KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

ASSESSMENT OF EFFECT OF LEACHATE ON WELL WATER QUALITY AT ATONSU DOMPOASE LANDFILL SITE

BY

OPONG, KWAME ASAMOAH

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MSc. ENVIRONMENTAL SCIENCE

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CERTIFICATION

I hereby declare that this submission is my own work towards the MSc. And that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

OPONG, KWAME ASAMOAH …………………. ……………………

Signature Date

Certified by:

R.C. ABAIDOO, Ph.D …………………. ....………………
(Supervisor)

Signature Date

Certified by:

(Head of Department) …………....…… ……......…………

Signature Date

DEDICATION

I dedicate this work to my family especially my sister Akua Fosuah Oppong.

ABSTRACT

Globally, safe drinking water is important and is fundamental to health, survival, and growth. Well water sources are treated and managed for safe use in developed countries like Germany whiles in developing countries like Ghana well water is assumed to be free from all pathogenic organisms and consumed without prior treatment. Only a small proportion of the populace have access to treated piped water across the globe including Ghana of which residents of Atonsu Dompoase is of no exception. The closeness of a landfill facility to well water sources have a potential of infiltrating the water and causing health related problems like cholera, skin rashes and diarrhoea as alluded to by residents of Atonsu Dompoase. The objective of this research was to assess the possible effect of leachate percolation on well water quality at Atonsu Dompoase Landfill Site. Concentrations of various physico-chemcial parameters including heavy metal elements (Cd, Cr, Cu, Fe, Ni, Pb and Zn) and microbiological parameters (total coliform, TC and faecal coliform, FC) were established in both leachate and well water samples. The effect of distance of wells from the Atonsu Dompoase Landfill was also investigated. Leachate and well water samples were collected from Atonsu Dompoase Landfil Site and Atonsu Dompoase community, respectively. Results were subjected to statistical evaluation using Analysis of Variance (ANOVA). The ANOVA was conducted with the Genstat software. All analyses were conducted at a significance level of 5 %. TC and FC counts; pH and electrical conductivity (EC) were significantly higher in well water samples collected from Atonsu Dompoase vicinity than the Ghana EPA/GSB standards and are of great concern to public health when the water from these wells is consumed without prior treatment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ASCE	Alliance for a Clean Environment
BOD	Biochemical Oxygen Demand
CFU	Coliform Forming Unit
COD	Chemical Oxygen Demand
GMT	Greenwich Meridian Time
GW	Groundwater Sample
HDPE	High Density Polyethylene
JSO	J-Stanley Owusu
KMA	Kumasi Metropolitan Assembly
KNUST	Kwame Nkrumah University of Science and Technology
LAWMA	Lagos State Waste Management Authoritys
LFG	Landfill gas
LLSI	Leak Location Services Incorporated
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NCP	Non-conventional pollutants
NGO	Non-Governmental Organization
PCB	Polychlorianated biphenyls
SP	Strategic Planning
SWM	Solid Waste Management
TIE	Toxicity Identification Evaluation
UNCHS	United Nations Centre for Human Settlements
USEPA	United States Environmental Protection Agency

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Pollution is a term generally applied to the introduction into the environment of substances which are potentially harmful to human health or which impair the legitimate use of the environment for economic, social, cultural, aesthetic and amenity uses (Akuffo, 1998; Alloway, 1998; Hawken, 2008). The causes of such pollutions (pollutants) are mostly waste materials that are released directly or indirectly into the environment. Such pollutants have varied sources which may either be natural or artificial. Pollution as a result of natural disasters such as the hurricanes often involves water contamination from sewage, and petrochemical spills from ruptured boats, pipes or automobiles.

These pollutants are the leachates which are liquids that, in passing through matter, extract solutes, suspended solids or any other component of the material through which they pass. The leachate from municipal solid waste (MSW) landfills is a highly concentrated "chemical soup", so concentrated that small amounts of it can pollute large amounts of groundwater rendering it unsuitable for use for domestic water supply (Lee and Jones, 1993).

Groundwater is a globally important and valuable renewable resource for human life and economic development. It constitutes a major portion of the earth's water circulatory system known as hydrologic cycle. This occurs in permeable geologic formations known as aquifers i.e. formations having structure that can store and transmit water at rates fast enough to supply reasonable amounts to wells. Its importance stems from its ability to act as a large reservoir of water that provides "buffer storage" during periods of drought.

Pollutants in groundwater can be from various sources, mainly municipal (i.e. leakages, liquid waste and solid wastes from landfill), industrial (i.e. liquid wastes, tank and pipeline leakages, oil field and brines) and agricultural sources (i.e. irrigation return flow which are sometimes saline).

Alternatively, it may also be from spills, surface discharges in the form of hydrocarbons in groundwater table or from stockpiles in industrial, constructional or agricultural sites. It may be as a result of contamination from cesspools, septic tanks, saline water intrusion and interchange through wells. All these are sources of leachate in groundwater. Dispersion plays an important role in groundwater pollution. This is because groundwater spreads out and changes in volume due to molecular diffusion and mechanical dispersion beneath the ground (Bharat *et al*., 2009).

Dispersion of pollutants in the soil is controlled by permeability and porosity of soil particles. In addition, proximity of the source of pollutants may play a prominent role in groundwater pollution. For example, a study conducted in India showed that the percentage of polluted wells significantly increased with increasing distance to pollution sources. For instance, 76.08% of the sampled wells got polluted when located close to pen drains, 64.40% were polluted when located near a pool of stagnant wastewater, while, 32.30% got polluted when garbage dump was nearby (Mahedeven *et al.*, 1984). In a similar study, Asimi (1998) in Ilorin (Nigeria) concluded that effluents from slaughtering slab increases groundwater COD, total hardness, total solids, turbidity and other water quality variables in the immediate vicinity of these slabs.

According to *Zero Waste America'*s website (www.zerowaste.com), a landfill is a carefully designed structure built into or on top of the ground in which trash is isolated from the surrounding environment. Although, the purpose of landfill construction is to avoid any water-related connection between the waste and the surrounding environment, particularly groundwater (Lee, 1996), it is, however, the most common site for organized waste disposal that provides almost all the necessary conditions for the production of leachate with moisture as a key ingredient. It can also be regarded as a viable and abundant source of materials and energy that pose major threats to groundwater resources (Lee and Jones, 1993; Fatta *et al.*, 1999; USEPA, 1984).

Landfilling is a controlled method of disposing solid waste on land with the dual purpose of eliminating public health effects, environmental hazards and without contaminating surface-subsurface resources of freshwater. The basic principle of a landfill operation is to prepare a site with a liner system that minimises the probability of groundwater contamination; deposit the refuse in the pit; compact it with specially built heavy duty machinery; cover the material with soil. When recharge water passes through the buried wastes, significant amounts of inorganic contaminants may be dissolved or leached from the waste (Tchobanoglous *et al*., 1992). The liquid that is derived from this process is responsible for degrading the quality of groundwater.

According to *Free Drinking Water's website* (www.freedrinkingwater.com), the recommended distance from potential pollution sources including septic systems to drinking wells is 160 metres. Again, according to the Free Drinking Website, the recommended safe distance between a landfill and a drinking well is 365 metres or more. The closest house to the Atonsu Dompoase Landfill site is about 300 metres away which is shorter than the recommended distance of 365 metres.

1.2 Problem Statement and Justification

Globally, water pollution is a major problem. It has been suggested that it is the leading worldwide cause of deaths and diseases and that it accounts for the deaths of more than 14,000 people daily (West, 2006). Research studies carried on water contamination in various parts of the world have showed widespread contamination of water resources in many countries (Pedersen and Johnson, 1997). Safe drinking water, sanitation and good hygiene are fundamental to health, survival, growth and development. However, these basic necessities are still a luxury for many of the world's poor people. Over 1.1 billion people do not use drinking water from improved sources, while 2.6 billion lack basic sanitation (WHO, 2006). Efforts to prevent death from diarrhoea and its related diseases or to reduce the burden of diseases like ascariasis, dracunculiasis, schistosomiasis, trachoma and hookworm infestations are doomed to failure unless people have access to safe drinking water and basic sanitation. Lack of basic sanitation indirectly inhibits the learning abilities of millions of school-aged children who are infested with intestinal worms transmitted through inadequate sanitation facilities and poor hygiene.

Although, quality drinking water is essential for life, many countries around the world do not have access to treated water due to its scarcity (International Development

Labour Organization, IDLO, 2006), hence only a small proportion of the populace have access to treated water. This makes inhabitants in such areas to rely on alternative sources of drinking water of which that from hand dug wells are of no exception. For instance, most of the inhabitants at Atonsu Dompoase depend on hand dug wells as sources of drinking water because of the unavailability or access to treated piped water. These hand dug wells are easy to construct, manually dug by hand, they are frequently patronized by rural dwellers and smaller communities. They also provide a cheap and low-technological solution to accessing groundwater. Public health researchers suggest of possible contamination of the water meant for drinking during the process of collection, transportation and storage, hence recommend prior drinking treatments like boiling or the addition of hypochlorite solution to kill most microbial parasites before drinking (Lindskog, 1988; Genthe *et al.*, 1997). Mariam and her colleagues ((Mariam *et al.*, 2009) made a similar recommendation when the quality of water from hand dug wells in the Kumasi Metropolis was assessed in 2009.

Unlike developed countries where water from sources like wells are well treated and managed for safe use for both industrial and domestic purposes, for example, in Germany where access to safe water is universal (more than 99 per cent of users are connected to a public water supply system) (WHO,1990), in developing countries like Ghana, the use of groundwater has become an agent of development because governments are unable to meet the ever increasing water demands by both industries and inhabitants. They, however, tend to look elsewhere for water in the form of shallow wells and boreholes (Azzeez, 1972; LAWMA, 2000). These shallow wells and boreholes although they naturally purify the water as the water strains through the layers of the soil, some harmful materials are allowed to pass through eventually entering into the groundwater supply (Monroe, 2001). It has, however, been realized that groundwater source is in serious danger of being contaminated as any liquid that finds its way into the ground eventually enters the groundwater supply (Speidel *et al.*, 1988).

One of the predominant contaminants is leachate which eventually finds its way into the groundwater supply. Many studies have been conducted on the effect of leachate-polluted groundwater on living systems around the globe. Two of such studies conducted in Nigeria by Albion (1995) and Dolk (1999) reported an increase in the occurrence of bladder cancer and leukemia. The common birth defect reported is low birth weight and the children tend to be shorter than those who do not consume leachate-polluted water (Dolk, 1999). Impaired locomotion and reduced spleen weight was also reported in mice after consuming leachate-contaminated water (Radi *et al.*, 1987). Residence of Atonsu Dompoase attributes their skin rashes and the frequent epidemics of cholera to the consumption of the perceived leachate-polluted water. The World Health Organization, (WHO) also reports in their 1990 bulletin that polluted water, is a major cause of many human diseases and death. According to WHO, as many as 4 million children die every year as a result of diarrhoea caused by water-borne infection. The bacteria most commonly found in polluted water are coliforms excreted by humans (WHO, 1990).

A visit to the Atonsu Dompoase landfill site in Kumasi revealed that it started its operation on 28th of January, 2004 on a 100-acre piece of land on which the solid waste receiving cells are built alongside with nine (9) waste stabilization ponds to receive and partially treat leachate coming out of the solid waste at the site. The design period for the facility is 15 years, planned to be developed in three phases of five years each. Solid waste from various communities of the Kumasi metropolis is brought to the site in truckloads of various types by different companies.

However, enquiries made from the company in charge of the operations at the Atonsu Dompoase landfill site (J- Stanley Owusu Company Limited), revealed that leachates from the landfill are partially treated and discharged into the nearby Oda River which serves as a source of drinking water in contradiction to the World Health Organisation's (WHO), Ghana Environmental Protection Agency's (Ghana EPA), and the Ghana Standard Board's (GSB) accepted guidelines. Moreover, available evidence suggests that inhabitants are oblivious of the environmental hazards associated with the improper management of the landfill site hence do not undertake measures to mitigate the health effects associated with these poor management practices thereby exposing themselves to serious health implications.

1.3 Objective of the study

The main objective of the study was to assess the effect of leachate percolation in the water from ten selected hand dug wells in the Atonsu Dompoase community.

Specific objectives

1. To establish the contamination levels of selected heavy metal elements like Zn, Pb, Fe, Cd, Cu, Ni and Cr in the leachate from the landfill and water from hand dug wells.
2. To establish the contamination levels of microbiological contaminants like faecal and total coliforms in both leachate from the landfill and water from hand dug wells.
3. To establish the contamination levels of selected physico-chemical parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), nitrate (NO_3^-), nitrite (NO_2^-), sulphate (SO_4^{2-}), total suspended solids (TSS) in both leachate from the landfill and water from hand dug wells.

CHAPTER TWO

2.0 LITRATURE REVIEW

2.1 Water and its quality

The term “water quality” was coined with reference to the quality of water required for human use: “good quality” water is “clean, unpolluted and suitable for drinking as well as for agricultural and industrial purposes. Although, scientific measurements are used to define the quality of water, it's not a simple thing to say that “this water is good," or “this water is bad ". The quality of water that is required to wash a car is not the same quality that is required for drinking purposes. Therefore, when we speak of water quality, we usually want to know if the water is good enough for its intended use, be it for domestic, farming, mining or industrial purposes, or its suitability to maintain a healthy ecosystem (Department of Water Affairs and Forestry, DWAF, 1996).

According to Alloway (1977) in Nigeria, leachates that originate from landfills pollute groundwater resources and this has been recognized for a long time. The extent of leachate toxicity depends on many factors including the age and composition of the waste material under which the leachate is formed. Although, the benefits accrued from leachates originating from non-hazardous, organic and nutrient rich wastes cannot be overlooked on, the continuous presence of some heavy metal elements and harmful chemicals as well as microbial presence and activities influence the level of toxicity of the leachate formed. Climatic conditions such as increase in rainfall have significant effects on the hazardous level of the leachate. For example, since rainwater facilitates the drainage of water and dissolved substances and chemicals through the soil, its presence will continue to leach chemicals, physicals and biological substances through the soil. Operationally, Ghana Environmental Protection Agency's (Ghana EPA) and other stakeholders in environmental sector recommend best practices that will reduce to the minimum, environmentally related problems such as one from sanitary landfills.

Jain *et al.* (1995) in India conducted a research on water quality and revealed that the quality of groundwater is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring and varies from place to place and with the depth of the water table.

Kumar (2004) also in India said that groundwater is particularly important as it accounts for about 88 % of safe drinking water in rural areas, where population is widely dispersed and the infrastructure needed for treatment and transportation of surface water does not exist.

Pollution of groundwater has been reported for a number of urban aquifers throughout the world because of its overwhelming environmental significance. A wide range of pollutants have been recognized including heavy metal elements, chlorinated hydrocarbons, phenols, cyanide, pesticides, major inorganic species and bacteria. Their impact on groundwater continues to raise concern and have become the subject of past and recent investigations (Ikem *et al.*, 2002; Ahmed and Sulaiman, 2001; Fatta *et al.*, 1999; Kdjelsen *et al.*, 1998; Bjerg *et al.*, 1995; Loizidou and Kapetanios, 1993; Gallorini *et al.*, 1993; Robinson and Gronow, 1992).

Rapid population growth and urbanization result in increasing environmental concerns of which the pollution of groundwater resource is of no exception. According to a World Bank report (2000a), the population of Nigeria was estimated at 140 million and about 43 % of the populace currently lives in cities or urban areas. The rate of urbanization in Nigeria is alarming and the major cities are growing at rates between 10-15 % per annum. Although, there is no proper documentation with regards to the population of the inhabitants at Atonsu Dompoase, residence of Atonsu Dompoase believe their population has increased tremendously. As the rate of population and urbanization increases, our natural resources of which groundwater is of no exception may be polluted if proper sanitation practices do not commensurate with the volume of waste produced with time. It is, therefore, prudent for the environmental sanitation units in the District Assemblies to implement their byelaws with regards to sanitation so that culprits will be sanctioned appropriately.

Okoye and Adeleke (1991) in Nigeria revealed that groundwater, if abstracted from adequately protected source has undoubtedly bacteriological and physical qualities comparable to those of treated water. The slow percolation and horizontal flow through the ground is superb filtration, removing pathogens including viruses and bacteria (Chanlett, 1979; Pelig-Ba, 1996). The quality limitations result from mineralization by the dissolved carbon dioxide as the waste passes over rock deposits and also from pollutants leached down from the earth surface.

The exposure of the environment to landfill leachate may occur in different ways, including uncontrolled overflow, rainfall run-off, subsidence and infiltration, so that the most common practice to avoid risks is to pump and discharge leachate into wastewater treatment plants. For example, the improper disposal of by-products of beer brewing, soap making and textile industries could lead to liberation of high levels of Ca^{2+}, Mg^{2+}, K^+, Cl^-, PO_4^{3-} and SO_4^{2-} into the environment which could be leached down into the groundwater.

2.2 Pollutants

The introduction of contaminants into natural environment causes instability, disorder, harm or discomfort to the ecosystem (Merriam-Webster Online Dictionary, 2010). Thus, pollution can take the form of chemical substances or energy, such as noise, heat, or light. Pollutants, the elements of pollution, can be foreign substances or energies, or naturally occurring. When naturally occurring, they are considered contaminants when they exceed natural levels. It is often classified as point source, when the pollutants are directly released into the environment or non-point, when the pollutants are not directly released into the environment. Also, point source pollution refers to contaminants that enter a waterway through a discrete conveyance, such as a pipe or ditch. Examples of sources in this category include discharges from a sewage treatment plant, a factory, or a city storm drain.

Non–point source (NPS) pollution also refers to diffuse contamination that does not originate from a single discrete source. NPS pollution is often the cumulative effect of small amounts of contaminants gathered from a large area. The leaching out of nitrogenous compounds from agricultural land which has been fertilized is a typical example. Nutrient run-off in storm waters from "sheet flow" over an agricultural field or a forest is also an example of NPS pollution. Also, contaminated storm water washed off of parking lots, roads and highways, called urban runoff, is sometimes included under the category of NPS pollution.

However, this run-off is typically channelled into storm drain systems and discharged through pipes to local surface waters, and is a point source. Not all, solute extracts, suspended solids or any other component of the material through which they pass are all examples of NPS of pollution. Thus, any liquid material that drains from land or stockpiled material could contain significantly any elevated concentration of undesirable material derived from the material through which it passes.

2.3 Water Pollution

Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds. Polluted water affects not only the individual species living in these water bodies, but also to the natural biological communities (West, 2006).

2.4 Water pollution as a public health problem

The increasing demand for water resulting from both the economic and population growth has to be met from limited resources shared by competing user groups (DWAF, 1986). Lack of safe drinking water supply and basic sanitation and hygienic practices are associated with high morbidity and mortality from excreta related diseases.

Diarrhoeal illness remains a major killer in children and it is estimated that eighty per cent (80 %) of all illness in developing countries is related to water and sanitation; and that 15 % of all child deaths under the age of 5 years in developing countries result from diarrhoeal diseases (UNICEF, 2004).

Water pollution is a major problem in the global context. It has been suggested that it is the leading worldwide cause of deaths and diseases (Pink, 2006) and that it accounts for the deaths of more than 14,000 people daily (West, 2006). An estimated 700 million Indians have no access to a proper toilet, and 1,000 Indian children die from diarrheal related sicknesses everyday. Some 90 % of China's cities suffer from some degree of water pollution and nearly 500 million people lack access to safe drinking water. In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well (USEPA, 2007).

2.5 Groundwater and its pollution

Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support human use, like serving as drinking water, or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish. Natural phenomena such as volcanoes, algal blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water.

Surface water and groundwater have often been studied and managed as separate resources, although they are interrelated (United States Geological Survey USGS, 1999). Surface water seeps down the soil to form groundwater. Close relationship exists between groundwater quality and land use. Various land use activities can result in groundwater contamination. Potential sources of groundwater pollution include solid waste landfills, on-site excreta disposal systems, cemeteries and animal wastes resulting from human activities among others. In a solid waste landfill (open dumping or sanitary landfill), the organic and inorganic by-products resulting from the decomposition of wastes are leached out by the infiltration of rainfall. If leachate is released to the surrounding soil without proper collection and treatment, it could contaminate groundwater resources (Somjai *et al*., 1993).

Studies have shown that the leachate causes an increase in dissolved inorganic substances such as chloride, sulphate, bicarbonate, sodium and potassium of groundwater (Zanoni *et al.*, 1973; Kelly, 1976). Groundwater contamination can originate on the surface of the ground, above the water table, or below the water table. Where contamination originates is a factor that can affect its actual impact on groundwater quality. In comparison with rivers, groundwater tends to move very slowly and with very little turbulence. Therefore, once the contamination reaches the groundwater, dilution or dispersion normally takes a longer time. The contaminants usually form a concentrated plume that flows along the same path as the groundwater. Among the factors that determine the size, form and rate of movement of contaminant plume are the amount and type of contaminant and the velocity of groundwater movement. Groundwater contaminants could be undetected for years until the supply is tapped for use.

2.6 Possible sources of groundwater pollution

Groundwater can be polluted in numerous ways in spite of the protective mantle which nature has provided. Liquid pollutants can originate, for example, from wastewater stabilization ponds, sludge lagoons, barnyard runoff, septic tanks, leaching fields or seepage pits, pit privies and the deep well disposal of certain industrial wastes or treatment plant effluents. Pollutants can also originate from the leachate of decomposing solid wastes (municipal solid waste) as in the case of open dumps, sanitary landfills, solid waste composting sites, industrial refuse and treatment plant sludge. The causes of such pollutions (pollutants) are mostly waste materials that are released directly or indirectly into the environment. Such pollutants have varied sources which may either be natural or artificial.

The specific contaminants leading to pollution in water include a wide spectrum of chemicals, pathogens, and physical or sensory changes such as elevated temperature and discolouration. While many of the chemicals and substances that are regulated may be naturally occurring (calcium, sodium, iron, manganese, etc.) the concentration is often the key in determining what is a natural component of water, and what is a contaminant. Oxygen-depleting substances may be natural materials, such as plant matter (e.g. leaves and grass) as well as man-made chemicals. Other natural and anthropogenic substances may cause turbidity (cloudiness) which blocks light and disrupts plant growth, and clogs the gills of some fish species (USEPA, 2005.)

Chemical contamination is a common problem with groundwater. Nitrates from sewage or fertilizers are a particular problem for children. Pesticides and volatile organic compounds from gasoline, dry cleaning, and many other sources are the most commonly occurring chemical pollutants in the U.S., and may be identifiable in more than a third of all U.S. wells, although this is mostly at levels below U.S. water standards. Other notable chemical contaminants include the fuel additive methyl tert-butyl ether (MTBE), and per chlorate from rocket fuel, airbag inflators, and other artificial and natural sources. Iron and manganese can appear as dark flecks that stain clothing and plumbing, and can promote the growth of iron and manganese bacteria that can form slimy black colonies that clog pipes (Driscoll, 1986).

2.7 Sanitary Landfill Sites

Solid waste landfills are necessities in modern-day society, because the collection and disposal of waste materials into centralized locations help minimize risk to public health and safety. However, they have been identified as one of the major threats to groundwater resources (Fatta *et al.*, 1999; USEPA, 1984). Sanitary landfills are sites of controlled burial of refuse with surface areas ranging from tens to hundreds of hectares. It is a method of disposing refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary, Alliance For a Clean Environment, (ASCE, 1959).

The purpose of the isolation is to avoid any water-related connection between the waste and the surrounding environment, particularly groundwater. Therefore, the siting of a landfill depends on its ability to be isolated from the groundwater bodies and other sources where leachates may cause pollution. There are four main components of any secured permitted landfill; a bottom liner, a leachate collection system, a cover and the natural hydrological setting.

An evolution in landfill design among developed countries over the last thirty years has resulted in highly engineered modern facilities with systematic containment of solids, liquids and gases. For example, in the U.S., 62 % of municipal solid waste was landfilled in 1993 (USEPA, 1994). Increasingly, more controlled landfilling practices are evolving in developing countries like South Africa and Brazil. After refuse burial, anaerobic conditions are quickly established with depletion of free oxygen and oxygenated species (USEPA, 1994).

Landfills function as small dispersed anoxic basins with high rates of microbially-mediated methane generation at temperatures and pressures slightly above ambient temperatures and pressures. This setting is similar to early digenetic conditions for anaerobically buried organic matter in geologic settings (Bogner, 1992; Bogner and Spokas, 1993; Bogner and Spokas, 1995). At a landfill, however, the transition between aerobic conditions at the top and anaerobic conditions in the thick refuse sequence below (zone of methanogenesis) occurs over short vertical distances. Aerobic soils at the top may be characterized by high capacities for methanotrophic methane oxidation as a natural bioremediation mechanism (Mancinelli *et al*., 1981; Mancinelli and McKay, 1985; Whalen *et al*., 1990; Knightley *et al*., 1995).

Despite all the highly engineered modern facilities, it is widely recognized that even the best installed plastic liners will succumb to deterioration and eventually will allow leachate to be created and released. For instance, a study conducted in the United States by Lee and Jones-Lee (2000) on landfill liners reiterates that liners and compacted clay will eventually fail.

According to Leak Location Services Incorporated (www.LLSI.org), 82 % of surveyed landfill cells had leaks while 41 % had a leak area of more than one square feet, which is an alarming statistic considering that in addition to leakage, landfills also provide problems to health and environment through hazardous contaminated air emissions and microbial pathogens. There is no debate that all landfills eventually contaminate our environment and pose a serious threat to our health. In a study of 163 municipal solid waste landfills, there was evidence of groundwater contamination or adverse trends in groundwater quality at 146 of them. That's 90 % contamination rate for groundwater beneath municipal solid waste landfills (www.zerowaste.com).

2.8 Leachate and its components

Classical unlined sanitary landfills are well-known to release large amounts of hazardous and otherwise deleterious chemicals nearby groundwater and to the air, via leachate ("garbarge juice") and landfill gas, respectively. It is known that such releases contain a wide variety of potential carcinogens and potentially toxic chemicals that represent a threat to public health. In addition to potential carcinogens and highly toxic chemicals, MSW leachate contains a variety of conventional pollutants that render a leachate-contaminated groundwater unusable or highly undesirable due to tastes and odours, reduced service life of appliances (e.g. dishwashers, hot water heaters, plumbing), fabric (clothes), etc. Further, both gas and leachate from MSW landfills contain many organic chemicals that have not been characterized with respect to specific chemical content or their associated public health or other hazards. These “non-conventional pollutants” include more than 95 % of the organics in MSW leachate (Lee and Jones, 1993).

The precipitation that falls into a landfill, coupled with any disposed liquid waste, results in the extraction of the water-soluble compounds and particulate matter of the waste, and the subsequent formation of leachate. The creation of leachte presents a major threat to the current and future quality of groundwater. Other major threats include underground storage tanks, abandoned hazardous waste sites, agricultural activities and septic tanks. The composition and polluting potential of the leachate is dependent on the landfill waste which comprises a wide range of inorganic, natural and xenobiotic compounds (Kjeldsen *et al*., 2002). Therefore, leachate quality is site specific, and even within a single landfill site, variability is frequently evident (Depart of Energy, DoE, 1995). Because leachate is any liquid that passes through matter and extracts solutes, suspended solids or any other component of the material through which it passes, organic and inorganic contaminants, water-based solution such as dissolved organic matter (alcohols, acids, aldehydes, short chain sugars etc.), inorganic macro components (common cations and anions including sulphate, chloride, iron, aluminium, zinc and ammonia), heavy metals like lead (Pb), nickel (Ni), Cupper (Cu), mercury (Hg), and xenobiotic organic compounds such as halogenated organics, (PCB’s, dioxins etc.) are always dissolved and extracted as the solvent (leachate) passes through the refuse. Once in contact with decomposing solid waste, the percolating water becomes contaminated and flows out of the waste material as leachate (Hickman *et al*., 2005). For example, in 1993, Lee and colleagues reported in the USA that municipal landfill leachate have highly concentrated complex contaminants which contain dissolved organic matters, inorganic compounds, such as ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, chlorides and heavy metals such as cadmium, chromium, copper, lead, nickel, zinc and xenobiotic organic substances (Lee and Jones, 1993).

According to Canter *et al.* (1988), McGinley *et al*. (1984), and Lee and Jones (1991), a typical leachate contains total alkalinity (as $CaCO_3$), chloride (Cl^-), calcium (Ca), magnesium (Mg), sodium (Na), sulphate (SO_4^{2-}), iron (Fe), total nitrogen (TN), potassium (K), chromium (Cr), manganese (Mn), copper (Cu), lead (Pb) and nickel (Ni).

Christensen *et al.* (1994) in addition to some of the components mentioned above also identified dissolved organic matter and anthropogenic organic carbons derived from household and industrial wastes including aromatic hydrocarbons and phthalate esters. The dissolved organic carbon is expressed as chemical oxygen demand (COD), or total organic carbon (TOC) and volatile fatty acids (VFA).

The contaminants carried in leachate are dependent on solid waste composition and on the simultaneously occurring physical, chemical and biological activities within the landfill (Monroe, 2001). Heavy metal elements such as Pb, Cr, Cu, and Cd, together with household chemicals and poisons can be concentrated in groundwater supplies beneath landfills (Wagner and Rhyner, 1984). These contaminants have been reported to possibly cause growth retardation and haematological abnormalities (Hogson, 2004).

2.8.1 The Chemistry of Landfill Leachate

Leachate quality varies throughout the operational life of the landfill and long after its closure. During the early stages of waste degradation and leachate generation, the composition is acidic and high in volatile fatty acids (the acetogenic phase). This acidic leachate may dissolve other components of the wastes, such as heavy metal elements. The leachate also contains high concentrations of ammoniacal nitrogen, organic carbon and biochemical oxygen demand (BOD).

As degradation of the waste progresses, conditions in the landfill become more anaerobic and the strongly reducing methanogenic phase is initiated. The majority of the remaining organic compounds are high molecular weight humic acids and the leachates are characterised by relatively low BOD values. Ammoniacal nitrogen generally remains at high concentrations in the leachate, but falling redox potential immobilises many metals as sulphides in the waste (Pohland *et al.*, 1993; Belevi and Baccini, 1992).

There are strong seasonal variations in both the quantity and quality of leachate generated. Differences in leachate chloride concentration from the same site indicate the variation in the volume of leachate being generated, since chloride is a conservative anion not affected by biodegradation or decay. Changes in other major ion concentrations may result from pH or redox changes in the leachate and interactions with the waste matrix.

Reinhart and Grosh (1998) in the USA in a work entitled '*Analysis of Florida Municipal Solid Waste Landfill Leachate Quality'* made a contribution that the leachate formed would vary widely in composition which would be dependent on many interacting factors including the composition and depth of waste, moisture and oxygen, landfill design, operation and age.

2.8.2 Release and Migration of Landfill Leachate.

Once leachate is formed and is released to the groundwater environment, it will migrate downward through the unsaturated zone until it eventually reaches the saturated zone**.** Leachate will then follow the hydraulic gradient of the groundwater system. A release of leachate to the groundwater may present several risks to human health and the environment. The release of hazardous and non-hazardous components of leachate may render an aquifer unusable for drinking water purposes and other uses. Leachate impacts to groundwater may also present a danger to the environment and to aquatic species if the leachate-contaminated groundwater plume discharges to wetlands or streams.

Monitoring wells at landfills allow scientists to determine whether contaminants in leachate are escaping into the local groundwater system. The wells are placed down the gradient of the landfill at appropriate depths and at various intervals to intercept any contaminants and monitor their movement.

A number of forces may act on or react with the migrating leachate, resulting in changes of chemistry and a general reduction of strength from the original release. These forces are physical (filtration, sorption, advection, and dispersion), chemical (oxidation-reduction, precipitation-dissolution, adsorption-desorption, hydrolysis, and ion exchange), and biological (microbial degradation). The extent of these reactions depends on the materials underlying the landfill, the hydraulics of the groundwater system, and the chemistry of the leachate.

Although, many of these reactions have the capability to reduce the potential impact to groundwater, some (such as microbial degradation) can actually increase the toxicity by producing by-products that are more hazardous than the original contaminant. This can be seen, for example, in the creation of vinyl chloride from the degradation of trichloroethene.

2.8.3 Management of Landfill Leachate

The risks of leachate generation can be mitigated by adopting properly and engineered landfill sites such as sites that are constructed on geologically impermeable materials or sites that use impermeable liners made of geotextiles or engineered clay. The use of linings is now mandatory within both the United States and the European Union and some parts of Africa like Ghana except where the waste is deemed inert. In addition, most toxic and difficult materials are now specifically excluded from landfilling.

However, despite much stricter statutory controls, leachates from modern sites are now found to contain a range of contaminants that may either be associated with some level of illegal activity or may reflect the ubiquitous use of a range of difficult materials in household and domestic products which enter the waste stream legally. Once groundwater is contaminated, it is very costly to clean up. Today's landfills, therefore, undergo rigorous siting, design, and construction procedures that provide many safeguards for the control of leachate migration. A designed lining system, which ensures low-permeability limit the movement of leachate into groundwater. Liners are made from low-permeability soils (typical clays) or synthetic materials (e.g. plastic). Landfills can be designed with more than one liner, and a mix of liner types may be used. The minimum requirements for waste disposal by landfill from the Department of Water Affairs and Forestry gives detail information on landfill liner designs for the different classes of landfill sites (DWAF, 1986).

2.8.4 Treatment of Landfill Leachate

Landfill leachate can be added into incoming wastewater stream at sewage works, where it is biologically, physically, and/or chemically treated. In South Africa, for example, the routine treatment of leachate has tended to concentrate on biological treatment in order to reduce the organic components to acceptable levels. Biological treatment can be preceded by treatment of the organic constituents by physical or chemical treatment, in order to make the liquid more acceptable for biological processing, since the best overall treatment efficiencies can generally be achieved by removing the inorganic constituents first, and then removing the organic constituents.

2.8.5 Physical treatment of Landfill Leachate

According to American National Research Council (ANRC, 1991), physical treatment methods are used to remove, separate and concentrate hazardous elements and compounds, both organic and inorganic, from dilute and concentrated waste streams. Most physical treatment methods that have been applied to leachate treatment are conventional technologies and can remove a variety of problem contaminants. Increasingly, membrane technologies other than simple reverse osmosis such as electrodialysis and ultrafiltration are being applied.

However, most membrane technologies suffer from problems associated with blockage of the membranes and landfill leachates with their relatively high COD's are often not good candidates for these technologies. Reverse osmosis has, however, had some success. Pre-treatment with physical technologies prior to biological treatment have been largely using sedimentation, coagulation and flocculation or filtration in order to remove suspended solids. After biological treatment, the presence of high concentrations of salts normally prevents direct discharge to the environment. Options for treatment include evaporation or reverse osmosis with the recovery of a brine or solid salt material that often has to be disposed back into the landfill. Clearly, unless this process is managed carefully it is essentially self-defeating, since the salt can re-enter the leachate and the treatment cycle has to be repeated.

2.8.6 Chemical treatment of Landfill Leachate

Chemical treatment methods have been widely used to treat leachate. This includes neutralization, oxidation, precipitation and wet-air oxidation. Chemical pre-treatment of leachate prior to biological treatment has included the addition of an alkali, usually lime, in order to raise the pH and to precipitate out heavy metal elements or, if the amount of Ca in leachate is a problem, soda ash is added to precipitate calcium carbonate.

Chemical oxidation has also been widely used in South Africa. Hydrogen peroxide is used at most sites in South Africa for the mitigation of odours produced by the leachate, since it readily reacts with any sulphide and mercaptan components that normally cause the odour. Hydrogen peroxide is expensive and large amounts would be required to have any significant impact on the concentration of organics in the leachate. In the UK, ozone has been used to oxidise recalcitrant organics such as humic acids, in order to break the molecules and make them more susceptible to biological treatment (ANRC, 1991).

2.8.7 Biological treatment of Landfill Leachate

Biological treatment methods are processes whereby microbes are used to destroy or at least reduce the toxicity of a waste stream. Normally, biological treatment of predominantly aqueous wastes such as leachate is accomplished in specially designed bioreactors. A suitable culture of the micro-organisms or microbial association, either aerobic or anaerobic, is chosen. Biological treatment is firmly established as the standard method of waste treatment for domestic sewage, waste from food processing, hazardous waste e.g. phenols, cyanide, oils and leachate. For leachates, a large number of approaches to biological treatment are proposed, but many are unproven and have not yet been shown to be effective on site. The general types of transformations that can be accomplished biologically include degradation of organics to products such as carbon dioxide, methane, water and inorganic salts e.g. phenols, reduction of inorganic compounds e.g. nitrate and complexation of heavy metal elements e.g. nickel. Discharge to sewage works, however, is not an option in all cases. The contaminants in leachate can sometimes upset sewage work operations. Typical leachate can often exceed the required discharge limits particularly in terms of COD and salt contents. The discharge of heavy metal elements into the sewer system is, normally strictly controlled. Those metals of concern to the water authority include Fe, Zn, Cd, As, and Hg. The last three are normally present in extremely lower amounts of leachate, particularly from domestic sites, although high amounts of Fe are often found, American National Research Council (ANRC, 1991).

2.8.8 On-site treatment and Recirculation of Landfill Leachate

When discharge to a sewage system is not feasible, constructing treatment facilities on-site with the sole purpose of treating leachate may be necessary. The Aloes Class H: H disposal facility in the Eastern Cape is an example of this. These facilities will add to the cost of a new facility, but may be required to meet environmental standards. On-site treatment reduces high concentrations of COD and BOD. Retention times from 10 to 50 days can result in the removal of 90% of COD and ammonia. Nitrification of high concentrations of ammonia can be achieved by extended aeration and at increased temperatures. The addition of phosphoric acid may be required for microbial growth and inputs of sodium hydroxide for pH adjustment. The operating parameters vary, depending on the quality and nature of the \leachate and extended trials are required to determine these for a specific leachate. Aerobic treatment results in a reasonable reduction in COD and ammonia and can be accomplished at quite high conductivity and chloride levels. However, the resulting effluents will still have a relative high COD and high conductivity, which is mainly related to chloride levels. Polishing of the leachate has included the use of artificial reed beds and ozone treatment prior to discharge to a watercourse. These methods have been applied widely to the on-site treatment of leachate from domestic waste sites, although waste sites that have accepted limited hazardous waste have also been successfully treated.

Recirculation is another management technique for leachate. When leachate is recirculated through the waste pile, the decomposition process in the landfill speeds up, resulting in a shorter time for the landfill to stabilize. The technique, however, does not eliminate the leachate. Ultimately, the leachate will have to be treated by one of the other methods. Especially in cases where too much leachate is produced for storage thereof in evaporation ponds (ANRC, 1991).

2.8.9 Economic Importance of Leachates

Although, leachates contain potential carcinogens which are otherwise deleterious to micro-organisms, they can be employed in phytoremediation which can provide an opportunity for closing cycling loop and simultaneously producing effluent of a suitable quality for discharge (Qasim and Chiang, 1994). Again, depending on the levels of the leachate contaminants, leachates aid in eutrophication which helps in the continual survival of aquatic organisms.

The impact of the leachate on the plant's microspora and microfauna is very high and governed by several factors, such as high load of organic matter, heavy metal elements, high content of nitrogen and mass flux of transported contaminants (Loizidou and Kapetanios, 1993; Kjeldsen and Grundtvig, 1995). The assessment of the potential impact of leachate components on a treatment plant and the choice of an appropriate reduction scheme requires the identification of the classes of compounds responsible for the toxicity observed. Identifying contaminants responsible for toxicities is difficult because of the restricted number of chemicals detected by routine analysis, the complexity of the leachate mixtures, and the uncertainty surrounding their bioavailability.

However, the toxicity identification evaluation (TIE) approach developed by the US Environmental Protection Agency (USEPA, 2007) is a useful tool to detect and identify the toxic agents. The method combines chemical and physical fractionation techniques with the response of test organisms and allows us to identify the nature of the toxicants before instrumental analysis. The TIE methodology is divided into three phases: toxicant characterization (Phase I) (King- Norberg *et al*., 1991), toxicant identification (Phase II) (Durhan *et al*., 1993) and toxicant confirmation (Phase III) (Mount, 1989).

2.9 Gaps in the Literature Review and proposed solution

The main objective of this work was to assess the effect of leachate percolation on well water quality at the Atonsu Dompoase landfill site. The specific objectives focused on: establishing the contamination levels of some selected heavy metal elements (Zn, Pb, Fe, Cd, Cu, Ni and Cr), physico-chemical parameters: (pH), electrical conductivity, (EC), total dissolved solids (TDS), nitrate (NO_3^-), nitrite (NO_2^-), sulphate (SO_4^{2-}), and total suspended solids (TSS), as well as microbiological parameters (total and faecal coliforms) in both leachate from Atonsu Dompoase landfill and well water from the Atonsu Dompoase community, respectively and comparing the results from the study with the Ghana Standard Board (GSB) /Environmental Protection Agency's standards (Ghana EPA). Many studies conducted on water quality around the globe including both developed and developing countries focus on depth of wells and lateral distance between the perceived pollution source (in this case the landfill) and the wells. For example, in the water quality analysis undertaken by Chu *et al.* (1994) in India, they considered the effect of depth of wells and the lateral distance between the pollution source (landfill site) and the wells. Chu and his colleagues simply used the effect of distance from the perceived pollution source (Gazipur landfill) and the depth of wells and failed to use alternate methodologies (like the use of tracer dyes) which are time consuming and capital intensive for water quality analysis. In a related study, Mariam and her colleagues in Kumasi (Ghana) assessed the quality of hand dug wells in the Kumasi metropolis using the usual methodology of distance and depth of hand dug wells from perceived pollution sources.

The current study (effect of leachate percolation on well water quality at Atonsu Dompoase landfill site) failed to use alternate methodologies like the use of a tracer dye like rhodamine WT in monitoring the movement of leachate contaminants from the landfill to the nearby wells in the Atonsu Dompoase community. Martin and McCutcheon (1999) in the U.S.A documented that rhodamine WT is the dye most commonly used as water tracer. Wilson *et al*. (1986) in the U.S.A, added their contribution and outlined the following desirable properties of rhodamine WT for tracer studies in water: high solubility in water, high fluorescence (easily detected), fluorescence in a part of the visible spectrum not common to materials generally found in water thereby reducing the problem of background fluorescence, harmless in low concentrations, inexpensive, and reasonably stable in a normal water environment. The current study, but for lack of time and money, could have employed the use of rhodamine WT tracer in monitoring the possible movement of the contaminants from the landfill site to the nearby wells.

The current study failed to gather enough geological and hydrogeological data about the study area due to time and financial constraints. The geological data include slope stability characteristics, and seismicity while the hydrogeological data include the groundwater regime, direction of flow, gradient and rate of flow including long-term and seasonal fluctuations, the permeability (horizontal and vertical) strata with maximum and minimum values, the distribution, thickness and depth of aquifers including the locations of any spring, the groundwater levels indicating hydraulic gradients and effective flow velocity in the individual strata components if any, the groundwater chemistry including determination of naturally occurring aggressive substances and water quality, the groundwater protection zones, the groundwater abstraction and its effects, the groundwater abstraction rights and groundwater recharge. Davidson (1995) in the USA argues that some of the geological and hydrogeological data mentioned above should be considered during water quality analysis.

The present study failed to establish the relationship that exists between land use and well water quality. According to United States Geological Survey, (USGS, 1999), a close relationship exist between land use and groundwater quality and that potential sources of well water pollution include solid waste landfills like the Atonsu Dompoase landfill.

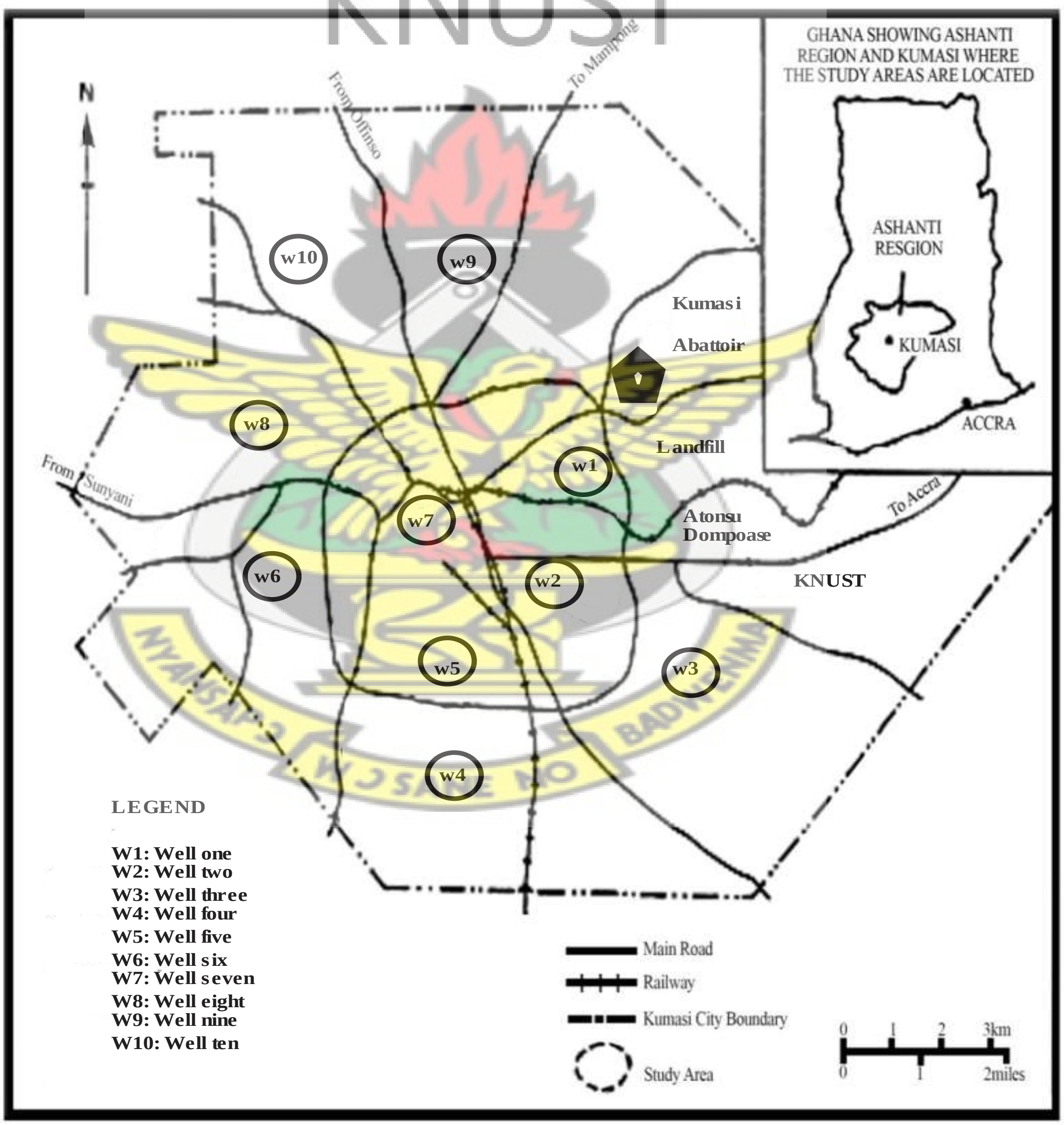
The study requires further research on the geology and hydrogeology of the Atonsu Dompoase landfill site taking into consideration the time and money as elements for successful execution of the research while using alternate methodologies like the use of rhodomine WT tracer dye in tracking leachate contaminants.

CHAPTER THREE

3.0: MATERIALS AND METHODS

3.1: Study Site

The study was conducted in the Atonsu Dompoase community in the Oforikrom sub-metro of the Kumasi Metropolis, Ghana.



3.1.1: Location and Climate

Kumasi Metropolis lies within latitudes $6^{0}35^{1}$ and $6^{0}40^{1}$ longitudes of $1^{0}30^{1}$ and $1^{0}35^{1}$, with an area of 254 km^2. The unique central location of the city as a traversing point from all parts of the country makes it a special place in terms of the social, economic, cultural and political life of the country. It has a good network of roads, with the Central Business District, (CBD) in the city centre, and other infrastructures like telephones (both mobile and landlines), electricity and water facilities. The topography of the city is gentle, with four main drainage basins. There are often flooding in low-lying areas where flood plains have not been protected from illegal developers and/or due to siltation of drains or unauthorized refuse dumps along the natural courses of storm water. The climate of the city is the wet sub-equatorial type with a double maxima rainfall regime of about 214.3 mm in June and 165.2 mm in September. The average temperature ranges between 21.5 to 30.7 ^{0}C, with the average humidity of about 84.16 % at 0900 GMT and 60 % at 1500 GMT.

3.1.2: Sampling Period

The sampling took place from December, 2010 to April, 2012. Permission (verbal communication) was sought from, J-Stanley Owusu Company Limited, the operators of the landfill site as well as owners of the hand dug wells in the Atonsu Dompoase community.

3.1.3: Sample Size

Out of thirty (30) hand dug wells found in the Atonsu Dompoase community, ten (10) hand dug wells were frequently used by the inhabitants of Dompoase community as source of drinking water. A sample each of well water was then fetched from this usable hand dug wells. The leachate samples were also collected from the Atonsu Dompoase landfill site.

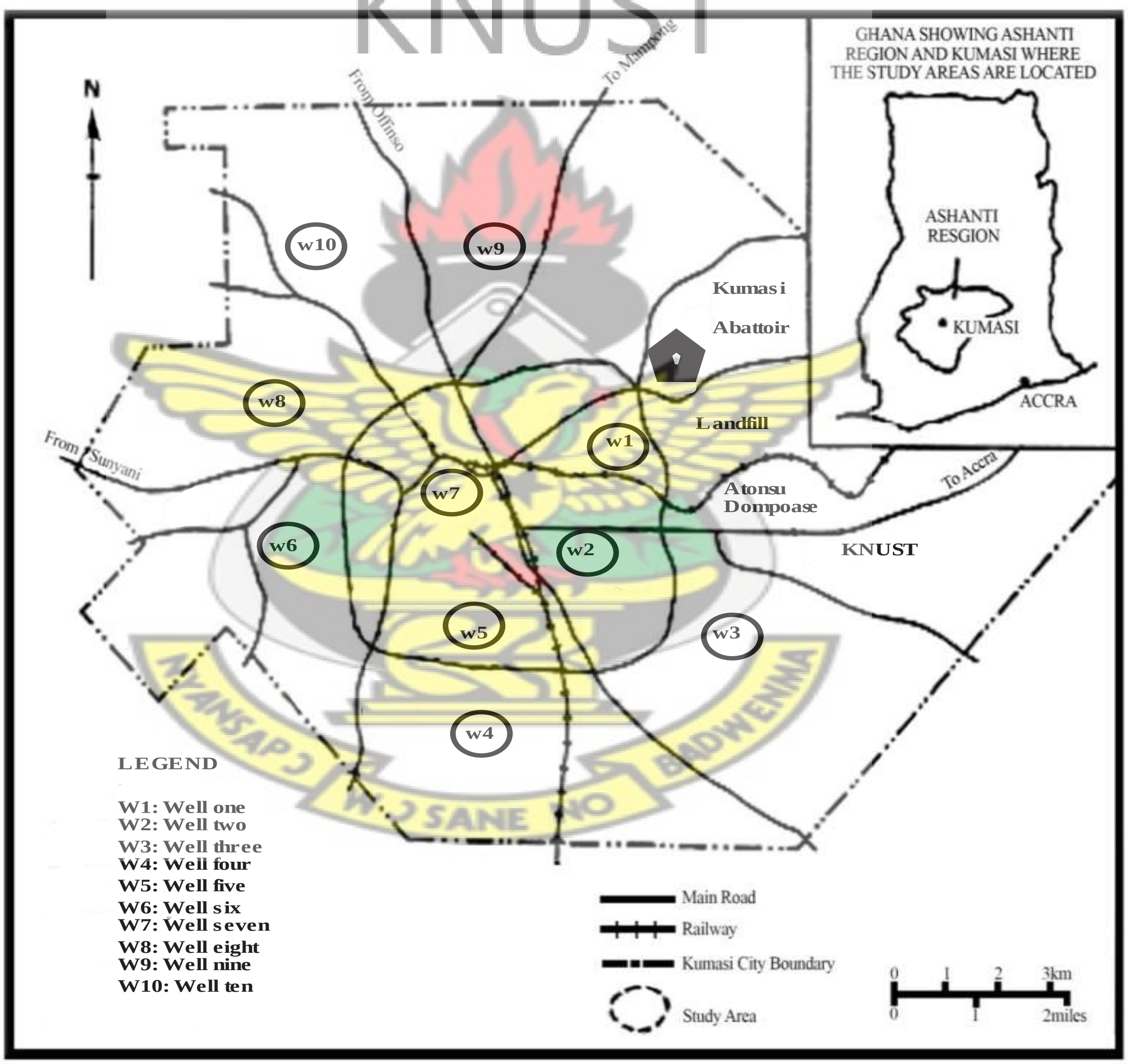


Plate 3.1:Map of Atonsu Dompoase showing the selected wells

The Atonsu Dompoase landfill site is located at Atonsu Dompoase in the south-east of Kaase, Kumasi. The site has 100-acre piece of land with nine (9) waste stabilization ponds to receive and partially treat leachate coming out of the solid waste. The design period for the facility is 15 years, planned to be developed in three phases of five years each and started its operations on 28th of January, 2004.

Topography of selected wells

Topographically, apart from well 1 which was slightly a low hill to the landfill site, all the other nine (9) selected wells were on varying levels. Wells 2, 3 and 6 were slightly on higher hills than wells 4, 5, 7, 8, 9 whiles 10 was also slightly on higher hills than wells 4, 5, 7, 8 and 9, respectively. The average distance from the landfill site to the ten selected wells was 1400 m.

3.1.4: Sampling Strategy

The ten water samples from the wells were aseptically fetched early in the morning by using already sterilized polythene sealed containers labelled as GW_1, GW_2, GW_3, GW_4, GW_5, GW_6, GW_7, GW_8, GW_9, and GW_{10}, for the well water samples from wells 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, respectively. Because the leachate released from the landfill site had one source of exit from the site, and to get a good representation of the leachate sample for analyses, three different leachate samples were taken in the morning, afternoon and evening, averaged and labelled as LS_m, LS_a, and LS_e , respectively. These containers were immediately placed in ice pack containers and sealed. Samples for bacteriological analyses were kept in ten screw-capped bottles that had been sterilized in an autoclave for 15 minutes at 121^0C. A graduated measuring stick (which had been sterilized by washing with carbolic soap, rinsed with distilled water and wiped with 70 % alcohol) was designed to measure the depth of the water on-site. The pH levels of both the well water and leachate samples were measured with an Aquatic Eco pH meter. The samples for microbiological analysis were put in an ice pack container and all collected samples were immediately transported to the Anglo Gold Ashanti (AGA) laboratory, Obuasi for physico-chemical and microbiological analyses within 24 hours of collection time.

3.2: Media for coliform bacteria detection and their preparations

The media used for the detection of the two main coliform bacteria (total and faecal) forms were M-Endo Broth and M-Fc Broth for the detection and enumeration of both total and faecal coliforms, respectively.

Preparation of M-Endo Broth

Dehydrated Endo medium of 4.8 g was weighed and suspended in 100 mL of distilled water containing 2.0 mL of 95 % ethanol. The suspension was then put in a beaker, covered with aluminium foil (acting as complete barrier to light and oxygen) and placed on a magnetic stirrer/heater for 5 minutes so that the magnetic stirrer/heater would automatically stir the suspension while heating it on the hot plate. The medium was removed from the hot plate immediately it began to boil and allowed to cool to room temperature.

Preparation of M-Fc Broth

Dehydrated FC medium of 3.7 g was weighed and suspended in 100 mL of distilled water. One milliliter (1 mL) of 1 % solution of rosolic acid, (which had been prepared by dissolving 0.08 g of NaOH and 0.1 g of rosolic acid in 10 mL distilled water), was added to a 0.2 N sodium hydroxide (NaOH). The mixture was then covered with aluminium foil (acting as complete barrier to light and oxygen) and placed on an electronic magnet stirrer/heater to stir and heat the mixture simultaneously. It was then removed from the hot plate immediately the medium began to boil and subsequently allowed to cool to room temperature.

3.2.1 Preparation of plates (Petri dishes)

Petri dishes of microbiological grade of 47 mm in diameter were labelled on the underside. The label contained the sample code, type of analysis and starting date. An absorbent pad was aseptically deposited into each of the dishes using a pair of flat-ended sterile forceps. Using a sterile pipette, 2 mL of the appropriate medium (at room temperature) was dispensed onto the absorbent pad. The pad was only saturated and not flooded. The cover of the Petri dish was lifted just enough to dispense the medium.

3.2.2 Filtration

In the filtration process, the leachate sample was thoroughly mixed by shaking and filtered through 0.45 µm pore size membrane filter paper, using vacuum filtration. Some of the micro-organisms present in the leachate remained on the filter surface. The filter was then placed in a sterile Petri dish and saturated with M-FC agar and incubated for

24 hours at 44.5 °C. Sample volumes of 1 mL and 10 mL were used for the water testing, with the goal of achieving a final desirable colony density range of 20 to 60 colonies per filter. This elevated temperature heat shocked non-faecal bacteria and suppressed their growth.

3.3 Determination of heavy metal elements by Atomic Absorption Spectrophotometry (AAS)

The heavy metal elements were determined by AAS. The samples were pre-treated before aspiration. In the pre-treatment of the heavy metal elements, 10 mL of deionised water (as standard blank), the standard solutions and the leachate (sample) solution were pipetted into separate 100 mL volumetric flasks. Ten millimeters (10 mL) of concentrated hydrochloric acid and 10 mL of saturated solution of sodium metal were added to each of the solutions and allowed to stand for 45 minutes at ambient temperature.

3.4 Digestion and extraction of metal elements (Fe, Cu, Pb, Cd, Cr and Zn)

A procedure recommended by United States Environmental Protection Agency (USEPA, Method 3050B) was used as the conventional acid extraction method. One hundred milliliters (100 mL) of the leachate sample was put in a 250 mL flask for digestion. The first step was to heat the leachate sample to 95 ^{0}C with 10 mL of 50 % HNO_3 without boiling. After cooling the leachate sample, it was refluxed with repeated additions of 65 % HNO_3 until no brown fumes were given off by the sample. Then the solution was allowed to evaporate until the volume was reduced to 5 mL. After cooling, 10 mL of 30 % H_2O_2 was added slowly without allowing any losses. The mixture was refluxed with 10 mL of 37 % HCl at 95 ^{0}C for 15 minutes (USEPA, 1996). The digestate obtained was filtered through a 0.45 µm membrane paper, diluted to 100 mL with deionized water and stored at 4 ^{0}C for analyses.

3.4.1 Analytical Procedure for AAS

A standard blank solution was made by measuring 10 mL of deionised water with the measuring cylinder. Also, a series of calibration solutions containing known amounts of analyte element (the standards) were made. The blank and standards were atomized in turn and the response for each solution measured. The concentration of the sample from the calibration was then determined based on the absorbance obtained for the unknown.

3.5 Statistical Analysis

The variations in the various water quality parameters were determined using one-way Analysis of Variance (ANOVA). Principal Factor Analysis (PFA) was performed to determine the parameters which were the main indicators of pollution in the Atonsu Dompoase community. The ANOVA was conducted with the Genstat software whiles the PFA was run using Minitab 15 software. All analyses were conducted at a significance level of 5 %. The PFA was used because of its ability to reduce number of variables, by combining two or more variables into a single factor and also its ability to identify groups of inter-related variables and to establish how these variables are related to each other.

3.6: Quality Control for both Water Quality Analysis and Analytical Procedure for AAS

The stored reagents were regularly monitored, samples and reagents from refrigerators were allowed to reach room temperatures and Petri dishes were placed upside down in the incubator to prevent condensation on the undercover. Also, counting of the colonies was not extended beyond 48 hours as the characteristics of most colonies change after long incubation periods and finally autoclaving all inoculated and incubated materials 15 minutes at 121 ^{0}C before disposal.

CHAPTER FOUR

4.0: RESULTS

The various methods employed in the study yielded three main groups of results which were physico-chemical parameters, heavy metal elements and microbial parameters. Emphasis on the microbiological analysis was on faecal and total coliforms as these were the main parameters indicative of possible microbial contamination. Developed colonies were identified as total coliforms when they appeared pinkish in colour with a metallic sheen; they were identified as faecal coliform when they appeared yellow in colour (USEPA, 2008).

4.1: Physico-chemical parameters in leachate sample

Table 4.1 below summarizes the concentrations of the various physico-chemical parameters in leachate samples. It could be seen that apart from pH, all the other parameters were significantly higher than the Ghana EPA/GSB standards.

Table 4.1: Physico-chemical parameters in leachate sample from Atonsu Dompoase Landfill

Physico-chemical parameters in leachate	Concentration (mg/L)	EPA/GSB Acceptable limits of concentration (mg/L)
pH	8.2	6.0-9.0
EC	2008	1500
TDS	1303	1000
TSS	1520	50
NO_2^-	780	50
NO_3^-	1600	50
SO_4^{2-}	1250	250
BOD	148	50

All units of parameters in mg/L except pH and EC (μScm^{-1})

4.2: Physico-chemical parameters in well water sample

From Table 4.2 below, it could be seen that out of the eight (8) physico-chemical parameters analyzed across the ten selected well water samples, EC had a higher mean concentration of 365.5 μS/cm as compared to the Ghana EPA acceptable limit of 250 mg/L while NO_2^- measured least mean concentration of 0.17 mg/L as compared to the Ghana EPA acceptable limit of 3.0 mg/L.

Table 4.2: Physico-chemical parameters in well samples from Atonsu Dompoase community

Physico-chemical parameters in well water samples	Concentration (mg/L)	EPA/GSB Acceptable limits of concentration (mg/L)
pH	5.9	6.0-9.0
EC	365.5	1500
TDS	72.25	1000
TSS	2.25	50
NO_2^-	0.17	50
NO_3^-	17.5	50
SO_4^{2-}	19.69	250
BOD	1.48	50

All units of parameters in mg/L except pH and EC (μScm^{-1})

4.3: Heavy metal elements in leachate samples

Figure 4.1 below shows the concentration of heavy metal elements obtained in leachate samples selected for the study. As expected, it could be seen that the heavy metal element concentration in the leachate samples were not always as low as the heavy metal element concentration in the well water samples. The concentration of Fe (16.148 mg/L) was higher than the Ghana EPA acceptable limit of 10 mg/L while Cd (0.059 mg/L) measured least mean value compared to the Ghana EPA standard value of 0.1 mg/L.

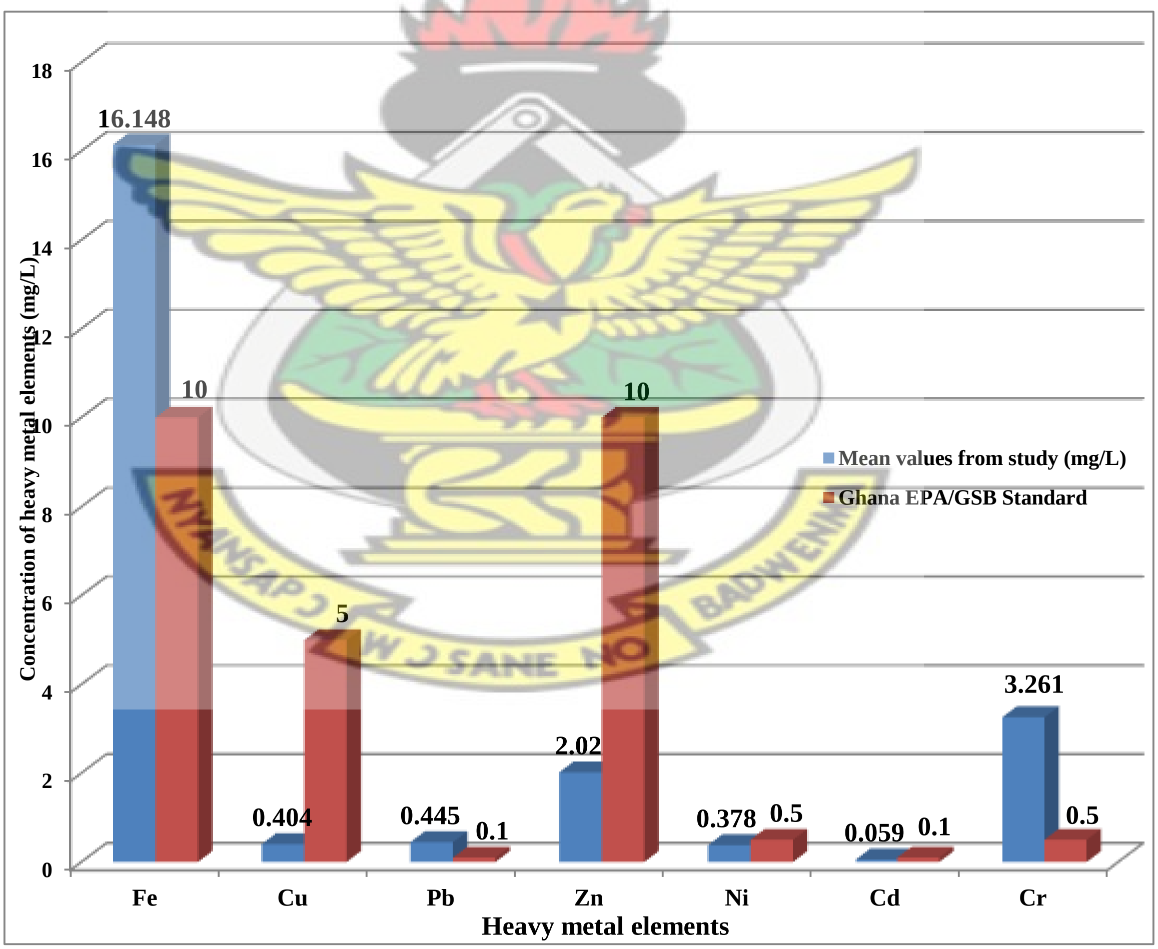


Figure 4.1: Concentrations of heavy metal elements in leachate samples from Atonsu Dompoase landfill

4.4: Heavy metal elements in well water samples

Table 4.3 presents the concentration (mg/L) of 7 heavy metal elements detected in the well water samples. These are iron: (Fe), copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), cadmium (Cd) and chromium (Cr). Apart from Fe whose mean concentration in the well water samples was 0.04 mg/L, each of the other six (6) heavy metal elements (Cu, Pb, Zn, Ni, Cd, Cr) had concentrations below detection limits (<0.01 mg/L).

Table 4.3: Comparison of heavy metal elements determined in well water samples compared with Ghana EPA/GSB Standards

Heavy Metal in Well water Samples	Concentration (mg/L)	EPA/GSB Acceptable Limits of Concentration (mg/L)
Fe	0.04	0.30
Cu	<0.01	1.00
Pb	<0.01	0.01
Zn	<0.01	3.00
Ni	<0.01	0.02
Cd	<0.01	0.003
Cr	<0.01	0.05

All units of parameters in mg/L except pH and EC (μScm^{-1})

4.5: Microbiological parameters determined in leachate samples

The results obtained showed that both faecal (2808 colony forming unit (cfu) /100 mL) and total (7160 cfu /100 mL) coliform counts were significantly higher in concentration in the leachate samples than the Ghana EPA acceptable standards of 0 cfu /100 mL and 10 cfu /100 mL, respectively.

4.6: Microbiological parameters determined across the ten selected well water samples

The coliform index was employed in the microbiological analysis where total and faecal coliforms were selected for analysis. This index was used because it is a rating of the purity of water based on a count of faecal bacteria. By testing for coliforms, one can determine if the water sample has probably been exposed to faecal contamination; that is, whether the water has come in contact with human or animal faeces since many disease-causing organisms are transferred from human and animal faeces to water, where they can be ingested by humans and infect them. According to the index, water that has been contaminated by faecal or total coliforms usually contains other pathogenic bacteria, which can cause disease (Gleeson and Gray, 1997). A possible breakdown of the liner (High Density Polyethylene liner) system at Atonsu Dompoase landfill site or the partial treatment of the refuse could possibly aid the transport of contaminants in leachates from the Atonsu Dompoase landfill site to the nearby wells in the vicinity with time. The wells were selected to demonstrate whether the effect of distance from the pollution source had any influence on water quality from the selected hand dug wells and Table 4.4 below illustrate the points reiterated above.

Table 4.4: Concentrations of selected microbiological parameters in well water samples with distance of well from landfill site and depth of well

Parameter	1	2	3	4	5	6	7	8	9	10
Distance/km	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Depth of well/m	15.7	12.0	13.8	9.0	8.0	7.0	8.2	7.0	8.4	6.0
Total Coliform/cfu/100 mL	740	728	700	566	500	488	450	430	418	398
Faecal Coliform Cfu/100 mL	64	59	45	38	29	26	20	17	10	6

4.7: Concentrations of selected physico-chemical parameters in leachate and well water samples

Table 4.5 below shows that all the physico-chemical parameters in the leachate samples were significantly higher in concentration than those parameters in the well water samples.

Table 4.5: Concentrations of selected physico-chemical parameters in leachate and well water samples

Physico-chemical parameters	Leachate sample	Well water sample
pH	8.2	5.9
EC	2008	365.5
TDS	1303	72.25
TSS	1520	2.25
NO_2^-	780	0.17
NO_3^-	1600	17.5
SO_4^{2-}	1250	19.69
BOD	148	1.48

All units of parameters in mg/L except pH and EC (μScm^{-1})

4.8: Heavy metal elements in leachate and well water samples

Table 4.6 below shows the comparison of heavy metal elements detected in leachate and well water samples. It could be seen that apart from Fe (0.04 mg/L), all the other heavy metal elements were below the limit of detection in the well water samples.

Table 4.6: Comparison of selected heavy metal elements in both leachate and well water samples

Heavy Metal	Concentration (mg/L)	
	Leachate sample	Well water sample
Fe	16	0.04
Cu	0.404	<0.01
Pb	0.445	<0.01
Zn	2.02	<0.01
Ni	0.378	<0.01
Cd	0.059	<0.01
Cr	3.261	<0.01

4.9: ANOVA Summary for Water Quality Parameters

A one-way ANOVA to determine the significant difference for each parameter (TSS, Fe, NO_2^-, SO_4^{2-}, and Total Coliform) yielded the results shown in Appendix V. The one way ANOVA showed statistically significant differences ($p \leq 0.05$) for Fe, NO_2^-, SO_4^{2-}, TSS, total coliform, faecal coliform and BOD.

There was a statistically significant difference ($p \leq 0.05$) in the concentration of TSS in wells 1, 2, 3, 4, 5 and 6 with reference to the control, GW_C. There were also a statistically a significant difference ($p \leq 0.05$) in the concentration of Fe in the wells with reference to the control except 7, 8, 9, and 10.

With the exception of wells, 4, 5, 6, 7, 8, 9 and 10, there was a statistically significant difference ($p \leq 0.05$) in the concentration of NO_2^- in three wells (1, 2 and 3) with reference to the control. There was a statistically significant difference ($p \leq 0.05$) in the concentration of NO_3^- in the wells 1 and 2 with reference to the control group (GW_C).

Also, with the exception of wells, 8, 9, and 10, there was a statistically significant difference ($p \leq 0.05$) in the concentration of SO_4^{2-} in all the other wells with reference to the control. Total coliform count in the wells 1, 3, 4, 5 and 6 were significantly higher with reference to the control group, GW_C. Faecal coliform count in the wells 1, 3, 4, and 5 were significantly higher with reference to the control, GW_C.

Finally, there was a statistically significant difference ($p \leq 0.05$) in the concentration of BOD in the wells 2, 3, and 4 with reference to the control, GW_C.

CHAPTER FIVE

5.0 DISCUSSION

The discussion was based on the establishment of the contamination levels of selected physical, chemical, microbiological parameters and heavy metal elements in both leachate and well water samples and compared them to the Ghana Standard Board (GSB)/Ghana Environmental Protection Agency's (Ghana EPA) standards.

5.1 Concentration of physico-chemical parameters in leachate sample

Physico-chemical characteristics of the leachate depend primarily upon the waste composition and water content in total waste. The pH was considered among the physico-chemical parameters. The pH is the logarithmic expression of the hydrogen ion concentration and reflects the degree of acidity (pH<7) or alkalinity (pH>7) of water; values lower than 6.5 are considered too acidic for human consumption and can cause health problems such as acidosis and pH values greater than 8.5 are considered to be too alkaline for human consumption (Domenico, 1972). From the results obtained, it could be seen that the pH of the leachate sample (Table 4.1) was 8.2 which is within the Ghana EPA/GSB's standard pH range of 6.0-9.0 and hence considered to be safe for human consumption in any event of infiltration of leachate into nearby wells in the Atonsu Dompoase community.

Electrical Conductivity (EC)

EC is a measure of water's ability to conduct an electric current. From Table 4.1, the leachate sample had a relatively high value of EC (2008 μS/cm). Domenico and his colleagues in 1998 alluded to the fact that higher EC values are an indication of the presence of inorganic materials. Therefore a high EC value of the leachate samples is an indication of a possible increase in the salt content of the water from the wells in the event of infiltration of the leachate into the wells.

Total Dissolved Solids (TDS)

From Table 4.1, a TDS value of 1303 mg/L indicates a higher concentration than the Ghana EPA/GSB's permissible standard of 1000 mg/L. Although, TDS is not generally considered a primary pollutant as it is not deemed to be associated with health effects, its presence indicates how hard the water will be. DeZuane (1997) in a study entitled '*Drinking Water Quality*' made a similar assertion. The presence of some dissolved ions like magnesium and chloride ions might account for the high TDS value obtained in the leachate sample.

Nitrate (NO_3^-)

The concentration of NO_3^- (1600 mg/L) in the leachate sample was high compared to Ghana EPA/GSB standard value of 50 mg/L. This may be due to different wastes coming from different sources including, manure, animal feedlots, municipal wastewater, and sludge. Although, there is no circumstantial evidence that there is infiltration of nitrate into nearby wells, it is worth noting that the higher levels in the leachate samples could be a nuisance, creating health-related problems like gastric cancer and birth defects if the lining of the engineered part of the landfill succumbs to the pressure of deterioration with time. Mirvish (1985) in USA, in a study captioned

'Gastric cancer and salivary nitrate and nitrite' made a similar case that there is circumstantial evidence linking nitrate ingestion to gastric cancer and birth defects.

Nitrite (NO_2^-)

According to a fact sheet published by the USEPA in 1974, nitrites are nitrogen-oxygen chemical units which combine with various organic and inorganic compounds. The concentration of NO_2^- (780 mg/L) was higher than the Ghana EPA/GSB permissible limit of 3 mg/L. A potential infiltration of nitrite into nearby wells could also create health-related problems like haemorrhaging of the spleen and increased starchy deposits when water from these well sources is consumed. The US '*Safe Drinking Water Act*" confirms the above assertion and among other things state that nitrite levels above the maximum permissible limits can cause diuresis in addition to the above diseases stated (USEPA, 1974).

Sulphate (SO_4^{2-})

From the results (Table 4.1), the concentration of SO_4^{2-} (1250 mg/L) was above the Ghana EPA/GSB standard of 250 mg/L. Higher levels of sulphates if they get into drinking wells either directly or indirectly could lead to diarrhoea and dehydration since the leachate emanating from the landfill site is partially treated and ultimately finds its way in the nearby Oda River which is used as a source of drinking water by neighbouring and adjoining communities.

Total Suspended Solids (TSS)

Total Suspended Solids are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life. The value of TSS (1520 mg/L) was higher than the Ghana EPA/GSB standard value (50 mg/L). This indicated the presence of higher level of settleable solids.

Biochemical Oxygen Demand (BOD)

According to *Free Drinking Water's website*, BOD is a measure of the quantity of oxygen used by micro-organisms (e.g., aerobic bacteria) in the oxidation of organic matter. From Table 4.1, the concentration of BOD in the leachate sample (148 mg/L) was above the Ghana EPA/GSB standard value of 50 mg/L. According to Pohland and colleagues (1993) in a study entitled *'Metal speciation and mobility as influenced by landfill disposal practices'* said that leachate has high BOD. As the degradation of the waste progresses, conditions in the landfill become more anaerobic and the strongly reducing methanogenic phase is initiated. The majority of the remaining organic compounds are high molecular weight humic acids and leachates are characterized by relatively low BOD values. This same point was repeated by Belevi and Baccini (1992) in a study entitled *'Long-term leachate emissions from municipal solid waste landfills'* (www.freedrinkingwater.com).

5.1.1 Concentration of heavy metal elements in leachate samples

The presence of heavy metal elements in the leachate sample suggests their origin could be from the various wastes dumped on Atonsu Dompoase landfill. The concentration of Fe (16.148 mg/L) in the leachate sample was higher than the Ghana EPA standard of 10 mg/L (Figure 4.1) although the levels determined were not exceedingly higher. The presence of Fe in the leachate indicates that iron and steel scraps are likely dumped on the Atosu Dompoase landfill. Chu *et al.* (1994) in India reported 70.62 mg/L in the leachate sample when they worked on the '*Impact of leachate percolation on groundwater quality in Gazipur Landfill in India*'.

The presence of Zn (2.020 mg/L) in the leachate shows that Atonsu Dompoase landfill receives waste from batteries and fluorescent lamps. The value of Zn (2.021 mg/L) is in line with the value of Zn (2.21 mg/L) obtained in a study conducted in India by Chu *et al.* (1994) on the topic '*Variations in the chemical properties of landfill leachate'*.

Lead (Pb) was found in the leachate sample analysed and this is an indication of the disposal of chemicals for photograph processing, Pb-based paints and pipes at the Atonsu Dompoase landfill site. This same point was also reported by Moturi *et al.* (2004) in India. The concentration of Pb (0.445 mg/L) was higher than the Ghana EPA value of 0.1 mg/L.

Chromium, Cr (3.261 mg/L) in the leachate sample from Atonsu Dompoase landfill was higher in concentration than the standard Ghana EPA value of 0.5 mg/L while

Cadmium, Cd (0.059 mg/L) measured a lower concentration than the recommended EPA value of 0.1 mg/L.

The concentrations of Cu (0.404 mg/L) and Ni (0.378 mg/L) in the leachate sample obtained from Atonsu Dompoase landfill were lower than the Ghana EPA value of 5 mg/L and 0.5 mg/L, respectively. This was also reported by Moturi *et al.* (2004); Mor *et al.* (2005) in India in a study captioned '*Distribution and fractionation of heavy metals in solid waste from selected sites in the industrial belt of Delhi, India*'. Christensen *et al.* (1994) in USA also reported the presence of some of these compounds in leachate.

5.1.2 Concentration of microbial coliform in leachate samples

Due to the difficulty in detecting low concentration of pathogenic bacteria and viruses from faecal contamination, coliform bacteria are used as indicator of faecal contamination. The concept of coliform bacteria used as indicator of microbial water quality is based on the premise that coliforms are present in high numbers in the faeces of humans and other warm-blooded animals. The coliform bacteria can multiply where leachate enters an oxygenated system. Stuart and Klink (1998) In UK found that when leachate was diluted with the bacteria-free groundwater, there was an increase in the number of thermotolerant coliform and the bacteria were able to survive for up to two weeks under laboratory conditions (Stuart and Klink, 1998), although no evidence was found of coliforms in leachate entering the well water at Atonsu Dompoase community.

5.1.3 Physico-chemical parameters in well water samples

The mean pH across the ten selected well water samples (Table 4.2) was 5.9, making the well water weakly acidic. The pH range across all the ten well water samples was 5.10 to 6.94. Also, the pH range across wells very far away from the landfill but within the adjoining communities is 5.0 to 6.0. From the above pH range of the wells within the adjoining communities, it could be seen that there is no sharp deviation in pH range across the wells. The pH for both the leachate (8.2) and well water (5.9) samples were all within the acceptable standard of 6.0-9.0. The basic nature of the leachate may be due to the deposition of calcium carbonate from snail and egg shell whiles the weakly acidic nature of the water from wells in Atonsu Dompoase community may be due to the geology of the study area.

Electrical Conductivity (EC)

EC is a measure of water's ability to conduct an electric current. From the study, (Table 4.2), the mean EC value of 365.5 μS/cm was higher than the GSB/EPA acceptable standard of 250 μS/cm. The high conductivity value may be due to excess amount of dissolved materials like charged ions in the wells. This allusion had been reported by Domenico and colleagues in 1998 in USA in a study entitled *'Concepts and models in groundwater hydrology*'. Poor drainage systems in the community may suggest that these charged ions including sulphate and magnesium ions might be originating from lather (soap) used for domestic activities. Comparing a higher EC mean value of 365.5 μS/cm obtained from the study to the Ghana EPA/GSB acceptable standard of 250 μS/cm indicates the presence of many charged ions like sulphate and magnesium which may be a potential source of pollution.

Total Dissolved Solids (TDS)

From Table 4.2, a mean TDS value of 72.25 mg/L across all the well water samples indicates an extremely lower concentration as compared to the Ghana EPA/GSB permissible standard of 1000 mg/L. Although, TDS is not generally considered a primary pollutant as it is not deemed to be associated with health effects, its presence indicates how hard the water will be (DeZuane, 1997). Hence lower TDS values obtained in this study indicate that the water is soft thereby lathering easily with soap to make washing easy (DeZuane, 1997). A lower TDS value of 72.25 mg/L across the ten well water samples at the Atonsu Dompoase community may be due to partial treatment of the leachate emanating from the landfill.

Nitrate (NO_3^-)

From the study (Table 4.2), the mean concentration of NO_3^- across the ten selected well water samples (17.5 mg/L) was below the Ghana EPA/GSB permissible limit of 50 mg/L. The lower mean concentration may be due to the lining of the engineered area of the landfill. Although, there is no official report on nitrate in drinking water from well water sources in the Atonsu Dompoase and its adjoining communities, it is important to note that higher levels of nitrate in drinking water have detrimental effects on infants as this assertion was reiterated by Alsabahi *et al.* (2009) in Yemen in a study entitled '*The characteristics of leachate and groundwater pollution*' said that high nitrate levels have detrimental effects on infants less than three to six months of age. Biochemically, nitrate is reduced to nitrite which can oxidize haemoglobin (Hb) to methaemoglobin (MetHb), thereby inhibiting the transportation of oxygen around the body. Chapman (1992) in London reiterates the above assertion about nitrate in a related study entitled '*Water Quality Assessments, a Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*".

Nitrite (NO_2^-)

The nitrite levels in the leachate samples (780 mg/L) were far higher than the nitrite levels in the selected wells (0.17 mg/L) (Table 4.2). The lower mean NO_2^- concentration (0.17 mg/L) across all the well water samples could be accounted for by the presence of the single high density polyethylene lining of the engineered part of the landfill. According to Lee and Jones-Lee (1993) in an International Landfill Symposium organized in Sardinia, Italy on "*Groundwater pollution by municipal landfills*" said that nitrate is biochemically reduced to nitrite which can oxidize haemoglobin (Hb) to methaemoglobin (metHb), thereby inhibiting the transportation of oxygen around the body.

Sulphate (SO_4^{2-})

The mean SO_4^{2-} concentration of 19.69 mg/L is below the GSB/EPA Standard of 250 mg/L. The lower concentration could be attributed to the monitoring wells located down the gradient of the landfill at appropriate depths and at various intervals to intercept contaminants and monitor their movement. This enables the contaminants trapped in the leachate to be treated partially before discharging it into the Oda River which is used as a source of drinking by neighbouring and adjoining communities.

Total Suspended Solids

According to Cornwell and Davis (1990), leachate contains large numbers of inorganic contaminants and high concentrations of total suspended solids (TSS). The suspended solids are a collection of organic and inorganic materials of various sizes and density. The mean TSS measured was 2.25 mg/L which was far below the Ghana EPA/GSB standard value of 50 mg/L (Table 4.2) (Cornwell and David, 1990).

Biochemical Oxygen Demand (BOD)

According to Sawyer *et al.* (2003), BOD is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The term also refers to a chemical procedure for determining this amount. This is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. From Table 4.2, the mean BOD for the ten well water samples was 1.48 mg/L which was above the Ghana EPA/EU standard value of 50 mg/L. A lower BOD in well water samples is an indication of good quality drinking water.

5.1.4 Concentration of heavy metal elements in well water sample

The well water samples were analyzed for heavy metal elements such as Cu, Fe and Zn which are characterized as undesirable metals when detected in drinking water, WHO

(1997), has proposed their permissible value of 1, 0.3 and 5 mg/L, respectively in drinking water. The mean concentrations of Cu and Zn were below detection limit (<0.01 mg/L) apart Fe (0.04 mg/L) whose mean concentration was higher than all the other undesirable metals in well water samples even though it was far lower the Ghana EPA/GSB standard of 0.3 mg/L (Table 4.3) (WHO, 1997). According to Rowe *et al.* (1995) in London in a study captioned '*Clay Barrier Systems for Waste Disposal Facilities'* said that the presence of Fe in water can lead to a change of colour of well water. The metals Pb, Cd, Cr, and Ni are characterized as toxic when detected in drinking water. The mean concentrations of all these metals (Pb, Cd, Cr and Ni) were found below limit of detection (<0.01 mg/L). Yanful *et al.* (1988) in Canada conducted a study entitled '*Heavy metal migration at a landfill site*' and said that heavy metals remain in the waste or at the waste-rock interface as a result of redox controlled precipitation reactions. Pohland *et al.* (1993) in the U.S.A in a study captioned '*Metals in Groundwater*' further stated that 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 metal elements. This fixing of heavy metal element reduces the risk of direct toxic effects due to ingestion of leachate contaminated groundwater.

5.1.5 Concentration of microbial coliform in well water samples

The mean concentrations of both total (542 cfu/100 mL) and faecal (31 cfu/100 mL) coliform counts were significantly higher across all the well water samples. The high proportion of total coliform (TC) and faecal coliform (FC) in most of the well samples may likely indicate the contamination of well water possibly due to the high loadings of faecal matter from the landfill and sanitary practices around most of the wells undertaken by residence of Atonsu Dompoase and the fact that most of the wells were not covered (1, 2, 3, 4, 6, 8 and 9).

5.1.6 Distance of selected hand dug wells from landfill sites

The extent of contamination of well water quality due to leachate percolation depends upon a number of factors like leachate composition, rainfall, distance of the well from the pollution source, the landfill site in the present case. Water samples collected from wells with different distances were analyzed for this study. The study revealed that the water sampled from wells closer to the landfill site significantly increased with contaminants. However, with increasing distance away from the landfill site, the water samples significantly decreased with contaminants. For example, well one (W_1) with a distance of 300 m from the landfill site had a faecal coliform count of 64 cfu/100 mL while well 10 (W_{10}) with a distance of 2000 m also had a faecal coliform count of 6 cfu/100 mL.

Table 5.1: Distances of selected hand dug wells from landfill site

Well	**1**	**2**	3	4	**5**	6	7	**8**	**9**	**10**
Distance/km	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Depth of well/m	15.7	12.0	13.8	9.0	8.0	7.0	8.2	7.0	8.4	6.0
Total Coliform/cfu/100 mL	740	728	700	566	500	488	450	430	418	398
Faecal Coliform/cfu/100 mL	64	59	45	38	29	26	20	17	10	6

For instance, a study conducted by Mahedeven and Krishamswamy (1984) in India found out that 76.08% of the sampled wells got polluted when located close to pen drains, 64.40% were polluted when located near a pool of stagnant wastewater, while, 32.30% got polluted when garbage dump was nearby. In a similar study, Asimi (1984) in Ilorin, Nigeria concluded that effluents from slaughtering slab increases groundwater COD, total hardness, total solids, turbidity and other water quality variables in the immediate vicinity of these slabs. Hence, the farther a well water supply is from the pollution source, the less the risk of pollution.

5.2 CONCLUSION AND RECOMMENDATION

5.2.1 Conclusion

The study revealed that among the selected physico-chemical parameters in both leachate and well water samples, none of the physico-chemical parameters in the leachate samples was significantly seen in the well water samples apart from EC which had a value of 2008 μS/cm in leachate and 365.5 μS/cm in well water samples (Table 4.2). The slightly acidic nature of the water in the selected wells may be attributed geology of the study area.

The study further revealed that the presence of the heavy metal elements in higher concentrations above Ghana EPA/GSB standards in the leachate samples and the presence of heavy metal elements below detection limits in the well water samples suggest that the landfill receives wastes that predominantly do not contain heavy metal elements hence distances farther away from the landfill drastically reduces their respective concentrations.

From the study, both total and faecal coliforms counts were significantly higher in the leachate samples suggesting that the origin of both the total and faecal coliforms might be from faecal matter deposited as the predominant waste on the Atonsu Dompoase landfill site and this could account for the significant amount of both total and faecal coliform counts in the well water samples from the selected wells above the EPA/GSB standards. In addition to faecal matter deposited on the landfill site, most of the selected wells had no aprons and were closer to septic systems and hence accounted for higher mean coliform (total and faecal) counts in the well water from Atonsu Dompoase community.

The results obtained in this study also showed that the leachate generated from the Atonsu Dompoase landfill site has significant impact on the well water quality in Atonsu Dompoase community.

5.2.2 Recommendations

The engineering of landfills in Ghana in the future should seriously take into consideration the type of liner system used. This is due to the fact that society produces many different wastes that pose different threats to the environment and to community health. Also, the potential threat posed by the waste determines the type of liner system employed. Although, Atonsu Dompoase landfill uses the single high density polyethylene (HDPE) liner, it does not necessarily prevent a possible breakdown of the single HDPE liner system with time. According to USEPA (2010), liners used in landfills will ultimately fail and that the site remains a threat for thousands of years suggesting that modern landfill designs delay but do not prevent well water pollution. It is, however, recommended that composite HDPE liner with chipped or waste tires could be used. According to Benson *et al.* (1996) in the U.S.A, chipped or waste tires could be used to support and insulate the liner to prevent an early possible breakdown of the liner system and to delay future contamination of well water from Atonsu Dompoase community.

It is also recommended that future landfills in Ghana should be sited for example, about fifteen kilometres (15 km) away from residential facilities to cater for a possible future growth in population. The closest house to the Atonsu Dompoase landfill in this present study was about three hundred metres (300 m) and the recommended safe distance for a house closer to a landfill facility is three hundred and sixty five metres or more (365 m) (www.freedrinkingwater.com). A possible breakdown of the single HDPE liner system is an indication of massive infiltration of leachate into nearby wells.

Again, it is recommended that construction of wells should take into consideration the use of aprons and the proper maintenance of the wells encouraged through public education within the Atonsu Dompoase community and Ghana at large.

Further studies on the geology and the hydrogeology of the study area need to be carried out in order to corroborate these findings and confirm the potential of leachate contamination of well water in the study area.

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APPENDICES

Appendix I: Comparison of selected physico-chemical parameters in leachate sample and Ghana EPA standard

Parameter	Concentration	Ghana EPA/EU Standard
EC	2008	250
pH	8.2	6.0-9.0
TDS	1303	1000
TSS	1520	50
NO_2^-	780	50
NO_3^-	1600	50
SO_4^{2-}	1250	250
BOD	148	3

All parameters in mg/L except pH and EC (μScm^{-1})

Appendix II: Comparison of selected heavy metals in leachate sample and Ghana EPA standard

Parameter	Concentration	Ghana EPA Standard
Fe	16.148	10.00
Cu	0.404	5.00
Pb	0.445	0.10
Zn	2.020	10.00
Ni	0.378	0.50
Cd	0.059	0.1
Cr	3.261	0.5

All parameters in mg/L

Appendix III: Comparison of selected microbiological parameters in leachate sample and Ghana EPA standard

Parameter	Concentration	Ghana EPA Standard
Total Coliform	7160	10 cfu/100 mL
Faecal Coliform	2808	0 cfu/100 mL

Appendix IV: Mean concentrations of selected microbiological parameters obtained from the analysis of well water samples relative to distance from pollution source and depth of well

Well	1	2	3	4	5	6	7	8	9	10
Distance/km	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
Depth of well/m	15.7	12.0	13.8	9.0	8.0	7.0	8.2	7.0	8.4	6.0
Total Coliform /cfu/100 mL	740	728	700	566	500	488	450	430	418	398
Faecal Coliform cfu/100 mL	64	59	45	38	29	26	20	17	10	6

Appendix V: ANOVA summary for water quality parameters

Water Quality Parameters	p-value
TSS	<0.05
Fe	<0.05
NO_2^-	<0.05
NO_3^-	<0.05
SO_4^{2-}	<0.05
Total Coliform	<0.05
Faecal Coliform	<0.05

Appendix VII: Distances of wells from landfill site

Wells	Distance/km	Depth of well/m
1	0.2	15.7
2	0.4	12.0
3	0.6	13.8
4	0.8	9.0
5	1.0	8.0
6	1.2	7.0
7	1.4	8.2
8	1.6	7.0
9	1.8	8.4
10	2.0	6.0

Appendix VII: Comparison of selected physico-chemical parameters in well water samples and Ghana EPA standard

Parameter	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	Mean Concentration
EC (μScm^{-1})	1118	47	184	113	1122	192	229	185	195	270	365.5
pH	6.33	5.10	6.94	5.10	6.20	5.82	6.12	5.41	6.33	5.33	5.89
TDS (mg/L)	76.00	32	110	73.00	64.50	81.00	83.00	90.00	52.00	66.00	72.75
TSS (mg/L)	3.00	2.00	2.00	2.00	2.00	2.00	3.000	2.00	2.00	2.50	2.25
NO_2^- (mg/L)	0.170	0.220	0.150	0.140	0.160	0.230	0.130	0.170	0.180	0.150	0.170
NO_3^- (mg/L)	3.00	11	14.000	42.000	4.000	9.000	16.000	41.000	16.000	19.000	17.5
SO_4^{2-} (mg/L)	19.940	19.186	20.000	19.640	18.940	20.640	20.000	19.580	19.370	19.660	19.370
BOD (mg/L)	1.60	2.10	1.00	1.20	1.40	1.30	1.70	1.50	1.70	1.3	1.48

All parameters in mg/L except pH and EC (μScm^{-1})

Appendix VIII: Comparison of the mean concentrations of selected microbiological parameters in well water samples with distance of well from pollution source and depth of well

Well	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	Mean Coliform Concentration
Distance/km	0.2	0.4	0.6	0.8	1.0	1.2km	1.4	1.6	1.8	2.0	-
Depth/m	15.7	12.0	13.8	9.0	8.0	7.0	8.2	7.0	8.4	6.0	-
Total Coliform/cfu/100 mL	740	722	700	566	500	488	450	430	418	398	5412
Faecal Coliform Cfu/100mL	64	59	45	38	29	26	20	17	10	6	31

Appendix IX: Heavy metal elements in selected wells

Well	Fe	Cu	Pb	Zn	Ni	Cd	Cr
1	0.046	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
3	0.0033	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4	0.059	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
7	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

All in mg/L

APPENDIX X: Summary of all parameters in leachate and well water samples compared with Ghana EPA/GSB standards

Parameter	Leachate Samples	Well Water Samples (mean concentration)	EPA/GSB Standards
pH	8.2	5.9	6.5-8.5
EC	2008	365.5	1500
TDS	1303	72.75	1000
TSS	1520	2.25	50
NO_2^-	780	0.170	3
NO_3^-	1600	17.5	50
BOD	148	1.48	50
SO_4^{2-}	1250	19.37	250
Total Coliform	7160	542	10 cfu/100 mL
Faecal Coliform	2808	31	0 cfu/100 mL
Fe	16.148	0.037	`10
Cu	0.404	<0.01	5

Pb	0.445	<0.01	0.1
Zn	2.020	<0.01	10
Ni	0.378	<0.01	0.5
Cd	0.059	<0.01	0.1
Cr	3.261	<0.01	0.5

All in mg/L except EC, total and faecal coliforms