrations recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for NH_3 showed an insignificant difference (P=0.195, P > 0.05) between recorded values.

4.2.5. Sulphur dioxide (SO_2)

The SO_2 concentration of the air sampled from the Pantang landfill ranged from 34060.0 - 41920.0 with a mean of 38603.3 and standard deviation of 4071.048 (Appendix 5). The highest SO_2 of 41920 for air sampled from the Pantang landfill was recorded in the month of February and the least 34060 in March. The SO_2concentration of the air sampled from the Mallam landfill ranged from 44540 - 49780 with a mean of 47236.67 and standard deviation of 2623.36 (Appendix 5).

The highest SO_2 concentration of 49780 for the air sampled from the Mallam landfill was recorded in the month of February and the least 44540 in March (Appendix 6, Figure 4.9). The SO_2 concentrations of the air sampled from the Pantang and Mallam landfills were above the EPA and WHO guidelines. The high SO_2 may be due to the anaerobic decomposition of the organic component of the waste disposed. The low SO_2 concentrations recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for SO_2 showed a significant difference (P=0.003, P< 0.05) between recorded values

4.2.6. Zinc (Zn)

The Zn concentration of the air sampled from the Pantang landfill ranged from 0.051 - 0.154, with a mean of 0.089 and standard deviation of 0.057 (Appendix 5). The highest Zn of 0.154 for air sampled from the Pantang landfill was recorded in the month of March and the least 0.051 in February (Appendix 6, Figure 4.9). The Zn concentration of the air sampled from the Mallam landfill ranged from 0.298 -0.359, with a mean of 0.334 and standard deviation of 0.032130 (Appendix 5). The highest Zn concentration of 0.359 for air sampled from Mallam was recorded in the month of April and the least 0.298 in February (Appendix 6, Figure 4.9). An analysis of variance for Zn showed an insignificant difference (P=0.612, P > 0.05) between recorded values.

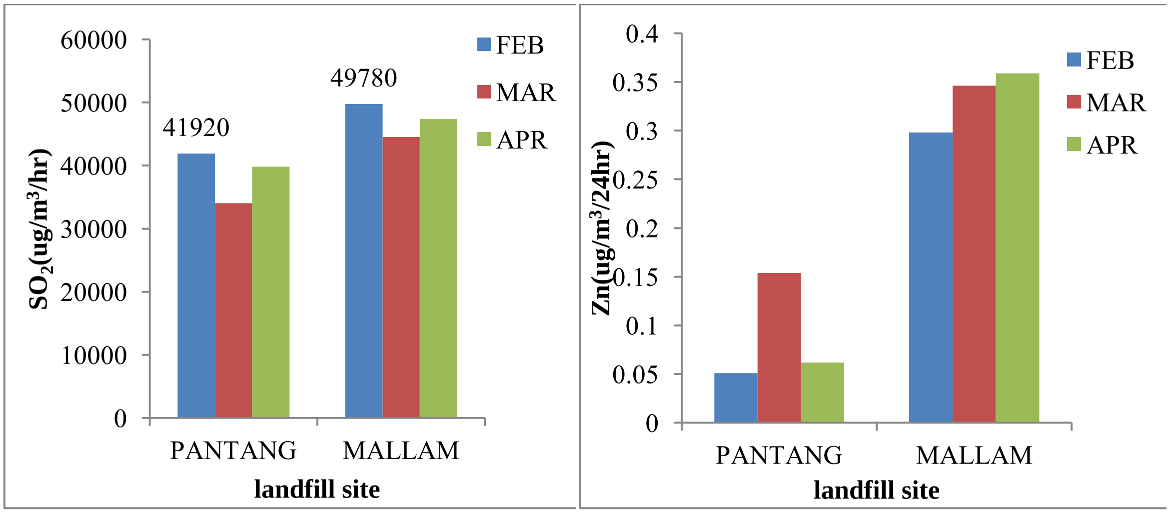


Figure 4.9: Plot of Sulphur dioxide (SO_2) and Zinc (Zn) for air sampled from the Pantang and Mallam landfill sites

4.2.7. Nickel (Ni)

The Ni concentration of the air sampled from the Pantang landfill ranged from0.048-0.053 with a mean of 0.051 and standard deviation of 0.003 (Appendix 5). The highest Ni of 0.053 for air sampled from the Pantang landfill was recorded in the month of March and the least 0.048 in February (Appendix 6). The Ni concentration of the air sampled from the Mallam landfill ranged from 0.006 -0.103 with a mean of 0.068 and standard deviation of 0.054 (Appendix 5).

The highest Ni concentration of 0.103 for air sampled from the Mallam landfill was recorded in the month of March and the least 0.006 in February (Appendix 6). The Ni concentrations of the air sampled from the Pantang and Mallam landfills were below the WHO guideline. An analysis of variance for Ni showed an insignificant difference ($P=0.783$, $P > 0.05$) between recorded values.

4.2.8. Copper (Cu)

The Cu concentration of the air sampled from the Pantang landfill ranged from 0.005 - 0.092, with a mean of 0.038 and standard deviation of 0.047 (Appendix 5). The highest Cu concentration of 0.092 for air sampled from the Pantang landfill was recorded in the month of April and the least 0.005 in March (Appendix 6). The Cu concentration of the air sampled from the Mallam landfill ranged from 0.020 -0.043, with a mean of 0.0293 and standard deviation of 0.012 (Appendix 5).

The highest Cu concentration of 0.043 for air sampled from Mallam was recorded in the month of April and the least 0.020 in March (Appendix 6). The low Cu concentrations recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for Cu showed an insignificant difference ($P=0.481$, $P > 0.05$) between recorded values.

4.2.9. Manganese (Mn)

The Mn concentration of the air sampled from the Pantang landfill ranged from 0.009 - 0.052, with a mean of 0.035 and standard deviation of 0.023 (Appendix 5). The highest Mn of 0.052 for air sampled from the Pantang landfill was recorded in the month of February and the least 0.009 in March (Appendix 6, Figure 4.10).

The Mn concentration of the air sampled from the Mallam landfill ranged from 0.035-0.059, with a mean of 0.047 and standard deviation of 0.012 (Appendix 5). The highest Mn concentration of 0.059 for air sampled from Mallam was recorded in the month of March and the least 0.035 in April (Appendix 6, Figure 4.10). The Mn concentrations of the air sampled from the Pantang landfill and Mallam landfills were below the WHO guideline. An analysis of variance for Mn showed an insignificant difference ($P=0.875$, $P > 0.05$) between recorded values.

4.2.10. Chromium (Cr)

The Cr concentration of the air sampled from the Pantang landfill ranged from 0.045 - 0.194, with a mean of 0.125 and standard deviation of 0.102 (Appendix 5). The highest Cr concentration of 0.194 for air sampled from the Pantang landfill was recorded in the month of February and the least 0.045 in March (Appendix 6, Figure 4.10). The Cr concentration of the air sampled from the Mallam landfill ranged from 0.036 -0.099 with a mean of 0.069 and standard deviation of 0.032 (Appendix 5).

The highest Cr concentration of 0.099 for air sampled from Mallam was recorded in the month of March and the least 0.036 in February (Appendix 6, Figure 4.10). Cr An analysis of variance for Cr showed an insignificant difference (P=0.130 P > 0.05) between recorded values.

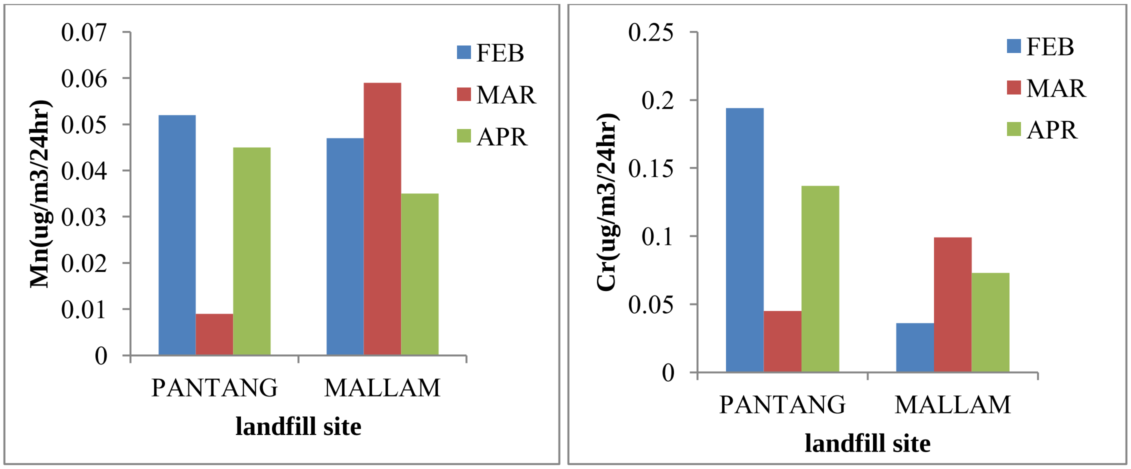


Figure 4.10: Plot of Manganese (Mn) and Chromium (Cr) for air sampled from the Pantang and Mallam landfill sites

4.2.11. Cadmium (Cd)

The Cd concentration of the air sampled from the Pantang landfill ranged from 0.022 - 0.045, with a mean of 0.035 and standard deviation of 0.012 (Appendix 5). The highest Cd of 0.045 for air sampled from the Pantang landfill was recorded in the month of March and the least 0.022 in February (Appendix 6, Figure 4.11). The Cd concentration of the air sampled from the Mallam landfill ranged from 0.005 -0.028, with a mean of 0.017 and standard deviation of 0.012 (Appendix 5).

The highest Cd concentration of 0.028 for air sampled from Mallam was recorded in the month of March and the least 0.005 in February (Appendix 6, Figure 4.11). The Cd concentrations of the air sampled from the Pantang and Mallam landfills were below the WHO guideline. An analysis of variance for Cd showed a significant difference ($P=0.000 P< 0.05$) between recorded value.

4.2.12. Lead (Pb)

The Pb concentration of the air sampled from the Pantang landfill ranged from 73.73 - 86.53 with a mean of 79.89 and standard deviation of 6.413 (Appendix 5). The highest Pb of 86.53 for air sampled from the Pantang landfill was recorded in the month of April and the least 73.73 in February. The Pb concentration of the air sampled from the Mallam landfill ranged from 21.90 - 29.50, with a mean of 25.63 and standard deviation of 3.802 (Appendix 5). The highest Pb of 29.50 for air sampled from Mallam was recorded in the month of March and the least 21.90 in February (Appendix 6, Figure 4.11).

The Pb of the air sampled from the Pantang landfill was above the EPA and WHO guidelines and this indicate the presence and combustion of materials such as lead batteries, chemicals for photograph processing, paints, plastics, paper etc. The Pb of the air from the Mallam landfill was above the EPA and WHO guidelines and this may be due to vehicular movement in the landfill vicinity. An analysis of variance for Pb showed an insignificant difference ($P=0.076$, $P > 0.05$) between recorded values.

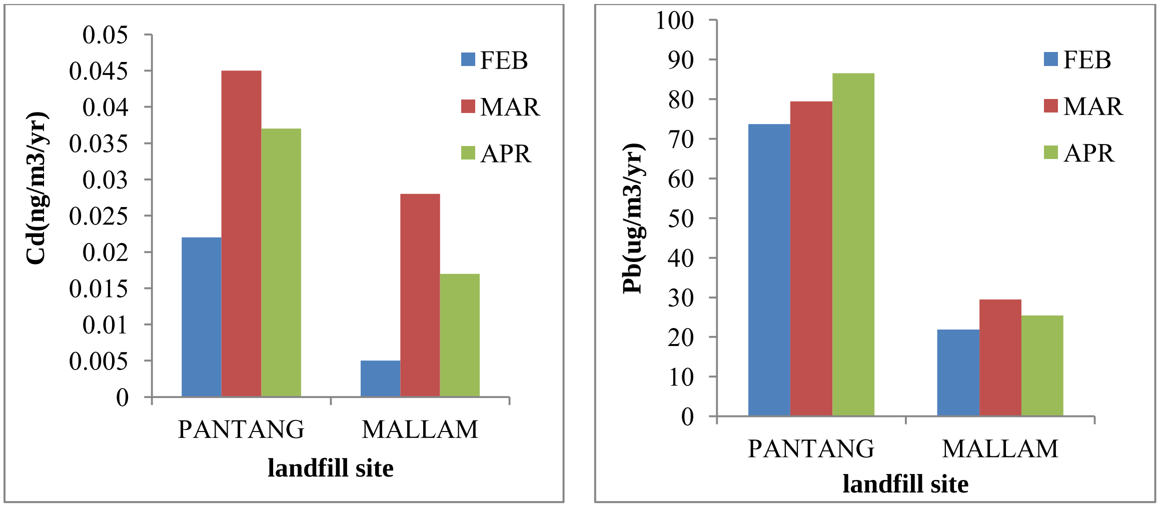


Figure 4.11: Plot of Cadmium (Cd) and Lead (Pb) for air sampled from the Pantang and Mallam landfill sites

4.2.13. Iron (Fe)

The Fe concentration of the air sampled from the Pantang landfill ranged from1.308 - 3.830, with a mean of 2.503 and standard deviation of 1.266 (Appendix 5). The highest Fe of 3.830 for air sampled from the Pantang landfill was recorded in the month of February and the least 1.308 in March. The Fe concentration of the air sampled from the Mallam landfill ranged from 0.472 -0.909, with a mean of 0.735 and standard deviation of 0.232 (Appendix 5). The highest Fe of 0.909 for air sampled from Mallam was recorded in the month of February and the least 0.472 in March.

The low Fe concentrations recorded in March may be due to the rainfall that was experience on both sites before and on the day of sampling which might have cleared the atmosphere of any suspended materials. An analysis of variance for Fe showed an insignificant difference (P= 0.133 P > 0.05) between recorded values.

4.2.14 Air quality index

The Air Quality Index (AQI) 598.8 of the Pantang landfill was higher than that of the Mallam dumpsite which was recorded as 28.9 (Table 4.2). The Mallam landfill site recorded a lower index probably because it has been decommissioned and is no more receiving Waste. The Pantang site might have recorded a higher index because it is still active and receiving waster and more over there is constant burning at the site. From the Air Quality Index (AQI) scale, the air quality at the decommissioned Mallam landfill site may be categorised as light air pollution whilst at the Pantang landfill site may be categorised as severe air pollution.

Table 4.2: Air quality index for the Pantang and Mallam sites

	Pantang air		Mallam air	
	PM10	TSP	PM10	TSP
MEAN	527.78	665.56	23.15	37.04
EPA	70	150	70	150
Air Quality Index	598.8		28.9	

4.3. Soil

4.3.1. pH

The pH ranged from 8.97 to 8.07 with a mean of 8.55 and standard deviation of 0.26 (Table 4.3). The research section (coded PS1) on the Pantang landfill recorded the highest pH of 8.97 pH units in February and the research section (coded PS2) on the Pantang landfill recorded the lowest pH of 8.07 in March (Appendix 7). The pH obtained of the soil was higher than that of the control site and this might be due to the flow of the high pH leachate on the soil surface and percolation through the soil. With the exception of the research section (coded PS3) which showed an increasing trend with time throughout the sampling period, all the other sampling points exhibited fluctuating trends over time.

4.3.2. Percentage organic carbon (%OC)

Organic carbon ranged from 2.46- 6.18 % with a mean of 4.75%and standard deviation of 1.26 (Table 4.3). The research section (coded PS5) on the Pantang landfill recorded the highest percentage organic carbon (%OC) of 6.18% in March and the research section (coded PS1) on the Pantang landfill recorded the lowest percentage organic carbon (%OC) of 2.46 in March (Appendix 7). The organic carbon content of the soil was higher than that of the control site and this may be due to the organic materials in the waste dumped at the landfill. The concentration of organic carbon for all the sampling sections showed a fluctuating trend indicating that the amount and rate of decomposition of organic waste varied from one sampling section to the other and with time.

4.3.3. Percentage organic matter (%OM)

Organic matter varied from 4.24 -10.66 mg/kg with a mean of 7.52 mg/kg and standard deviation of 2.28 (Table 4.3). The research section (coded PS3) on the Pantang landfill recorded the highest organic matter content of 10.66mg/kg in March. The lowest organic matter content was measured at the research section (coded PS1) on the Pantang landfill with a value of 4.24 mg/kg in March (Figure 4.12). The organic matter content of the soil was higher than that of the control site and this may be due to the organic materials in the waste dumped at the landfill.

The organic matter concentrations showed a fluctuating trend for all the sampling points throughout the sampling period indicating that the amount and rate of decomposition of organic waste varied in the site. There was an increasing trend in February across the sampling sections with research location PS1- PS4 and decreasing trend from PS4 -PS5 and also in March, there was also an increasing trend from PS1-PS3 and decreasing trend from PS3-PS5.

4.3.4. Electrical conductivity (EC)

EC ranged from 710-1650 µS/cm with a mean of 1169.07 µS/cm and standard deviation of 304.15 (Table 4.3). The research section (coded PS1) on the Pantang landfill recorded the highest EC of 1650 µS/cm in the month of February which may be due to the high nitrate content at that section because of low rainfall and PS3 measured the lowest EC of 710 µS/cm in April (Figure 4.12).

The EC of the soil was higher than that of the control site and this may be due to the organic materials in the waste dumped at the landfill. The research sections (coded PS2 and PS5) showed an increasing trend with time which may be due to increased percolation whilst the other sections exhibited fluctuating trend with time.

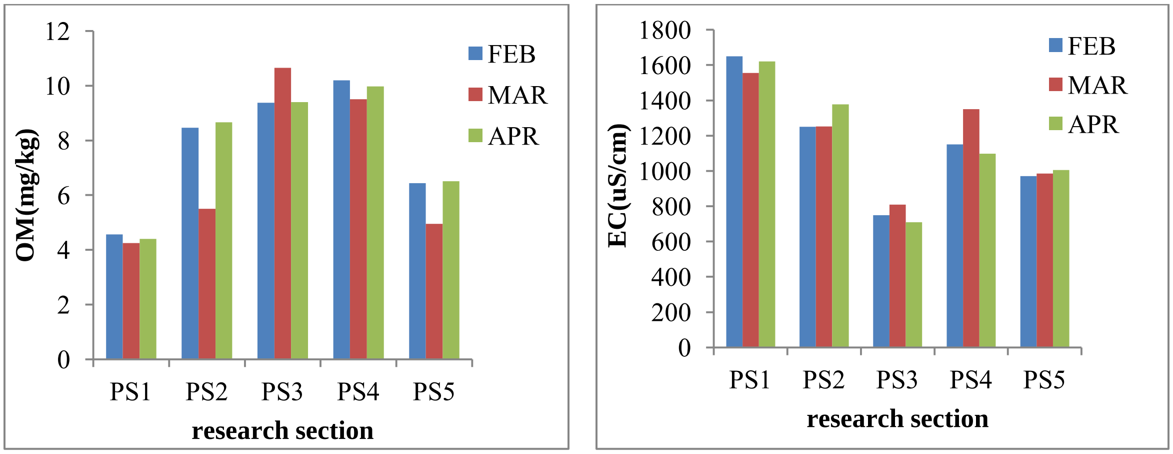


Figure 4.12: Plot of Percentage organic matter (%OM) and Electrical conductivity (EC) for soil sampled from the Pantang landfill site

4.3.5. Nitrate (NO_3)

Nitrate ranged from 802-4795.20mg/kg with a mean of 1906.12mg/kg and standard deviation of 1404.36 (Table 4.3). The highest nitrate content was measured at the research section (coded PS1) with a value of 4795.20 mg/kg in February and the least measured at the research section (coded PS5) with a value of 802 mg/kg in February (Appendix 7). The nitrate concentration of the soil was higher than that of the control site and this may be due to the organic materials in the waste dumped at the landfill. The sampling sections exhibited fluctuating trend with time which indicates that the amount and rate of decomposition of organic waste varied from one sampling section to the other and with time.

4.3.6. Ammonia (NH_3)

Ammonia ranged from 491.20-932 mg/kg with a mean 736.11mg/kg and standard deviation of 148.168 (Table 4.3). The research section (coded PS1) on the Pantang landfill recorded the highest ammonia concentration of 932 mg/kg in March and the least at PS4 measured 491.20 mg/kg in March (Appendix 7). The Ammonia concentration of the soil was higher than that of the control site and this may be due to the organic materials in the waste dumped at the landfill. The sampling sections exhibited fluctuating trend with time which indicates that the amount and rate of decomposition of organic waste varied from one sampling section to the other and with time with the exception of PS2 which exhibited a decreasing trend.

4.3.7. Manganese (Mn)

The Manganese ranged from 199.30 to 1693 mg/kg with a mean of 651.40 and standard deviation of 506.11 (Table 4.3). The highest manganese content was measured at the research section (coded PS3) with a value of 1693 mg/kg in April and PS2 recorded the least Manganese content with a value of 199.30 mg/kg in April (Appendix 7, Figure 4.13). Generally, PS3 has the highest Mn content which may be due to increased amount of Mn containing substances at the section. All sections showed fluctuating trend with time except PS1 which exhibited an increasing trend. The Manganese content of the soil was lower than the world average shale value reported by Turekian and Wedepohl (1961).

4.3.8. Copper (Cu)

Copper ranged from 540.70 to 4737 mg/kg with a mean of 2568.76 and standard deviation of 1412.94 (Table 4.3). The highest copper content was recorded at the research section (coded PS4) with a value of 4737 mg/kg in March and the least concentration of 540.70 mg/kg was obtained by PS2 in February (Appendix 7, Figure 4.13). All sections showed fluctuating trend with time except PS1 which exhibited a decreasing trend. Copper was higher than the world average shale value reported by Turekian and Wedepohl (1961) and this may be due to the high content of batteries, fluorescent tube, paint cans etc in the disposed of waste.

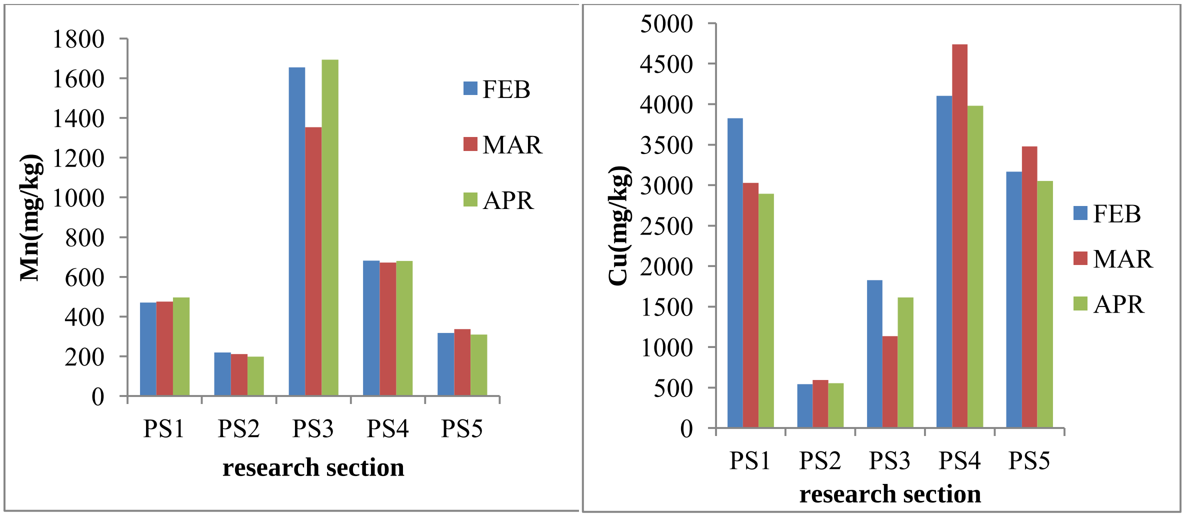


Figure 4.13: Plot of Manganese (Mn) and Copper (Cu) for soil sampled from the Pantang landfill site

4.3.9. Zinc (Zn)

Zinc ranged from 581 to 3141 mg/kg with a mean of 2332.87 and standard deviation of 809.74 (Table 4.3). The highest zinc concentration of 3141 mg/kg was recorded by the soil sampled at the research section (coded PS4) in the month of April and the least at PS5 with a value of 581 mg/kg in the month of April (Appendix 7). Zinc was higher than the world average shale value reported by Turekian and Wedepohl (1961) and this may be due to the high content of batteries, fluorescent tube, paint cans etc in the disposed of waste. All sections showed fluctuating trend with time except PS4 which exhibited an increasing trend.

4.3.10. Iron (Fe)

Iron ranged from 3136 to 5945 mg/kg with a mean of4552.07and standard deviation of917.88 (Table 4.3). The research section (coded PS3) had the highest Iron content of 5945mg/l in March and the section PS5 recorded the lowest concentration of 3136 mg/kg in March (Appendix 7). Iron was lower than the world average shale value reported by Turekian and Wedepohl (1961). All sections showed fluctuating trend with time.

4.3.11. Chromium (Cr)

Chromium ranged from 28.3 to 91.1mg/kg with a mean of 58.394 and standard deviation of21.474 (Table 4.3). The highest chromium content was measured at the research section (coded PS3) with a value of 91.1 mg/kg in February and the least at PS2 with a value of 28.3 mg/kg in March (Appendix 7, Figure 4.14). Chromium was lower than the world average shale value reported by Turekian and Wedepohl (1961). All sampling sections showed fluctuating trend with time.

4.3.12. Lead (Pb)

Lead ranged from 27.8 to 103.1 mg/kg with a mean of 62.33 and standard deviation of 24.03 (Table 4.3). The highest lead concentration was measured at the research section (coded PS1) with a value of 103.10mg/kg in March and the least at PS3 measured 27.80mg/kg in March (Figure 4.14). Lead was higher than the world average shale value reported by Turekian and Wedepohl (1961) and this may be due to the high content of batteries, fluorescent tube, paint cans etc in the disposed of waste. All sections showed fluctuating trend with time except PS4 which exhibited an increasing trend.

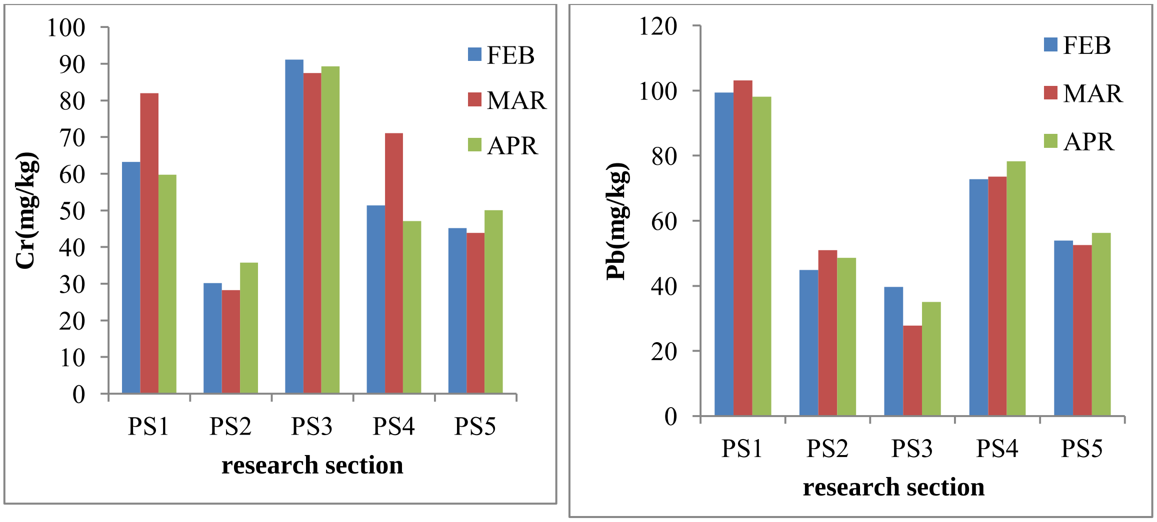


Figure 4.14: Plot of Chromium (Cr) and Lead (Pb))for soil sampled from the Pantang landfill site

4.3.13. Cadmium (Cd)

Cadmium ranged from 3.50 to 13.10 mg/kg with a mean of 8.24 and standard deviation of 2.86 (Table 4.3). The research section (coded PS4) on the Pantang landfill recorded the lowest cadmium concentration of 3.50 mg/kg march and PS3 measured the highest concentration of 13.10 mg/kg in March (Appendix 7). Cadmium was higher than the world average shale value reported by Turekian and Wedepohl (1961) and this may be due to the high content of batteries, fluorescent tube, paint cans etc in the disposed waste. All sampling sections showed fluctuating trend with time

4.3.14. Nickel (Ni)

Nickel varied from 4.5 to21.3 mg/kg with a mean of 14.29 and standard deviation of 5.095 (Table 4.3). The research section (coded PS4) on the Pantang landfill recorded the highest nickel content of 21.3 mg/kg in April and PS2 measured the least value of 4.5 mg/kg April (Appendix 7). Nickel was lower than the world average shale value reported by Turekian and Wedepohl (1961). All sampling sections showed fluctuating trend with time.

Table 4.3: Basic statistical analysis of parameters determined on soil from the Pantang landfill site

PARAMETERS	RANGE	MEAN	STD DEV	CTL	AVERAGE SHALE
PH	8.07-8.97	8.55	0.26	8.01	
OC (%)	2.46-6.18	4.75	1.26	3.18	
OM(mg/kg)	4.24-10.66	7.52	2.284	5.48	
EC(μS/cm)	710.00-1650.00	1169.07	2.284	283.00	
Nitrate (mg/kg)	802.00-4795.20	1906.12	304.15	271.00	
Ammonia (mg/kg)	491.20-932.00	736.11	148.17	163.00	
Mn(mg/kg)	199.30-1693.00	651.40	506.11		850.00
Cu(mg/kg)	540.70-4737.00	2568.76	1412.94		45.00
Zn (mg/kg)	581.00-3141.00	2332.87	809.74		95.00
Fe(mg/kg)	3136.00-5945.00	4552.07	917.88		47,200.00
Cr(mg/kg)	28.30-91.10	58.39	21.47		90.00
Pb(mg/kg)	27.80-103.10	62.33	24.03		20.00
Cd(mg/kg)	3.50-13.10	8.24	2.86		0.30
Ni(mg/kg)	4.50-21.3	14.29	5.09		68.00

Data for average shale value reported by Turekian and Wedepohl (1961)

4.3.15. Contamination factor and pollution load index

The contamination factor (CF) values of the metals Mn, Cr, Fe and Ni calculated above were lower than 1 (Table 4.4). But, CF values for the metals Pb, Cu, Zn and Cd were greater than 1 and this may be attributed to the influence of the waste deposited on the landfill site. The Pollution Load Index value (Table 4.4) was found to be greater than 1in the studied area and this confirms that the soil of the landfill is polluted. Runoff and wind deposits of the soil would pollute surrounding environment with the dangerous heavy metals Pb and Cd.

Table 4.4: Contamination factor and pollution load index on soil from the Pantang landfill site.

	C metal	Background value	CF
Chromium	58.39	90	0.65
Manganese	651.40	850	0.77
Iron	4552.07	47,200	0.096
Nickel	14.29	68	0.21
Copper	2568.76	45	57.08
Zinc	2332.87	95	24.56
Cadmium	8.24	0.3	27.47
Lead	62.33	20	3.12
Pollution Load Index (PLI)			2.429

4.4. GROUNDWATER

4.4.1. pH

The pH of groundwater sampled from the well coded PG1 ranged from 6.84-7.4 pH units with a mean of 7.180 pH units and standard deviation of 0.299 (Table 4.5). The highest pH of 7.40 for the research location (coded PG1) on the Pantang landfill was recorded in the month of April and the least 6.84 in the month of March (Tables 4.6). pH of groundwater sampled from the well coded PG2 ranged from 7.56-8.6 pH units with a mean of 8.060 pH units and standard deviation of 0.521 (Table 4.5). The highest pH of 8.6 for the research location (coded PG2) on the Pantang landfill was recorded in the month of April and the least 7.56 in the month of March (Tables 4.6).

The pH of PG1 fell within the WHO guideline of 6.5-8.5 for drinking water. Mor et al (2006) reported a pH range of 6.75 -7.56 for groundwater in wells located near a landfill at Malang, Indonesia. Mor et al (2006) reported a pH range of 7.02-7.15. Addo et al (2013) reported a pH ranged of 4.9 to 7.6 with a mean value of 6.1 pH units in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana**.** Tay and Kortatsi (2007) reported pH range of 4.37–7.40 in the Densu Basin. Nkansah and Ephraim (2009) reported a mean of 6.0 in the Bosomtwi-Atwima-Kwanwoma District. Tay (2008) reported 5.4-7.06 pH range with a mean of 6.42 pH unit in the same geographical area.

Groundwater with pH lower than 6.5 is considered acidic for human use. The mean pH of PG2 was in the WHO guideline for drinking water. The low pH for both wells in March may be due to rainfall which leached out dissolved organic matter thus lowering the acidity of the water. Both wells exhibited a fluctuating trend with sampling period. The high pH at PG2 compared to PG1 may be due to it closeness to the landfill which allows the seepage of leachate into the groundwater.

4.4.2. Total suspended solids (TSS)

The total suspended solids (TSS) of groundwater sampled at PG1 was in the range of 4.7-5.0 mg/l with a mean of 4.867mg/land standard deviation of 0.153 (Table 4.5). The TSS fell within the WHO guideline. The highest TSS of 5.0mg/l for the research location (coded PG1) on the Pantang landfill was recorded in the month of March and the least 4.7mg/l in the month of February (Tables 4.6, Figure 4.15). TSS measured at the research location (coded PG2) on the Pantang landfill was in the range of 60.2-67mg/l with a mean of 63.067mg/l and standard deviation of 3.523. The highest TSS of 67mg/l for PG2 was recorded in the month of March and the least 60.2mg/l in the month of February. The TSS recorded for PG1 fell within the WHO guideline of 5 mg/l.

The low TSS in the groundwater PG1 may be due to the filtration of any suspended material by the soil interface which serves as a natural filter. The high TSS recorded in March (Tables 4.6, Figure 4.15) for both wells may be attributed to rainfall which caused a disturbance in the water thus making substances in the water to be suspended. Both wells exhibited a fluctuating trend with sampling period. The high TSS at PG2 compared to PG1 may be due to it closeness to the landfill which allows the seepage of leachate into the groundwater. Addo et al. (2013) reported a TSS ranged of 10.0 – 141.0 mg/L with a mean of 46.2 mg/L in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana**.**

4.4.3. Turbidity (Tur)

The turbidity of groundwater sampled from the research location (coded PG1) ranged from 3.1 - 4.6 NTU with a mean of 4.00 NTU and standard deviation of 0.794 (Table 4.5). The highest turbidity of 4.6 NTU for the research location (coded PG1) on the Pantang landfill was recorded in the month of March and the least 3.1 NTU in the month of February (Tables 4.6, Figure 4.15). Turbidity of the research location (coded PG2) on the Pantang landfill ranged from 31.4-35 NTU with a mean of 33.700 NTU and standard deviation of 1.997. The highest turbidity of 35NTU for PG2 was recorded in the month of March and the least 31.4 NTU in the month of February. The well PG1 recorded turbidity values below the WHO guideline value of 5 NTU whilst PG2 recorded a value above the WHO guideline.

The high turbidity recorded in March (Tables 4.6, Figure 4.15) for both wells may be due to the high TSS recorded for that month. Addo et al. (2013) reported a turbidity range of 11.1 to 198.0 NTU with a mean of 57.96 NTU in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana. Schafer et al. (2010) found turbidities in the range of 2–266 NTU in most borehole water throughout Ghana. The high turbidity recorded may be due to the presence of large particle of OM and dissolved solids. The high turbidity at PG2 may be due to it closeness to the landfill which allows the seepage of leachate into the groundwater. Both wells exhibited a fluctuating trend with sampling period.

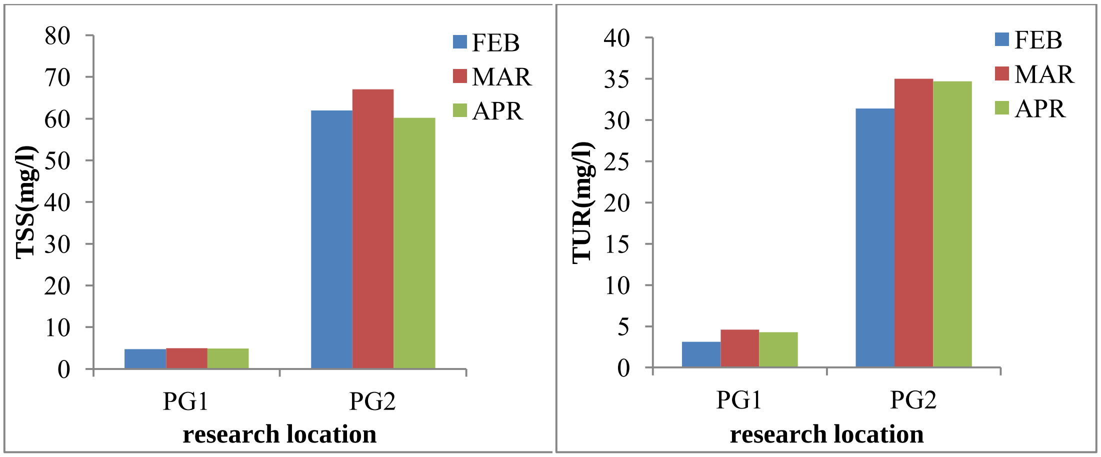


Figure 4.15: Plot of Total suspended solids (TSS) and Turbidity (Tur) for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site

4.4.4. Electrical conductivity (EC)

The electrical conductivity of groundwater sampled from the research location (coded PG1) ranged from 1081 to 1475µS/cm with a mean of 1337.667µS/cm and standard deviation of 222.462 (Table 4.5). The highest EC of 1475µS/cm for PG1 was recorded in the month of March and the least 1081µS/cm in the month of February (Tables 4.6). Electrical conductivity of the research location (coded PG2) on the Pantang landfill ranged from 3077-3999µS/cm with a mean of 3640.667µS/cm and standard deviation of 494.108. The highest EC of 3999µS/cm for the research location (coded PG2) on the Pantang landfill was recorded in the month of February and the least 3077µS/cm in the month of March. The Electrical conductivity for both wells exceeded the WHO guideline limit. Mor et al (2006) reported of an electrical conductivity range of 617-3620μS/cm.

Addo et al (2013) reported conductivity ranged of 377- 12,228 μS/cm with a mean value of 2969 μS/cm in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana. The high electrical conductivity recorded may be attributed to the relatively high salt content dissolved in the water. For PG1 March recorded, the highest EC which is a reflection of the high TDS and TSS recorded in that month. The high EC at PG2 may be due to it closeness to the landfill making it more likely to receive pollutants. Both wells exhibited a fluctuating trend with sampling period.

4.4.5. Total dissolved solids (TDS)

The total dissolved solids (TDS) of groundwater sampled from the research location (coded PG1) ranged from 1140-1648 mg/l with a mean of 1379 mg/l and standard deviation of 255.325 (Table 4.5) for PG1. The highest TDS of 1648mg/l for the research location (coded PG1) on the Pantang landfill was recorded in the month of March and the least 1140mg/l in the month of February (Tables 4.6). TDS of the research location (coded PG2) ranged from 1998-2560mg/l with a mean of 2310.667 mg/l and standard deviation of 286.303. The highest TDS of 2560mg/l for PG2 was recorded in the month of February and the least 1998mg/l in the month of March.

The TDS for both wells exceeded the WHO guideline limit and this may be attributed to the seepage of leachate into the groundwater. The high TDS at PG2 may be due to it closeness to the landfill. Both wells exhibited a fluctuating trend with sampling period.

Mor et al (2006) reported a trend were TDS recorded a range of 302-2208 mg/l. Adeolu et al (2011) also measured a TDS range of 160-5310 mg/l. Addo et al (2013) reported a TDS range of 187 to 8990 mg/L with a mean level of 1883 mg/L in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana.

4.4.6. Biological oxygen demand (BOD)

The Biological oxygen demand (BOD) of groundwater sampled from the research location (coded PG1) ranged from 51-88.7 mg/l with a mean of 67.567 mg/l and standard deviation of 19.260 (Table 4.5). The highest BOD of 88.7 mg/l for PG1 on the Pantang landfill was recorded in the month of March and the least 51 mg/l in the month of April (Tables 4.6, Figure 4.16). BOD of PG2 ranged from 98-112mg/l with a mean of 106.333 mg/l and standard deviation of 7.371.

The highest BOD of 112 mg/l for PG2 was recorded in the month of April and the least 98 mg/l in the month of March (Tables 4.6, Figure 4.16). The BOD for both wells fell below the WHO guideline limit and this may be attributed to the seepage of leachate into the groundwater. Both wells exhibited a fluctuating trend with sampling period. The high BOD at the research location (coded PG2) may be due to it closeness to the landfill thus making it to receive more pollutants compared to PG1.

4.4.7. Chemical oxygen demand (COD)

The Chemical oxygen demand (COD) of groundwater sampled from the research location (coded PG1) ranged from 102-106 mg/l with a mean of 104.333 mg/l and standard deviation of 2.082 (Table 4.5). The highest COD of 106mg/l for the research location (coded PG1) on the Pantang landfill was recorded in the month of March and the least 102mg/l in the month of April (Tables 4.6, Figure 4.16) The COD of the research location (coded PG2) ranged from 350-395mg/l with a mean of 370.000mg/l and standard deviation of 22.913.

The highest COD of 395mg/l for PG was recorded in the month of April and the least 350mg/l in the month of March (Tables 4.6, Figure 4.16). The COD concentrations for both wells were above the WHO guideline and this may be an indication of seepage of leachate into the groundwater system. Both wells exhibited a fluctuating trend with sampling period. The high COD at the research location coded PG2 may be due to it closeness to the landfill thus making it to receive more pollutants compared to PG1.

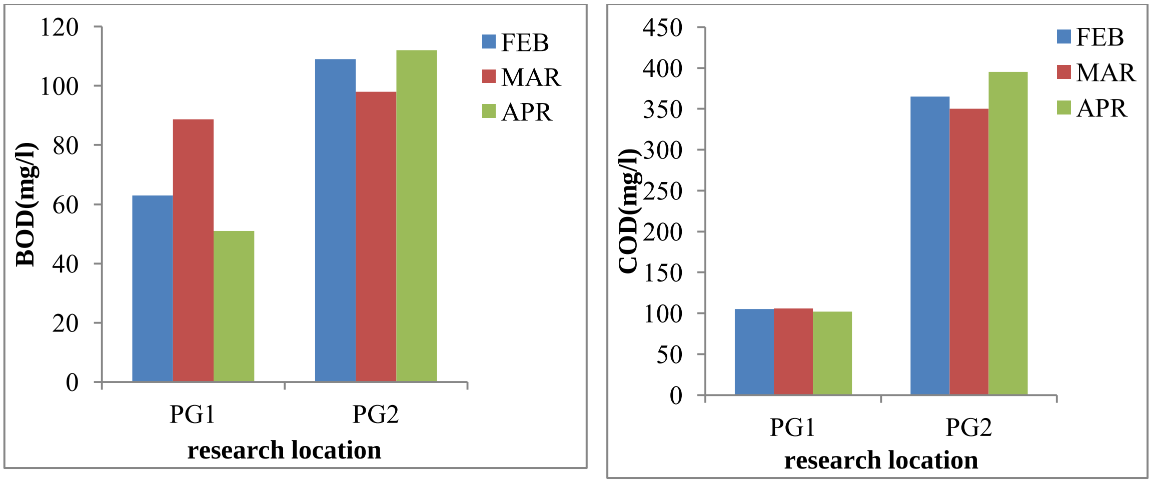


Figure 4.16: Plot of Biological oxygen demand (BOD) and Chemical oxygen demand (COD) for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site

4.4.8. Dissolved oxygen (DO)

The Dissolved oxygen (DO) of groundwater sampled from the research location (coded PG1) ranged from 3.3 -3.5 mg/l with a mean of 3.423 mg/l and standard deviation of 0.108 (Table 4.5). The highest DO of 3.50mg/l for PG1 was recorded in the month of April and the least 3.30mg/l in the month of March (Tables 4.6, Figure 4.17). DO of PG2 ranged from 2.7-2.81mg/l with a mean of 2.753mg/l and standard deviation of 0.055. The highest DO of 2.81mg/l for the research location (coded PG2) on the Pantang landfill was recorded in the month of March and the least 2.7mg/l in the month of April (Tables 4.6, Figure 4.17).

The DO concentrations for both wells were below the WHO guideline and this may be an indication of seepage of leachate into the groundwater system which tends to use the oxygen in the groundwater for decomposition. Compared to PG1,PG2 recorded a much lower DO indicating that it has higher organic content which may be due to it closeness to the landfill. Both wells exhibited a fluctuating trend with sampling period. Efe et al (2005) reported a range of 3.42-6.84 mg/l for open well water in Delta State, Nigeria. Addo et al (2013) reported a DO range of 4.30 and 5.70 with a mean of 5.06 in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana.

4.4.9. Nitrate (NO_3)

The nitrate concentration of groundwater sampled from the research location (coded PG1) ranged from 1.00-1.88 mg/l with a mean of 1.523 mg/l and standard deviation of

0.463 (Table4.5). The highest nitrate of 1.88 mg/l for PG1 was recorded in the month of March and the least 1.00 mg/l in the month of February (Tables 4.6, Figure4.17).) Nitrate of the research location (coded PG2) ranged from 11.6-20.1mg/l with a mean of 17.000mg/l and standard deviation of 4.694. The highest nitrate of 20.1mg/l for PG2 was recorded in the month of February and the least 11.6 mg/l in the month of March (Tables 4.6, Figure 4.17). For PG1 nitrate was below the WHO guideline value whilst that of PG2 exceeded the guideline.

The high nitrate in PG2 may be due to it closeness to the landfill thus making it to receive more organic pollutants and dissolved salts. Both wells exhibited a fluctuating trend with sampling period. Addo et al. (2013) reported a Nitrate range of 0.69 to 1.41 mg/l with a mean of 1.13 mg/l in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana.

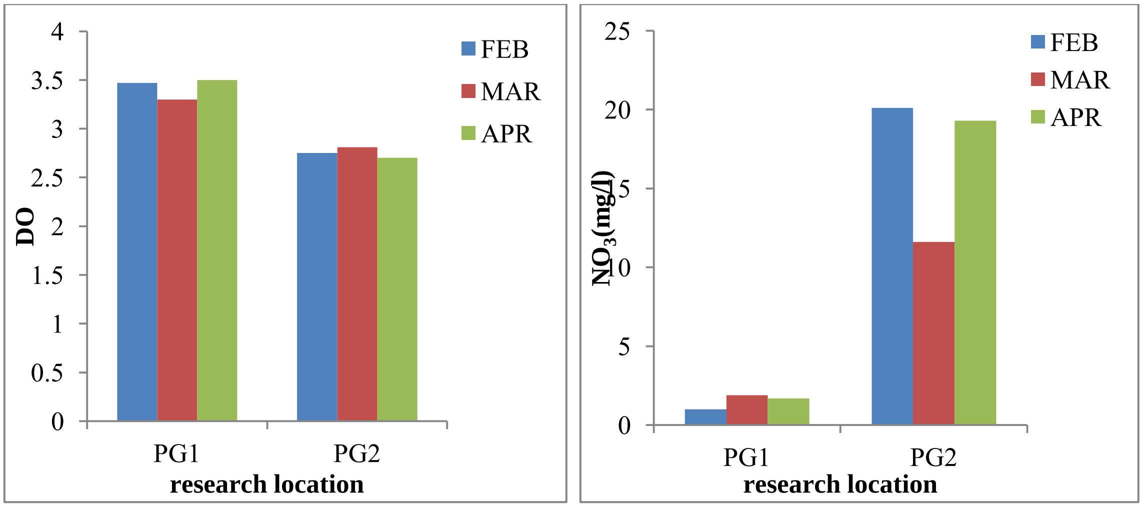


Figure 4.17: Plot of Dissolved oxygen (DO) and Nitrate (NO_3) for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site

4.4.10. Nitrite (NO_2)

The nitrite concentration of groundwater sampled from the research location (coded PG1) ranged from 0.019-0.026 mg/l with a mean of 3.423 mg/l and standard deviation of 0.004 (Table 4.5). The highest nitrite of 0.026 mg/l for PG1 was recorded in the month of March and the least 0.019mg/l in the month of February (Tables 4.6). Nitrite of the research location (coded PG2) ranged from 0.375-0.44mg/l with a mean of 0.415mg/l and standard deviation of 0.035. The highest nitrite of 0.44 mg/l for PG2 was recorded in the month of March and the least 0.375mg/l in the month of February (Tables 4.6).

The Nitrite concentrations for both wells were below the WHO guideline. The high nitrite in PG2 may be due to it closeness to the landfill thus making it to receive more organic pollutants and dissolved salts. Both wells exhibited a fluctuating trend with sampling period. Mor et al. (2006) reported a nitrite range of 0- 0.56 mg/l.

4.4.11. Ammonia (NH_3)

The ammonia concentration of groundwater sampled from the research location (coded PG1) ranged from 0.01-0.014 mg/l with a mean of 3.423 mg/l and standard deviation of 0.002 (Table 4.5). The highest ammonia of 0.014mg/l for PG1 was recorded in the month of February and the least 0.010mg/l in the month of March (Tables 4.6). Ammonia of the research location (coded PG2) ranged from 0.016-0.32 mg/l with a mean of 0.145mg/l and standard deviation of 0.157.

The highest ammonia of 0.32 mg/l for PG2 was recorded in the month of March and the least 0.016mg/l in the month of February (Tables 4.6). Both wells exhibited a fluctuating trend with sampling period. The Ammonia concentrations for both wells were below the WHO guideline. The high Ammonia in PG2 may be due to it closeness to the landfill thus making it to receive more organic pollutants and dissolved salts.

4.4.12. Total phosphorus (TP)

The total phosphorus concentration of groundwater sampled from the research location (coded PG1) ranged from 0.3 – 0.39 mg/l with a mean of 0.353 mg/l and standard deviation of 0.047 (Table 4.5). The highest TP of 0.39 was recorded in the month of February and the least 0.30 in the month of March (Tables 4.6, Figure 4.18). Total phosphorus measured at the research location (coded PG2) on the Pantang landfill ranged from 2.4-3mg/l with a mean of 2.780mg/l and standard deviation of 0.330.The highest TP of 3.00 was recorded in the month of February and the least 2.4 in the month of March (Tables 4.6, Figure 4.18).

Both wells exhibited a fluctuating trend with sampling period. TP is an indication of anthropogenic biological pollution. Most natural waters record phosphorus levels of 0.005-0.020 mg/l (Addo et al., 2011). Addo et al. (2013) reported a PO_4-P range of 0.001 and 0.024 mg/l with a mean concentration of 0.007 mg/L in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana**.**

4.4.13. Sulphate (SO_4)

The Sulphate concentration of groundwater sampled from the research location (coded PG1) ranged from 15-22.5 mg/l with a mean of 19.667 mg/l and standard deviation of

4.072 (Table 4.5) .The highest sulphates of 22.5mg/l was recorded in the month of February and the least 15.0mg/l in the month of March (Tables 4.6, Figure 4.18). The concentration of Sulphate of the research location (coded PG2) ranged from 53-65mg/l with a mean of 60.767mg/l and standard deviation of 6.735. The highest sulphate of 65mg/l was recorded in the month of February and the least 53mg/l in the month of March (Tables 4.6, Figure 4.18). The concentrations of sulphate for both wells were below the WHO guideline.

The high sulphate in PG2 may be due to it closeness to the landfill thus making it to receive more organic pollutants and dissolved salts. Both wells exhibited a fluctuating trend with sampling period. Mor et al. (2006) reported a result ranging from12-1096 mg/l. Addo et al. (2013) reported a sulphate range of 22.84mg/l to a high of 998.65mg/l with a mean of 233.47mg/l in groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana.

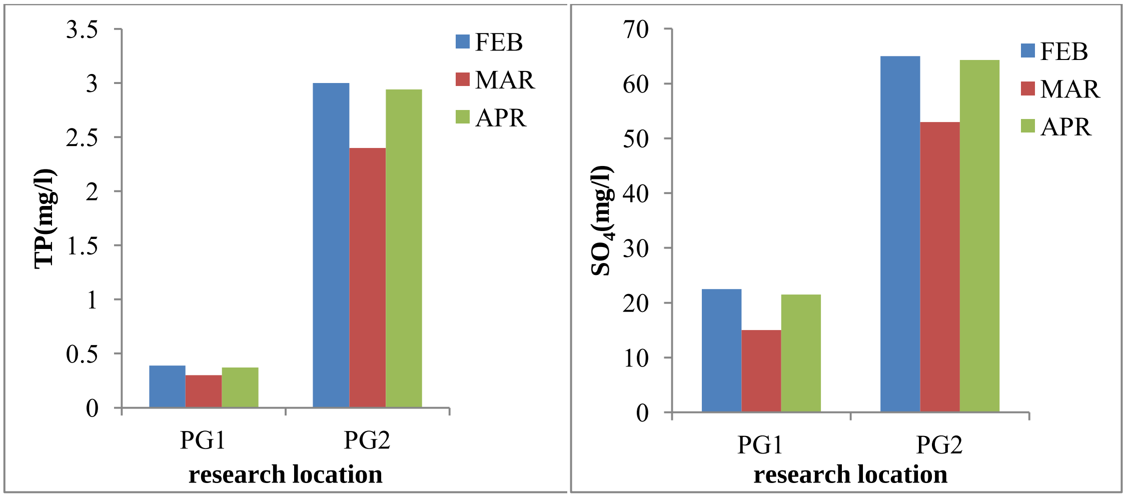


Figure 4.18: Plot of Total phosphorus (TP) and Sulphate (SO_4) for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site

4.4.14. Sulphite (SO_3)

The Sulphite concentration of groundwater sampled from the research location (coded PG1) ranged from 2.90-3.20 mg/l with a mean of 3.03 mg/l and standard deviation of 0.153 (Table 4.5). The highest sulphite of 3.2mg/l was recorded in the month of April and the least 2.9mg/l in the month of February (Tables 4.6). Sulphite of the research location (coded PG2) on the Pantang landfill ranged from 32-36mg/l with a mean of 34.367mg/l and standard deviation of 2.098. The highest sulphite of 36mg/l was recorded in the month of March and the least 32mg/l in the month of February (Tables 4.6). Both wells exhibited a fluctuating trend with sampling period.

The high Sulphite contents of PG2 may be due to the high degree of seepage of leachate into the groundwater. Generally, the entire nutrient loads (TP, SO_4 andSO_3) for both wells were below the WHO guidelines and this means organic pollution by leachate is quite low and this may be due to the natural filtration, absorption and adsorption of the nutrients unto the soil interface and the natural geology of the area.

4.4.15. Zinc (Zn)

The Zn concentration of groundwater sampled from the research location (coded PG1) ranged from 0.013-0.015 mg/l with a mean of 0.014 and standard deviation of 0.001 (Table 4.5). The highest Zn of 0.015mg/l for PG1 was recorded in the month of March and April; and the least 0.013mg/l in the month of February (Tables 4.6). Concentration of Zn measured at the research location (coded PG2) on the Pantang landfill ranged from 0.049-0.142mg/l with a mean of 0.110 and standard deviation of 0.053. The highest Zn of

0.142mg/l for PG2 was recorded in the month of February and the least 0.049mg/l in the month of March (Tables 4.6). Both wells exhibited a fluctuating trend with sampling period.

4.4.16. Copper (Cu)

The Cu concentration of groundwater sampled from the research location (coded PG1) ranged from 0.017 – 0.025mg/l with a mean of 0.022mg/l and standard deviation of 0.004 (Table 4.5). The highest Cu of 0.025mg/l for PG1 was recorded in the month April and the least 0.017mg/l in the month of March (Tables 4.6, Figure 4.19). The concentration of Cu for the research location (coded PG2) on the Pantang landfill ranged from 1.135-1.216mg/l with a mean of 1.188 mg/l and standard deviation of 0.046. The highest Cu of 0.025mg/l for PG2 was recorded in the month April and the least 0.017mg/l in the month of March (Tables 4.6, Figure 4.19). Both wells exhibited a fluctuating trend in concentration with sampling period.

4.4.17. Chromium (Cr)

The Cr concentration of groundwater sampled from the research location (coded PG1) ranged from 0.186 -0.196 mg/l with a mean of 0.192 mg/l and standard deviation of 0.006 (Table 4.5). The highest Cr of 0.196mg/l for PG1 was recorded in the month April and the least 0.186mg/l in the month of February (Tables 4.6, Figure 4.19). The concentration of Cr measured at the research location (coded PG2) ranged from 0.101-0.132mg/l with a mean of 0.119mg/l and standard deviation of 0.016. The highest Cr of

0.132mg/l for PG2 was recorded in the month February and the least 0.101mg/l in the month of March (Tables 4.6, Figure 4.19). Both wells exhibited a fluctuating trend in concentration with sampling period.

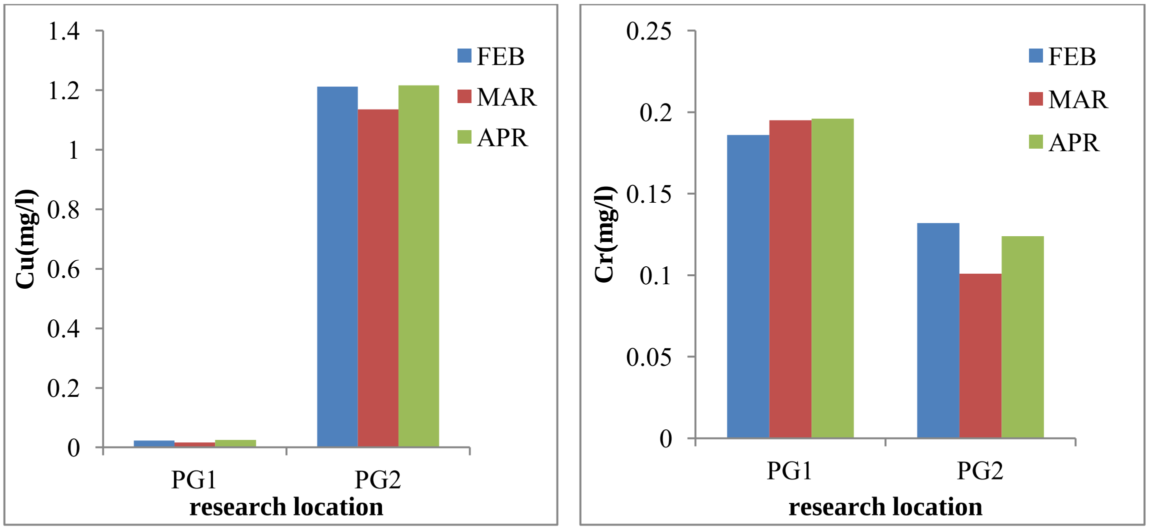


Figure 4.19: Plot of Copper (Cu) and Chromium (Cr) for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site

4.4.18. Manganese (Mn)

The Mn concentration of groundwater sampled from the research location (coded PG1) ranged from 0.042 – 0.086mg/l with a mean of 0.068mg/l and standard deviation of 0.023 (Table 4.5). The highest Mn of 0.086mg/l for PG1 was recorded in the month of April and the least 0.042mg/l in the month of February (Tables 4.6). The concentration of Mn measured at the research location (coded PG2) ranged from 1.02-1.137mg/l with a mean of 1.084mg/l and standard deviation of 0.059.

The highest Mn of 1.137mg/l for PG2 was recorded in the month of February and the least 1.02mg/l in the month of March (Tables 4.6). Both wells exhibited a fluctuating trend in concentration with sampling period.

4.4.19. Iron (Fe)

The Fe concentration of groundwater sampled from the research location (coded PG1) ranged from 0.053 – 0.073 mg/l with a mean of 0.066 mg/l and standard deviation of 0.011 (Table 4.5). The highest Fe of 0.073mg/l for PG1 was recorded in the month of April and the least 0.053mg/l in the month of February (Tables 4.6). The concentration of Fe measured at the research location (coded PG2) ranged from 4.501-7.83mg/l with a mean of 6.240mg/l and standard deviation of 1.670. The highest Fe of 7.83mg/l for PG2 was recorded in the month of February and the least 4.501mg/l in the month of March (Tables 4.6). Both wells exhibited a fluctuating trend in concentration with sampling period.

4.4.20. Cadmium (Cd)

The Cd concentration of groundwater sampled from the research location (coded PG1) ranged from 0.007 mg/l and 0.036 mg/l with an average of 0.024 mg/l and standard deviation of 0.015 (Table 4.5). The highest Cd of 0.036mg/l for PG1 was recorded in the month of February and the least 0.007mg/l in the month of March (Tables 4.6, Figure 4.20). The concentration of Cd measured at the research location (coded PG2) ranged from 0.022-0.042mg/l with an average of 0.034mg/l and standard deviation of 0.011. The highest Cd of 0.042mg/l for PG2 was recorded in the month of April and the least

0.022mg/l in the month of February (Tables 4.6, Figure 4.20). Both wells exhibited a fluctuating trend in concentration with sampling period.

4.4.21. Nickel (Ni)

The Ni concentration of groundwater sampled from the research location (coded PG1) ranged from 0.01 – 0.013mg/l with a mean of 0.011mg/l and standard deviation of 0.002 (Table 4.5). The highest Ni of 0.013mg/l for PG1 was recorded in the month of February and the least 0.010mg/l in the month of March (Figure 4.20). The concentration of Ni measured at the research location (coded PG2) ranged from 0.013-0.019mg/l with a mean of 0.016mg/l and standard deviation of 0.003 (Table 4.5). The highest Ni of 0.019mg/l for PG2 was recorded in the month of February and the least 0.013mg/l in the month of March (Figure 4.20). Both wells exhibited a fluctuating trend in concentration with sampling period.

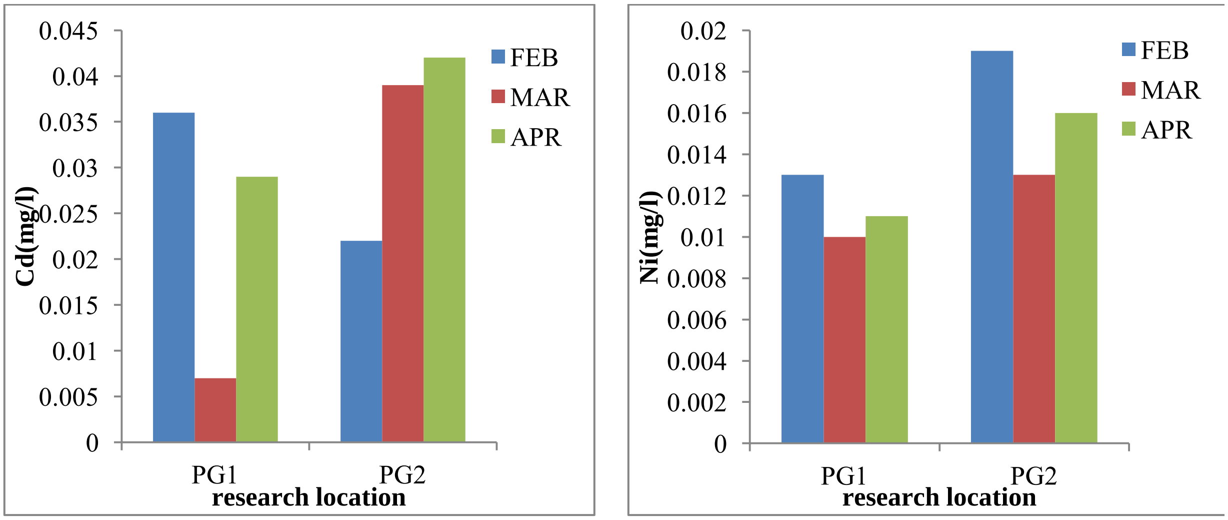


Figure 4.20: Plot of Cadmium (Cd) and Nickel (Ni) for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site

The Zn, Cr and Cd concentrations of both wells were above the WHO guideline. The high Zn concentration in PG2 may be due to it closeness to the landfill thus making it to receive more organic pollutants, dissolved salts and ions.

The Cu, Mn, Fe and Ni concentrations of both wells were below the WHO guideline. This likely indicates that these metals may be absorbed by the soil strata or by the organic matter in soil. Metals remain in the waste or at the waste–rock interface as a result of redox controlled precipitation reactions (Yanful et al., 1988).

Further, the metal mobility is also controlled by physical sorptive mechanisms and landfills have an inherent *in situ* capacity for minimizing the mobility of toxic heavy metals (Pohland et al., 1993). This fixing of heavy metals reduces the risk of direct toxic effects due to ingestion of leachate contaminated groundwater. Both wells exhibited a fluctuating trend in concentration with sampling period.

Tables 4.5: Basic statistical analysis of parameters determined on groundwater sampled from the Pantang landfill site.

	RANGE PG1	MEAN PG1	STD DEV PG1	RANGE PG2	MEAN PG2	STD DEV PG2	WHO
pH(pHunits)	6.84-7.4	7.180	0.299	7.56-8.6	8.060	0.521	6.5-8.5
TSS(mg/l)	4.7-5.0	4.867	0.153	60.2-67	63.067	3.523	5
TUR(NTU)	3.1-4.6	4.000	0.794	31.4-35	33.700	1.997	5
EC(μS/cm)	1081-1475	1337.667	222.462	3077-3999	3640.667	494.108	400
TDS(mg/l)	1140-1648	1379.000	255.325	1998-2560	2310.667	286.303	500
BOD(mg/l)	51-88.7	67.567	19.260	98-112	106.333	7.371	300
COD(mg/l)	102-106	104.333	2.082	350-395	370.000	22.913	7.5
DO	3.30-3.50	3.423	0.108	2.7-2.81	2.753	0.055	7.5
NO_3(mg/l)	1.0-1.88	1.523	0.463	11.6-20.1	17.000	4.694	10
NO_2(mg/l)	0.019-0.026	0.022	0.004	0.375-0.44	0.415	0.035	3.0
NH_3(mg/l)	0.010-0.014	0.012	0.002	0.016-0.32	0.145	0.157	1.5
T P(mg/l)	0.300-0.390	0.353	0.047	2.4-3	2.780	0.330	
SO_4(mg/l)	15.0-22.5	19.667	4.072	53-65	60.767	6.735	250
SO_3(mg/l)	2.90-3.20	3.033	0.153	32-36	34.367	2.098	
Zn(mg/l)	0.013-0.015	0.014	0.001	0.049-0.142	0.110	0.053	0.01
Cu(mg/l)	0.017-0.025	0.022	0.004	1.135-1.216	1.188	0.046	2.0
Cr(mg/l)	0.186-0.196	0.192	0.006	0.101-0.132	0.119	0.016	0.05
Mn(mg/l)	0.042-0.086	0.068	0.023	1.02-1.137	1.084	0.059	0.1
Fe(mg/l)	0.053-0.073	0.066	0.011	4.501-7.83	6.240	1.670	0.3
Cd(mg/l)	0.007-0.036	0.024	0.015	0.022-0.042	0.034	0.011	0.003
Ni(mg/l)	0.010-0.013	0.011	0.002	0.013-0.019	0.016	0.003	0.02

Tables 4.6: Monthly results obtained for groundwater sampled from the wells (PG1) and (PG2) located close to the Pantang landfill site.

PARAMETERS	FEBRUARY-PG1	MARCH-PG1	APRIL-PG1	FEBRUARY-PG2	MARCH-PG2	APRIL-PG2
pH(pHunits)	7.30	6.84	7.40	8.02	7.56	8.60
TSS(mg/l)	4.7	5.0	4.9	62	67	60.2
TUR(NTU)	3.1	4.6	4.3	31.4	35.0	34.7
EC(µS/cm)	1081	1475	1457	3999	3077	3846
TDS(mg/l)	1140	1648	1349	2560	1998	2374
BOD(mg/l)	63	88.7	51	109	98	112
COD(mg/l)	105	106	102	365	350	395
DO	3.47	3.30	3.50	2.75	2.81	2.70
NITRATE(mg/l)	1.00	1.88	1.69	20.1	11.6	19.3
NITRITE(mg/l)	0.019	0.026	0.021	0.375	0.440	0.430
AMMONIA(mg/l)	0.014	0.010	0.012	0.099	0.320	0.016
TP(mg/l)	0.39	0.30	0.37	3.00	2.40	2.94
SULPHATE	22.5	15.0	21.5	65.0	53.0	64.3
SULPHITE	2.9	3.0	3.2	32.0	36.0	35.1
Zn(mg/l)	0.013	0.015	0.015	0.142	0.049	0.139
Cu(mg/l)	0.023	0.017	0.025	1.212	1.135	1.216
Cr(mg/l)	0.186	0.195	0.196	0.132	0.101	0.124
Pb(mg/l)	ND	ND	ND	BD	ND	ND
Mn(mg/l)	0.042	0.077	0.086	1.137	1.020	1.095
Fe(mg/l)	0.053	0.072	0.073	7.830	4.501	6.390
Cd(mg/l)	0.036	0.007	0.029	0.022	0.039	0.042
Ni(mg/l)	0.013	0.010	0.011	0.019	0.013	0.016

4.4.22. Kerndoff Contamination Factor

The Kerndorff Contamination Factors for Cd, Mn, Cr, TP, Cu, NH_3, SO_3, Fe, SO_4, Ni, and NO_3 were all above 1.0 and this indicates that these parameters might be leaking into the ground water system (Table 4.7). NO_2 and Zn recorded lower Kerndorff Contamination Factors and this means these parameters may not be leaking. Cd had the highest Kerndorff Contamination Factors of 12 and the lowest factor 0.108 was recorded by Zn. The pollutants were ranked in the reducing migration order as Cd>Mn>Cr>TP>Cu>NH3>SO3>Fe>SO4>Ni>NO3>NO2>Zn.

Table 4.7: Kerndoff Contamination Factor for PG1

Parameters	Polluted water(Ai)	Control water (Bi)	KC factors(Ai)÷ (Bi)
Cd(mg/l)	0.024	0.002	12
Mn(mg/l)	0.068	0.012	5.667
Cr(mg/l)	0.192	0.038	5.053
TP(mg/l)	0.353	0.073	4.836
Cu(mg/l)	0.022	0.005	4.4
NH3(mg/l)	0.012	0.003	4.00
SO_3	3.03	1.2	2.525
Fe(mg/l)	0.066	0.030	2.200
SO_4	19.7	10.10	1.950
Ni(mg/l)	0.011	0.006	1.833
NO_3(mg/l)	1.52	1.1	1.382
NO_2(mg/l)	0.022	0.042	0.524
Zn(mg/l)	0.014	0.120	0.117

4.5. CORRELATION ANALYSIS OF PARAMETERS

Turbidity of PL had a strong positive correlation with TSS and this implies that there is a close association between the two parameters. This may also mean that TSS and turbidity are from a common source. The TDS of ML had a strong positive correlation with turbidity. The NO_3 of PL had a strong negative correlation with DO. The TP of ML had a negative correlation with turbidity, (Appendix 8). SO_4 of PL had a strong positive correlation with TP. The Cu of ML had a positive correlation with NO_3 (Appendix 8). Zn of PL had a negative correlation with TP.

The TSP of the air sampled from the Pantang landfill has a strong positive correlation with PM_{10} (Appendix 9). NH_3 of the air sampled from the Mallam landfill has a strong positive correlation with PM10 and TSP and this implies that there is a close association between the two parameters. The SO_2 of the air sampled from the Pantang landfill has a strong positive correlation with TSP and NH3. Zn of the air sampled from the Mallam landfill has a strong negative correlation with NH3 and SO_2, (Appendix 9). The Ni of the air sampled from the Pantang landfill has a strong negative correlation with PM10, TSP, and SO_2.

Cu of the air sampled from the Mallam landfill has a strong positive correlation with PM10, TSP and this implies that there is a close association between the parameters. The Mn of the air sampled from the Pantang landfill has a strong positive correlation with NH_3 and SO_2; and negative correlation with Ni. Cr of the air sampled from the Mallam landfill has a strong positive correlation with Zn and Ni. The Cd of the air sampled from the Pantang landfill has a negative correlation with SO_2, Mn and Cr (Appendix 9). Pb of the air sampled from the Mallam landfill has a strong positive correlation with Mn, Cr and Cd.

OM showed a strong positive correlation with OC. EC showed a strong negative correlation with OC and OM. NO_3showed a strong negative correlation with OC and OM; and strongly positive correlation with EC. Mn showed a strong positive correlation with pH, OC and OM; and a strong negative correlation with EC (Appendix 10). Cu showed a positive correlation with pH and negative correlation with NH_3. Zn correlated positively with EC and NO_3 (Appendix 10). Fe showed a strong positive correlation with OC, OM, Mn and Zn; and this implies that there is a close association between the parameters. Cr correlated positively with pH, Fe and Mn. Pb correlated positively with EC, Cu and NO_3; and negatively with OC and OM. Cd showed only negative correlation with EC, Cu, Zn and Pb; and NO_3 (Appendix 10). Ni correlated positively with pH, Pb and Cu; and negatively with Cd.

Turbidity of PG1 had a strong positive correlation with TSS and negative correlation with pH (Appendix 11). NO_3 of PG1 had a strong positive correlation with EC, TDS and negative correlation with pH and DO (Appendix 11). The TP of PG2 had a strong positive correlation with NO_3 and negative correlation with TSS (Appendix 11). Cr of PG1 had a strong positive correlation with TSS, EC, TDS and NO_3 and this implies that there is a close association between the two parameters; and negative correlation withNH_3 TP and SO_4. The Cd of PG2 had a strong positive correlation with turbidity, $NO_{2,}$ and SO_3; and negative correlation with EC, TDS and Cr (Appendix 11).

CHAPTERFIVE

CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The leachate from the Pantang landfill recorded higher concentration values compared to the Mallam landfill. This may be due to the fact that the Pantang landfill is active while the Mallam site has been closed for more than a decade now. For the Pantang landfill, with the exception of pH, Cu, Cr, Mn, Cd and Ni, all the other parameters measured recorded concentrations above the EPA guideline for effluent discharge into the environment. The Pantang landfill recorded higher concentrations in the pollutants compared to Mallam because of the input of waste and also because the Mallam site no longer receives waste. The concentration of pollutants exhibited a lower trend in March probably due to the rainfall experienced in that month during sampling which might have led to dilution. With the exception of pH, Zn, Cr, Ni. Mn, Cu and Cd all the other parameters determined on the leachate from the Mallam landfill, recorded concentrations above the EPA guideline for effluent discharge into the environment. The low metals concentrations in the leachates from both sites may be due to sorption, complexation and precipitation.

The analysis of the air sampled from the landfills revealed that air sampled from the Pantang landfill is releasing huge amounts of PM_{10} and TSP into the environment compared to the Mallam landfill. The PM10 and TSP of the Pantang landfill was above the EPA and WHO guidelines whilst that of Mallam was within the guideline. The high PM10 and TSP of the Pantang landfill may be attributed to the regular combustion of waste on it. With the exception of Ni, Mn and Cd all the parameters determined for air sampled from the Pantang landfill had their concentrations above EPA and WHO guideline values. The air sampled from the Mallam landfill had all the parameters determined being below the EPA and WHO guideline values with the exception of SO_2 and Pb which were above the guideline. Rainfall affected the trend in the concentrations of PM_{10} and TSP sampled on both sites. Rainfall in March during sampling led to lower concentrations in air parameters determined for both sites.

The physical and nutrient parameters determined for the soil sampled from the vicinity of the Pantang landfill recorded higher vales compared to values obtained for the control site. This may be due to the presence of large amounts of organic matter on and around the landfill. For the metals determined for the soil, with the exception of Cu, Zn and Cd all other metals were lower than their World average shale values and this may be due to processes sorption, complexation and precipitation. The well on the Pantang landfill coded PG2 recorded higher pollutant concentrations compared to the well PG1 and this may be due to it closeness to the landfill. For PG1 with the exception of the TSS, EC, TDS, Zn, Cr, Mn and Cd which recorded concentration values above the WHO guideline ,all other parameters had lower concentrations and this may be due to it distance away from the landfill which allows more interaction of pollutants with the soil interface leading to their adsorption hence the low concentrations. For the well PG2 with the exception of BOD, NO_2, NH_3 Cu and Ni which recorded lower values, all other parameters had concentrations above the WHO guidelines for drinking water quality.

The pollution indexes calculated revealed that both the Pantang and Mallam landfills are sources of pollution. The LPI for the Pantang landfill was 18.573 and that of Mallam was 4.799. The AQI calculated for the Pantang landfill was 598.8 and Mallam 28.9.

The implication of data obtained is that the Pantang and Mallam landfills are impacting negatively on the air, soil and water in their vicinity and this confirms the school of thought that landfills impact negatively on their environment.

5.2. RECOMMENDATIONS

Selection of sites for land filling should be done in a manner that would result in the protection of the integrity of the environment. The EPA must ensure the implementation of regulations governing landfill construction, ownership and operation. The EPA must also work to enforce the' no burning policy' to minimize burning and reduce the smoke that is emitted into the air at the Pantang landfill site.

There is the need for the government to put up a sanitary landfill for the Accra metropolis and put an end to the reliance on abandoned quarry site and marshy areas for waste disposal. There is also the need for AMA to reinforce the capping system at the Mallam landfill site and also reconstruct drains with covers to carry leachates from the landfill away from the community.

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APPENDICES

APPENDIX 1: Research locations on the Pantang and Mallam landfill sites

Research locations(Codes)	**GPS location**	
	North	West
PLI	5°42'80	0°11'36
PL2	5°42'12	0°11'33
PL3	5°42'17	0°11'29
PL4	5°42'20	0°11'27
PL5	5°42'25	0°11'25
M_1L1	5°568	0°286
M_1L2	5°569	0°287
M_1L3	5°569	0°287
M_1L4	5°570	0°288
M_1L5	5°570	0°287
PA1	5°42'22	0°11'42
PA2	5°42'14	0°11'28
MA1	5°570	0°288
MA2	5°568	W 0°287
P1S1	5°42'14	0°11'40
P2S1	5°42'10	0°11'39
P3S1	5°42'61	0°11'37
P1S2	5°42'16	0°11'37
P2S2	5°42'13	0°11'36

P3S2	5°42'81	0°11'34
P1S3	5°42'22	0°11'36
P2S3	5°42'18	0°11'33
P3S3	5°42'16	0°11'31
P1S4	5°42'25	0°11'32
P2S4	5°42'22	0°11'31
P3S4	5°42'18	0°11'27
P1S5	5°42'29	0°11'31
P2S5	5°42'27	0°11'29
P3S5	5°42'25	0°11'27
PG1	5°42'81	0°11'41
PG2	5°42'29	0°11'25

APPENDIX 2: Basic statistical analysis of parameters determined on leachate sampled from the Pantang and Mallam landfill sites

	RANGE-PL	MEAN-PL	STD. DEV-PL	RANGE-ML	MEAN-ML	STD. DEV-ML	EPA(G)
PH	8.00-8.90	8.345	0.263	8.15-8.90	8.388	0.224	6 – 9
DO	1.00-3.70	2.226	0.894	0.941-3.600	2.184	0.822	
TSS(mg/l)	1320-1723	1582	91.418	209.0-391.0	266.467	49.492	50
TUR(NTU)	93-309	213.973	85.581	127.0-194.0	152.507	18.771	75
EC(□ S/cm)	50163-74830	63463.6	8543.705	10150-36490	19232.267	9066.951	1500
TDS(mg/l)	20134-48141	32923.933	7274.217	1649.0-4325.0	3135.667	990.548	1000
BOD(mg/l)	124.00-293.00	192.133	51.017	123-207	160.6	28.623	50
COD(mg/l)	583.00-829.00	719.133	91.818	760-1520	1122.533	229.880	250
NO_3(mg/l)	24.3-57.3	37.038	10.907	34.2-79	59.613	10.972	50
NO_2(mg/l)	2.95-6.90	4.741	1.165	0.7502.850	1.602	0.632	
NH_3(mg/l)	2.50-5.10	3.831	0.797	0.58-1.93	1.169	0.406	1.0
TP(mg/l)	5.13-8.94	7.010	1.166	15.4-31.0	22.373	4.813	2.0
SO_4(mg/l)	989.0-1982.0	1451.933	376.906	108-290	210.533	53.235	200
SO_3(mg/l)	39.0-77.0	58.160	11.104	4.30-8.70	7.434	1.195	
Zn(mg/l)	10.43-23.01	15.692	3.988	0.145-0.984	0.549	0.237	5.0
Cr(mg/l)	2.73O-5.99	4.386	1.143	0.073-0.471	0.241	1.165	0.5
Pd(mg/l)	0.267-0.952	0.609	0.200	0.094-0.343	0.186	0.075	0.1
Mn(mg/l)	1.359-4.510	2.267	1.066	0.110-0.793	0.353	0.231	2.5
Fe(mg/l)	29.5-58.3	43.190	9.070	11.62-18.97	15.734	2.588	
Cd(mg/l)	0.019-0.099	0.077	0.020	0.014-0.097	0.054	0.027	<0.1
Ni(mg/l)	0.169-0.844	0.550	0.207	0.062-0.436	0.208	0.118	0.5

APPENDIX 3: Concentration of parameters for leachate sampled from the Pantang landfill site during the sampling period.

	PLI			PL2			PL3			PL4			PL5		
	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR
PH	8.3	8.08	8.2	8.8	8.30	8.5	8.1	8.10	8.0	8.2	8.90	8.6	8.4	8.40	8.3
DO	2.9	2.69	2.3	1.4	1.64	1.2	3.7	2.95	2.7	3.1	2.71	2.9	1.0	1.20	1.0
TSS(mg/l)	1590	1600	1575	1723	1540	1694	1320	1610	1506	1573	1643	1617	1542	1598	1599
TUR (NTU)	260	281.6	279	295	256.0	301	93	293.0	117	137	309.0	148	104	238.0	98
EC(µS/cm)	71030	63350	69241	67384	53524	62035	73951	50163	74830	69352	58301	73498	59150	51972	54173
TDS(mg/l)	35513	48141	36381	27341	38512	29042	38460	32751	36193	30627	39632	30452	20134	29627	21053
BOD(mg/l)	155	173	171	205	213	251	124	159	169	129	165	163	293	257	255
COD(mg/l)	703	793	723	652	603	605	829	798	792	583	632	642	794	814	824
NO$_3$(mg/l)	24.60	30.0	29.60	43.14	48.7	42.33	28.40	27.4	27.90	39.60	37.2	38.80	57.30	24.3	56.30
NO$_3$(mg/l)	4.10	5.50	3.91	4.80	6.10	6.90	3.94	3.45	3.43	5.70	5.90	5.73	2.95	4.20	4.50
NH$_3$(mg/l)	3.6	3.1	4.10	2.7	2.9	2.50	5.1	4.8	4.30	3.8	3.7	3.47	4.2	4.8	4.40
T P(mg/l)	7.40	6.48	8.46	5.20	5.73	5.13	8.34	7.98	8.94	6.91	6.95	6.41	7.10	6.28	7.84
SO$_4$(mg/l)	1982	1820	1785	1267	1223	1297	1942	1849	1892	989	998	993	1205	1262	1275
SO$_3$(mg/l)	63	61	71.4	59	53	57	68	74	77	47	52	57	39	45	49
Zn(mg/l)	11.26	16.51	12.26	21.23	23.01	22.23	17.50	15.9	16.50	13.91	14.70	15.91	11.43	12.60	10.43
Cu(mg/l)	1.517	1.606	1.317	2.580	2.530	2.534	1.935	1.913	1.953	1.524	1.528	1.538	2.280	2.310	2.610
Cr(mg/l)	5.990	4.446	3.948	2.730	3.172	2.760	5.380	5.132	5.980	5.239	5.376	5.039	3.502	3.189	3.902
Pd(mg/l)	0.952	0.731	0.759	0.753	0.789	0.713	0.625	0.573	0.685	0.274	0.267	0.294	0.582	0.551	0.583
Mn(mg/l)	1.359	1.432	1.95	2.725	1.749	1.74	1.820	2.05	2.35	1.390	1.47	1.48	3.610	4.51	4.37
Fe(mg/l)	43.14	38.98	53.16	36.26	49.35	38.76	58.30	47.30	55.30	45.20	44.60	47.20	29.50	30.90	29.90
Cd(mg/l)	0.060	0.019	0.083	0.093	0.084	0.083	0.074	0.078	0.058	0.083	0.080	0.083	0.092	0.089	0.099
Ni(mg/l)	0.844	0.575	0.739	0.427	0.639	0.635	0.603	0.524	0.524	0.645	0.728	0.758	0.169	0.218	0.228

APPENDIX 4: Concentration of parameters for leachate sampled from the Mallam landfill site during the sampling period

	M_1L1			M_1L2			M_1L3			M_1L4			M_1L5		
	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR
PH	8.40	8.18	8.68	8.16	8.15	8.45	8.26	8.67	8.17	8.90	8.40	8.20	8.30	8.50	8.40
DO	2.40	2.520	3.60	2.00	0.941	1.50	2.30	2.440	3.47	1.20	1.060	2.00	1.76	2.370	3.20
TSS(mg/l)	298	249	253	211	228	218	209	239	259	265	273	265	302	391	337
TUR (NTU)	150.3	129	150.3	172	194	172.0	154	143	154.0	163	153	163.0	127	136	127.0
EC(µS/cm)	10150	36490	35990	36290	19000	18720	16290	15831	15231	13761	13539	13139	15093	14980	13980
TDS(mg/l)	1695	1649	1695	4021	4134	4021	2372	2618	2372	4065	4325	4065	3195	3613	3195
BOD(mg/l)	147	127	123	165	201	207	164	138	128	174	193	195	167	145	135
COD(mg/l)	1193	1400	1431	760	800	830	1520	1195	1295	963	1027	1087	1037	1105	1195
NO_3 (mg/l)	67	64.0	69	54	34.2	57	48	79.0	51	59	67.0	53	61	72.0	59
NO_3 (mg/l)	1.320	1.55	1.35	1.000	0.79	0.75	0.913	2.85	2.35	1.900	2.05	2.45	1.600	1.36	1.79
NH_3(mg/l)	0.58	0.71	0.73	1.04	0.87	0.87	1.23	1.56	1.37	1.93	1.74	1.24	0.99	1.05	1.62
T P(mg/l)	27.0	24.00	26.14	22.5	18.90	21.70	15.4	17.35	16.80	18.5	20.80	19.30	29	27.20	31.00
SO_4(mg/l)	132	108	162	245	290	225	194	176	174	206	216	256	233	258	283
SO_3(mg/l)	4.30	8.20	8.70	6.50	7.00	7.37	8.36	8.11	7.81	7.20	6.90	5.90	8.19	8.50	8.47
Zn(mg/l)	0.584	0.952	0.984	0.276	0.145	0.236	0.614	0.697	0.754	0.471	0.409	0.491	0.519	0.537	0.569
Cu(mg/l)	0.138	0.168	0.158	0.120	0.200	0.215	0.345	0.237	0.275	0.173	0.238	0.274	0.250	0.272	0.292
Cr(mg/l)	0.374	0.212	0.474	0.211	0.114	0.215	0.322	0.471	0.392	0.197	0.201	0.147	0.099	0.112	0.073
Pd(mg/l)	0.138	0.142	0.158	0.094	0.114	0.099	0.147	0.193	0.187	0.182	0.198	0.192	0.303	0.298	0.343
Mn(mg/l)	0.685	0.282	0.295	0.169	0.110	0.135	0.476	0.753	0.793	0.146	0.135	0.193	0.392	0.359	0.379
Fe(mg/l)	14.24	13.868	13.90	11.62	17.968	12.24	18.86	18.24	17.98	18.37	17.57	18.97	13.65	14.39	14.15
Cd(mg/l)	0.033	0.024	0.027	0.048	0.019	0.014	0.037	0.071	0.063	0.097	0.093	0.073	0.063	0.057	0.087
Ni(mg/l)	0.102	0.108	0.128	0.142	0.065	0.062	0.436	0.203	0.253	0.372	0.368	0.326	0.183	0.181	0.184

APPENDIX 5: Basic statistical analysis of parameters determined on air sampled from the Pantang and Mallam landfill sites.

	RANGE-PA	MEAN-PA	STD. DEV-PA	RANGE-MA	MEAN-MA	STD. DEV-MA	EPA	WHO
PM10(ug/ m^3/24hr)	250.00-680.56	527.78	240.965	13.89-27.78	23.15	8.019	70	50
TSP(ug/ m^3/24hr)	291.67-875.00	665.56	324.576	27.78-41.67	37.04	8.019	150	
CO mg/m^3/15min	11000.0-20000.0	16433.3	4781.562	0.00-0.00	0.00	0.00	100	100
NH_3(ug/ m^3/hr)	6390-12070	9797	3005.007	4970.00-8520.00	6657.667	1781.434		
NO_2(ug/ m^3/hr)	0.00	0.00	0.00	0.00-0.00	0.00	0.00	0.00	0.00
SO_2(ug/ m^3/hr)	34060.0-41920.0	38603.3	4071.048	44540-49780	47236.67	2623.36	700	500
Zn(ug/ m^3/hr)	0.051-0.154	0.089	0.057	0.298-0.359	0.334	0.032		
Ni(ug/ m^3/hr)	0.048-0.053	0.051	0.003	0.006-0.103	0.068	0.054		1.0
Cu(ug/ m^3/hr)	0.005-0.092	0.038	0.047	0.020-0.043	0.029	0.012		
Mn(ug/ m^3/hr)	0.009-0.052	0.035	0.023	0.035-0.059	0.047	0.012	1.00	0.15
Cr(ug/ m^3/hr)	0.045-0.194	0.125	0.102	0.036-0.099	0.069	0.032		
Cd(ug/ m^3/hr)	0.022-0.045	0.035	0.012	0.005-0.028	0.017	0.012	20	5
Pb(ug/ m^3/hr)	73.73-86.53	79.89	6.413	21.90-29.50	25.63	3.802	2.5	0.5
Fe(ug/ m^3/hr)	1.308-3.830	2.503	1.266	0.472-0.909	0.735	0.232		

APPENDIX 6: Concentration of parameters for air sampled from the Pantang and Mallam landfill sites during the sampling period

	PANTANG AIR			MALLAM AIR		
	FEB	MAR	APRIL	FEB	MAR	APRIL
PM10(ug/ m^3/24hr)	652.78	250.00	680.56	27.78	13.89	27.78
TSP(ug/ m^3/24hr)	830.00	291.67	875.00	41.67	27.78	41.67
CO mg/m^3/15min	20,000	11000	18300	0.00	0.00	0.00
NH_3(ug/ m^3/hr)	12,070	6390	10931	8520	4970	6483
NO_2(ug/ m^3/hr)	0.00	0.00	0.00	0.00	0.00	0.00
SO_2(ug/ m^3/hr)	41920	34060	39830	49780	44540	47390
Zn(ug/ m^3/hr)	0.051	0.154	0.062	0.298	0.346	0.359
Ni(ug/ m^3/hr)	0.048	0.053	0.051	0.006	0.103	0.094
Cu(ug/ m^3/hr)	0.016	0.005	0.092	0.025	0.020	0.043
Mn(ug/ m^3/hr)	0.052	0.009	0.045	0.047	0.059	0.035
Cr(ug/ m^3/hr)	0.194	0.045	O.137	0.036	0.099	0.073
Cd(ug/ m^3/hr)	0.022	0.045	0.037	0.005	0.028	0.017
Pb(ug/ m^3/hr)	73.73	79.41	86.53	21.90	29.50	25.48
Fe(ug/ m^3/hr)	3.830	1.308	2.371	0.909	0.472	0.825

APPENDIX 7: Concentration of parameters for soil sampled from the Pantang landfill site during the sampling period

	PS1			PS2			PS3			PS4			PS5		
	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR	FEB	MAR	APR
PH	8.97	8.29	8.56	8.28	8.07	8.37	8.54	8.74	8.87	8.44	8.34	8.91	8.73	8.53	8.65
OC (%)	2.647	2. 461	2.549	4.911	3. 191	5.023	5.440	6.183	5.456	5.916	5.513	5.800	3.735	2. 871	3.773
OM(mg/kg)	4.563	4.243	4.394	8.467	5.501	8.659	9.379	10.659	9.406	10.199	9.504	9.979	6.439	4.949	6.505
EC(µS/cm)	1650	1556	1620	1250	1253	1378	750	810	710	1150	1350	1098	970	986	1005
NO_3(mg/kg)	4795.2	4064.0	4573	1324.0	1383.0	949	1000.8	937.0	1039	2008.8	2149	1832	802.0	916.0	819
NH_3(mg/kg)	900.0	932.0	870	871.2	783.2	773	806.4	867.4	796	511.2	491.2	601	579.0	647.0	613
Mn(mg/kg)	470.5	475	496	220.2	211.2	199.3	1654	1354	1693	682.4	672.4	680	317.0	337.0	309
Cu(mg/kg)	3827.0	3027	2893	540.7	593.7	556	1825.0	1137	1613	4103.0	4737	3981	3168.0	3479	3051
Zn (mg/kg)	3060	2984	3101	1942	2734	1591	2694	1953	2176	2984	3060	3141	1050	1942	581
Fe(mg/kg)	4522	4328	4613	3884	3979	3892	5389	5945	5197	5444	5411	5712	3438	3136	3391
Cr(mg/kg)	63.2	82.0	59.71	30.2	28.3	35.8	91.1	87.5	89.3	51.4	71.1	47.1	45.2	43.9	50.1
Pb(mg/kg)	99.4	103.1	98.1	44.9	51.0	48.6	39.7	27.8	35.0	72.8	73.6	78.3	53.9	52.5	56.3
Cd(mg/kg)	6.6	4.5	7.3	11.0	9.7	10.9	10.4	13.1	10.3	4.3	3.5	5.6	8.2	9.7	8.5
Ni(mg/kg)	16.6	16.2	18.0	6.6	7.4	4.5	16.3	9.5	15.7	20.7	18.3	21.3	13.6	15.8	13.9

APPENDIX 8: Correlation matrix for leachate where the bottom is the correlation coefficient for Pantang leachate (PL) and the top is the correlation coefficient for Mallam leachate (ML).

	PH	DO	TSS	TUR	EC	TDS	BOD	COD	NO_3	NO_2	NH_3	TP	SO_4	SO_3	Zn	Cu	Cr	Pb	Mn	Fe	Cd	Ni
PH	1.0	0.103	0.471	-0.508	-0.481	-0.118	-0.199	0.446	0.725	0.790	0.484	0.088	-0.289	-0.117	0.490	0.195	-0.093	0.434	0.057	0.477	0.710	0.664
DO	-0.427	1.0	0.269	-0.738	0.167	-0.930*	-0.992**	0.897*	0.700	0.167	-0.364	0.274	-0.667	0.621	0.881*	0.196	0.501	0.258	0.879*	-0.123	-0.255	-0.152
TSS	0.849	-0.532	1.0	-0.829	-0.414	-0.033	-0.347	0.184	0.660	0.215	0.127	0.791	0.251	0.518	0.241	0.357	-0.410	0.934*	0.047	-0.269	0.471	0.051
TUR	0.210	-0.042	0.614	1.0	0.289	0.543	0.792	-0.692	-0.897*	-0.393	-0.005	-0.609	0.249	-0.676	-0.710	-0.417	-0.061	-0.801	-0.557	0.105	-0.297	-0.101
EC	-0.286	0.921*	-0.229	0.345	1.0	-0.422	-0.162	-0.015	-0.120	-0.763	-0.939*	0.207	-0.451	-0.403	0.117	-0.874	-0.205	-0.670	-0.124	-0.663	-0.940*	-0.836
TDS	-0.424	0.784	-0.194	0.541	0.938*	1.0	0.931*	-0.891*	-0.657	-0.082	0.520	-0.173	0.879*	-0.293	-0.919*	0.121	-0.448	0.054	-0.762	0.134	0.431	0.230
BOD	0.315	-0.977**	0.373	-0.152	-0.974**	-0.857	1.0	-0.908*	-0.781	-0.191	0.365	-0.350	0.681	-0.580	-0.914*	-0.157	-0.412	-0.306	-0.829	0.146	0.211	0.143
COD	-0.802	-0.010	-0.775	-0.606	-0.263	-0.170	0.191	1.0	0.795	0.518	-0.083	0.026	-0.810	0.404	0.975**	0.236	0.584	0.201	0.858	0.247	0.013	0.217
NO_3	0.782	-0.849	0.647	-0.091	-0.818	-0.859	0.813	-0.322	1.0	0.476	-0.057	0.498	-0.547	0.315	0.864	0.135	0.016	0.551	0.470	-0.002	0.252	0.164
NO_2	0.855	-0.103	0.843	0.603	0.158	0.079	-0.077	-0.993**	0.418	1.0	0.788	-0.370	-0.212	0.184	0.420	0.645	0.454	0.402	0.408	0.859	0.808	0.939*
NH_3	-0.619	0.261	-0.858	-0.889*	-0.104	-0.206	-0.053	0.846	-0.314	-0.867	1.0	-0.474	0.388	0.113	-0.218	0.733	0.243	0.388	-0.005	0.830	0.918*	0.931*
TP	-0.850	0.624	-0.929*	-0.560	0.360	0.317	-0.460	0.768	-0.753	-0.830	0.860	1.0	0.126	0.275	0.173	-0.200	-0.657	0.556	-0.148	-0.785	-0.121	-0.548
SO_4	-0.946*	0.431	-0.668	0.118	0.414	0.616	-0.384	0.605	-0.828	-0.661	0.331	0.676	1.0	0.138	-0.854	0.317	-0.426	0.356	-0.557	-0.122	0.358	0.029
SO_3	-0.750	0.708	-0.614	0.226	0.709	0.807	-0.716	0.227	-0.882*	-0.328	0.138	0.554	0.853	1.0	0.289	0.753	0.420	0.694	0.693	-0.050	0.158	0.037
Zn	0.292	-0.088	0.317	0.558	0.089	0.158	-0.071	-0.585	0.170	0.556	-0.665	-0.579	-0.085	0.262	1.0	0.056	0.406	0.178	0.742	0.102	-0.059	0.096
Cu	0.252	-0.831	0.223	-0.071	-0.842	-0.727	0.815	0.066	0.726	0.004	-0.149	-0.502	-0.272	-0.380	0.434	1.0	0.520	0.666	0.510	0.549	0.675	0.645
Cr	-0.493	0.948*	-0.660	-0.314	0.775	0.604	-0.863	0.213	-0.806	-0.311	0.523	0.788	0.403	0.570	-0.370	-0.840	1.0	-0.148	0.836	0.601	-0.006	0.394
Pb	-0.483	-0.255	-0.008	0.562	-0.058	0.290	0.197	0.272	-0.241	-0.256	-0.259	-0.039	0.671	0.434	0.266	0.274	-0.375	1.0	0.204	-0.013	0.639	0.282
Mn	-0.013	-0.742	-0.092	-0.589	-0.924*	-0.878	0.866	0.583	0.580	-0.492	0.452	0.013	-0.195	-0.581	-0.393	0.655	-0.508	0.028	1.0	0.274	-0.055	0.181
Fe	-0.439	0.891*	-0.491	0.167	0.871	0.815	-0.920*	-0.103	-0.799	-0.017	0.052	0.442	0.524	0.879*	0.333	-0.542	0.731	0.007	-0.797	1.0	0.652	0.941*
Cd	0.665	-0.677	0.349	-0.391	-0.784	-0.909*	0.690	-0.188	0.919*	0.257	-0.041	-0.532	-0.800	-0.771	0.167	0.727	-0.597	-0.440	0.610	-0.624	1.0	0.866
Ni	0.024	0.722	0.144	0.618	0.926*	0.889*	-0.846	-0.578	-0.582	0.495	-0.466	-0.016	0.188	0.529	0.298	-0.716	0.504	-0.016	-0.990**	0.732	-0.654	1.0

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX 9: Correlation matrix for air where the bottom is the correlation coefficient for Pantang air and the top is the correlation coefficient for Mallam air

	PM10	TSP	CO	NH3	SO2	Zn	Ni	Cu	Mn	Cr	Cd	Pb	Fe
PM10	1	1.000**	0.820	0.890	-0.314	**-0.571**	0.668	0.866	**-0.812**	**-0.853**	**-0.882**	0.983	1.000**
TSP	1.000**	1	0.820	0.890	-.0314	**-0.571**	0.668	**-0.866**	**-0.812**	**-0.853**	**-0.882**	0.983	0.820
CO	0.972	0.969	1	0.991	**-0.801**	**-0.938**	0.123	-0.425	**-1.000****	-0.998*	**-0.993**	0.910	0.991
NH3	0.969	0.966	1.000**	1	**-0.712**	**-0.882**	0.256	**-0.543**	**-0.989**	**-0.997***	**-1.000***	0.958	**-0.712**
SO2	0.950	0.946	0.997	0.998*	1	0.959	0.496	-0.202	0.810	0.763	0.724	-0.481	0.959
Zn	**-0.988**	**-0.986**	**-0.997**	**-0.996**	**-0.987**	1	0.229	0.084	0.943	0.915	0.890	**-0.710**	0.229
Ni	**-0.767**	**-0.760**	**-0.896**	**-0.901**	**-0.929**	0.857	1	**-0.951**	0.107	-0.182	0.239	0.522	**-0.951**
Cu	0.642	0.651	0.445	0.434	0.371	**-0.516**	-0.001	1	0.411	0.478	0.529	**-0.761**	0.411
Mn	0.978	0.976	1.000*	0.999*	0.994	**-0.998***	**-0.884**	0.469	1	0.411	0.478	0.529	**-0.761**
Cr	0.902	0.897	0.978	0.980	0.992	**-0.958**	**-0.969**	0.249	0.972	1	0.997*	0.991	-0.904
Cd	**-0.728**	**-0.720**	**-0.868**	**-0.874**	**-0.906**	0.825	0.998*	0.058	**-0.855**	**-0.953**	1	0.998*	**-0.934**
Pb	0.122	0.134	-0.114	-0.125	-0.194	0.033	0.543	0.839	-0.087	-0.318	0.591	1	**-0.953**
Fe	0.783	0.775	0.907	0.912	0.938	**-0.869**	**-1.000***	0.026	0.895	0.975	**-0.997**	**-0.522**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX 10: Correlation coefficients for soil parameters determined at the Pantang landfill

	PH	OC	OM	EC	NO_3	NH_3	Mn	Cu	Zn	Fe	Cr	Pb	Cd	Ni
PH	1.0													
OC	-0.051	1.0												
OM	0.083	0.983**	1.0											
EC	-0.363	**-0.643**	**-0.602**	1.0										
NO_3	0.162	**-0.676**	**-0.568**	0.836	1.0									
NH_3	-0.149	-0.399	-0.445	0.311	0.436	1.0								
Mn	0.646	0.509	0.564	**-0.642**	-0.190	0.163	1.0							
Cu	0.585	-0.237	-0.081	0.213	0.393	**-0.596**	-0.112	1.0						
Zn	0.157	0.031	0.163	0.539	0.715	0.184	0.196	0.328	1.0					
Fe	0.467	0.575	0.692	-0.200	0.135	-0.029	0.761	0.183	0.717	1.0				
Cr	0.823	0.098	0.200	-0.341	0.214	0.310	0.892*	0.133	0.355	0.691	1.0			
Pb	0.139	**-0.663**	**-0.542**	0.857	0.921*	0.076	-0.412	0.647	0.634	0.018	-0.017	1.0		
Cd	-0.254	0.249	0.098	**-0.573**	**-0.617**	0.431	0.301	**-0.881***	**-0.626**	-0.239	0.051	**-0.841**	1.0	
Ni	0.784	-0.088	0.092	0.075	0.423	-0.435	0.250	0.925*	0.499	0.499	0.479	0.564	**-0.790**	1.0

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX 11: correlation coefficient for groundwater where the bottom is the correlation coefficient for PG1and the top is the correlation coefficient for PG2

	pH	TSS	TUR	EC	TDS	BOD	COD	DO	NO$_3$	NO$_2$	NH$_3$	TP	SO$_4$	SO$_3$	Zn	Cu	Cr	Mn	Fe	Cd	Ni
Ph	1.0	-0.945	-0.009	0.735	0.605	0.927	0.992	-0.993	0.780	-0.077	-0.948	0.777	0.801	-0.149	0.815	0.854	0.666	0.580	0.510	0.205	0.441
TSS	**-0.636**	1.0	-0.916	-0.831	-0.999*	-0.898	0.977	-0.942	0.397	1.000**	-0.940	-0.952	0.463	-0.959	-0.977	-0.873	-0.814	-0.762	0.125	-0.710	-0.916
TUR	**-0.519**	0.990	1.0	-0.685	-0.801	-0.384	0.115	0.127	-0.632	0.998*	0.325	-0.636	-0.606	0.990	-0.587	-0.527	-0.751	-0.820	-0.865	0.977	-0.901
EC	-0.386	0.957	0.989	1.0	0.985	0.936	0.645	-0.810	0.998*	-0.733	-0.912	0.998*	0.995	-0.780	0.992	0.980	0.995	0.979	0.958	-0.514	0.933
TDS	**-0.831**	0.958	0.907	0.834	1.0	0.860	0.502	-0.965	0.958	-0.840	-0.826	0.971	0.961	-0.877	0.955	0.931	0.997	1.000*	0.993	-0.656	0.981
BOD	**-0.989**	0.514	0.387	0.245	0.740	1.0	0.873	-0.971	0.697	-0.446	-0.998*	0.957	0.967	-0.510	0.973	0.987	0.898	0.843	0.796	-0.178	0.746
COD	**-0.804**	0.052	-0.091	-0.238	0.338	0.883	1.0	-0.971	0.697	0.047	-0.902	0.693	0.721	-0.026	0.737	0.784	0.569	0.475	0.400	0.324	0.327
DO	1.000*	**-0.658**	**-0.543**	-0.412	**-0.847**	**-0.984**	**-0.787**	1.0	-0.849	0.195	0.979	-0.846	-0.866	0.265	-0.878	-0.910	-0.750	-0.672	-0.608	-0.087	-0.545
NO$_3$	**-0.533**	0.992	1.000*	0.986	0.914	0.402	-0.074	**-0.557**	1.0	-0.683	0-.938	1.000**	0.999*	-0.735	0.998*	0.992	0.986	0.962	0.936	-0.452	0.905
NO$_2$	**-0.901**	0.908	0.839	0.748	0.990	0.827	0.466	**-0.913**	0.847	1.0	0.389	-0.687	-0.659	0.997*	-0.641	-0.584	-0.794	-0.857	-0.897	0.960	-0.929
NH$_3$	0.770	**-0.982**	**-0.945**	**-0.886**	**-0.995**	**-0.667**	-0.240	0.788	**-0.950**	**-0.971**	1.0	0-.937	-0.949	0.455	-0.957	-0.975	-0.869	-0.808	-0.756	0.117	-0.703
TP	0.928	**-0.877**	**-0.800**	**-0.701**	**-0.978**	**-0.863**	**-0.525**	0.938	**-0.810**	**-0.998***	0.952	1.0	0.999*	-.738	0.998*	0.991	0.987	0.963	0.938	-0.457	0.908
SO$_4$	0.958	**-0.831**	**-0.743**	**-0.634**	**-0.956**	**-0.905**	**-0.600**	0.966	**-0.753**	**-0.988**	0.921	0.996	1.0	-.712	1.000*	0.995	0.980	0.952	0.923	-0.422	0.891
SO$_3$	0.351	0.500	0.619	0.729	0.229	-0.485	**-0.839**	0.324	0.606	0.091	-0.327	-0.023	0.067	1.0	-0.695	-0.641	-0.837	-0.892	-0.927	0.937	-0.953
Zn	-0.348	0.945	0.982	0.999*	0.811	0.205	-0.277	-0.375	0.979	0.721	**-0.866**	**-0.672**	**-0.603**	0.756	1.0	0.997*	0.975	0.945	0.914	-0.401	0.880
Cu	0.997*	**-0.577**	-0.454	-0.316	**-0.787**	**-0.997***	**-0.846**	0.995	-0.469	**-0.866**	0.721	0.898	0.934	0.419	-0.277	1.0	0.957	0.919	0.882	-0.334	0.843
Cr	-0.261	0.911	0.961	0.991	0.754	0.116	-0.363	-0.289	0.956	0.655	**-0.817**	**-0.602**	**-0.528**	0.812	0.996	-0.189	1.0	0.994	0.981	-0.593	0.963
Mn	-0.160	0.864	0.927	0.972	0.682	0.012	-0.458	-0.188	0.920	0.573	**-0.753**	**-0.516**	-0.437	0.868	0.981	-0.086	0.995	1.0	0.996	-0.679	0.987
Fe	-0.306	0.929	0.973	0.996	0.784	0.162	-0.320	-0.333	0.969	0.689	**-0.843**	**-0.638**	**-0.567**	0.784	0.999*	-0.234	0.999*	0.989	1.0	-0.738	0.997*
Cd	0.920	**-0.887**	**-0.812**	**-0.716**	**-0.982**	**-0.852**	**-0.508**	0.931	**-0.821**	**-0.999***	0.958	1.000*	0.994	-0.043	**-0.687**	0.889	**-0.618**	**-0.533**	**-0.654**	1.0	-0.788
Ni	0.636	**-1.000****	**-0.990**	**-0.957**	**-0.958**	**-0.514**	-0.052	0.658	**-0.992**	**-0.908**	0.982	0.877	0.831	**-0.500**	**-0.945**	0.577	**-0.911**	**-0.864**	**-0.929**	0.887	1.0

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX 12: Photos of research site

Pantang landfill showing thick smoke emanating from it due to the constant burnig at the site

Peripheral drains to carry leachates from decommissioned landfill site at Mallam

Air sampling at the Mallam landfill site.

LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviations and acronyms	Meaning
AQI	Air Quality Index (AQI)
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CNGAA	Carnegie Next Generation of Academics in Africa
CF	Contamination factor
DO	Dissolved Oxygen
LPI	Pollution Index (LPI)
MA	Mallam air
OC	Organic carbon (%OC)
OM	Organic matter (%OM)
PA	Pantang air
PG	Pantang groundwater
PS	Pantang soil
PL	Pantang leachate
TSS	Total suspended solids
TDS	Total dissolved solid
TP	Total Phosphorus
TSP	Total suspended solids
TUR	Turbidity
VFA	Volatile fatty acid
VOA	Volatile organic acid