HEAVY METAL POLLUTION OF FARMLANDS BY ILLEGAL MINING (GALAMSEY) ACTIVITIES AND ITS EFFECTS ON THE FERTILITY OF FARMLANDS IN THE PRESTEA/HUNI-VALLEY DISTRICT OF THE WESTERN REGION OF GHANA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

In

Environmental Science,

By

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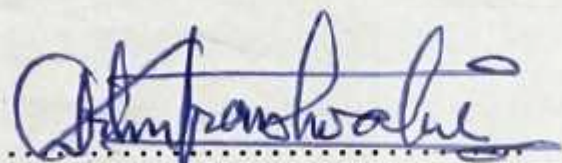
KWAME NKRUMAH UNIVERSITY OF SCIENCE & TECHNOLOGY,

KUMASI

SEPTEMBER, 2012

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DECLARATION

The experimental work described in this thesis was carried out at the Department of Environmental Science, KNUST. This work has not been submitted for any other degree.

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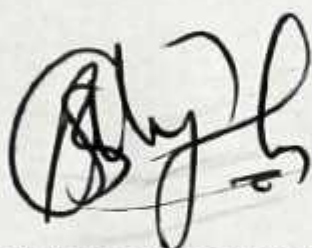
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ABSTRACT

Illegal mining activities (galamsey operations) in the country keep increasing with each passing day despite the many environmental and health risks posed by this form of mining. Vast stretches of land are degraded as a result of the activities of these galamsey operations, and for farmlands could be rendered uncultivable. The various chemicals used in their activities could moreover be potential sources of toxic heavy metals in the environment. This study aimed at investigating the effect of such illegal mining activities on the fertility of farm lands in the Prestea/Huni Valley District of the Western Region, as well as the extent of heavy metal pollution of the farmlands. Four farmlands that were being used for galamsey operations were selected from two communities in the district: two from Prestea and two from Abosso. In addition, two control farmlands that had seen no galamsey operations were selected from Bompieso, another farming community in the district. Soil samples were taken from all the farmlands and soil fertility analysis done. The levels of five heavy metals namely, cadmium, mercury, copper, lead and arsenic in the soil samples were determined. The results show that the galamsey farmlands have serious problems with soil fertility as the levels of soil organic matter, organic carbon, total nitrogen and phosphorus were very low compared to the control lands and compared to minimum required levels for optimum plant growth. Moreover, galamsey farmlands had very low cation exchange capacity as the levels of major soil cations were very low. Notwithstanding this however, the pH of galamsey farmlands compared with that of non-galamsey lands were within acceptable ranges. Particle size analysis showed that soils from the galamsey farmlands were mostly sandy whereas the non-galamsey lands contained loamy soil. Heavy metal analysis of the soil samples revealed that the galamsey farmlands are heavily polluted with the five metals. The mean concentration of each of the metals in mg/kg was as follows: 82.95 ± 2.9 for arsenic; 496.5 ± 76.3 for copper; 432 ± 5.3 for lead; 898.25 ± 9.1 for mercury; and 90.75 ± 2.2 for cadmium. These levels were found to be above the threshold limits allowed by the EPA in soils. Galamsey activities in the district are drastically causing infertility of farmlands and could affect agricultural output. Heavy metal pollution of the lands could pose serious health threat to inhabitants living on and around these lands.

DEDICATION

This work is dedicated to my wife Elizabeth Baidoo, who had indeed worked tirelessly to support me in all endeavors. May God richly bless her.

ACKNOWLEDGMENT

I sincerely thank the Almighty God for giving me life, good health and the needed wisdom to produce this wonderful work.

I also owe considerable debt to Derick Armoah and his friend Joseph Osei Yeboah for their enormous contribution made towards the writing of this project.

I would not forget my colleague teachers Mr. Emmanuel Boakye former Senior Housemaster, Huni-valley Senior High School and Hon. Elvis Agyei Duah who gave me much encouragement to go through my course and also provided me with a lot of information about the galamsey activities in his areas. I also owe much gratitude to Konzin Daniel who helped much during the editing process.

Finally I wish to express my sincere gratitude to Rev. Stephen Akyeampong, my supervisor who guided me throughout the writing of this project.

May God richly bless them all.

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CHAPTER ONE

INTRODUCTION

Mining activities are one of the sub-economical activities of modern industrialized civilization and is a major economic activity in many developing countries. The mining sector plays a vital role in the economic development of many African countries and Ghana is no exception.

The mining sector of the country accounts for 5% of the country's GDP and contributes 41% to the country's foreign exchange hence making it the leading foreign exchange earner. Gold contributes over 90% of the total mineral exports. Of the $612.9 million in total mineral export income in 1997, gold accounted for $579.2 million (94.5%), while diamond, bauxite and manganese contributed to the remaining 5.5% (ISSER, 2001). Ghana is Africa's 2 second largest gold producer, with gold now earning over U$600 million and hence replacing cocoa as the chief foreign exchange earner (Awudi, 2002). The main focus of Ghana's mining and minerals development industry thus remains on gold.

Gold production in Ghana is dominated by AngloGold Ashanti which is the largest of 20 large-scale gold mining companies in the country. In addition, there are also over 300 registered small scale mining groups and 90 mine support service companies. Other major large scale mining companies in the country include the Golden Star Resources Ltd operating the Bogoso/Prestea and Wassa open pit mines, Aboso Gold Fields Ltd operating the Damang open pit mine, and the Newmont Mining Coporation operating the Ahafo mines; with all companies operating within the Ashanti and/or Western Regions of the Ghana (Hilson and Potter , 2003).

Artisanal and Small Scale (ASM) mining has been defined differently around the world. The United Nations defines it as "any single unit mining operation having an annual production of unprocessed material of 50,000 tonnes, or less as measured at the entrance of the mine". Small-scale miners are considered as "poor people; individuals or small groups who depend upon mining for a living; who use rudimentary tools and techniques (e.g. picks, chisels, sluices and pans) to exploit their mineral deposits"(UN, 1971). Artisanal and Small Scale provides direct employment to between 11.5 and 13 million retrenched large-scale mine workers, nomads and seasonal farmers worldwide (Aryee et al., 2003). In diverse areas of the world, artisanal mining has become the principal livelihood for millions

of miners and their families and the mainstay of local rural economies. Such is the case in Ghana, where the industry appears to have become a safe haven for poverty stricken nomadic peoples and seasonal farmers in recent years. Its operators are lured by the prospect of extracting gold, which yields a substantial return on the market.

Some two to three decades ago, many governments, claiming to have finally recognized the economic importance of resident Artisanal and Small Scale output, introduced series of regulations and licensing schemes in an attempt to regularize operations. Artisanal and Small Scale gold mining was legalized in Ghana in 1989, after the passing of the Small-Scale Gold Mining. Artisanal and Small Scale gold mining was defined as "…mining (gold) by any method not involving substantial expenditure by an individual or group of persons not exceeding nine in number or by a co-operative society made up of ten or more persons". The law necessitates that its operators adhere to a rigid regulatory framework. To register – hence, legitimize – oneself as a miner, one must comply with guidelines stipulated in a series of laws and codes. Moreover, each miner or mining party must secure, from the government, a license to operate on a designated parcel of land.

Ghana's artisanal and Small Scale gold mining sector is comprised of two main groups of miners: (1) registered operators (the 'Official System'); and (2) illegal operators (Hilson and Potter , 2003). Mainly nomadic in nature, galamsey operators are noted for ravaging landscapes and quickly abandoning unproductive sites ('hit and miss' nature) without reclaiming excavated pits and trenches. Operators defy regulations, electing to carry out activities in remote areas of the field, well out of reach of authoritative bodies. The sector has been responsible for significant environmental damages and the recent rises in school dropout rates in various rural areas.

Notable among these environmental damages, which is a major health threat is the pollution of lands by various heavy metals. Excess accumulation of these heavy metals which includes cadmium (Cd), copper (Cu), mercury (Hg), Nickel (Ni), lead (Pb), zinc (Zn), chromium (Cr), arsenic (As), cobalt (Co), barium (Ba), silver (Ag) and selenium (Se) in soils is toxic to humans and other animals. Exposure to heavy metals is normally chronic (exposure over a longer period of time) due to food chain transfer (USDA, 2000). It is estimated that as many as 85% of the country's artisanal and small-scale gold mining operators are, in fact, galamsey, who, for a variety of reasons, have opted to remain unregistered.

operators are, in fact, galamsey, who, for a variety of reasons, have opted to remain unregistered.

This study assessed the effects of such illegal mining activities on farmlands in one of the mining districts of the Western Region: the Prestea/Huni – Valley Distict. The district, with a population of about 159,304 and a land size of $1514km^2$ is well noted for its mining activities. The three major large scale mining companies in the district are the Golden Star Resources at Bogoso, the Sankofa Goldfield at Prestea and the Aboso Goldfields Ltd operating at Damang. These companies engage the services of more than 50% of residents. In addition a considerably high number of small scale miners also reside and operate in the district, making the problem of illegal mining in the District no different from what happens everywhere in the country. Such miners operate without licenses and deteriorate vast quantities of lands, abandoning them after exploitation.

Apart from mining, agriculture is another major occupation that indulges many of the folks of the district. This stems from the good climatic patterns and geography of the area: the forest vegetation, fertile soil and abundant rainfall throughout the year. The activities of such galamsey operators are a major threat to the overall agricultural output from the district, both in terms of pollution of the farmlands with heavy metals used in their operations, and most importantly the drastic reduction in fertility of these farmlands. The study will hence assessed the levels of heavy metal pollution of selected farmlands in the district and also assessed the fertility of these lands.

1.1   STUDY RATIONALE AND PROBLEM STATEMENT

Galamsey operations appear to be on the increase rather than waning in the Western Region, even some 23 years after the legalization of small scale mining in Ghana. Despite the various regulations and rules as well as the existence of bodies like the Precious Minerals and Marketing Corporation (PMMC), a majority of the country's 200,000 artisanal and small-scale gold miners remain unregistered (Hilson and Potter, 2003). A common observation one would make in most communities in the district are open pits besieged by unskilled youth confidently digging for gold to sell to prospective buyers, without any concern about the dangers being created for these operators, the inhabitants and the environment as a result of their unregulated activities. Because they are unregulated and operate outside the law, the galamsey operators, often cause major environmental damage,

The Western region of Ghana is endowed with considerable natural resources, which give it a significant economic importance within the context of national development. The region is the largest producer of cocoa, rubber and coconut, and one of the major producers of oil palm and its rich tropical forests makes it one of the largest producers of raw and sawn timber as well as processed wood products (Akabza and Draimani, 2001).

The Prestea/Huni-Valley District contributes a significant quota to the region's overall agricultural output, with cocoa and oil palm being the major agricultural products from the district. It should therefore be an issue of great concern if the actions of galamsey operators in the district are threatening agricultural production. Notable activities of these operators include the destruction of lands that are suitable for crop production for illegal mining, pollution of rivers and streams that farmers depend on and pulling down of farms established with cocoa. The impact this could have on agricultural output are clear. Galamsey operators keep expanding their coverage with each passing day and many are now resorting to setting up their operations on farmlands, leaving the farmers with either a limited farm space or no choice than abandon their farms completely. The unavailability of land for farming as a result is hence notable, but most notable is the loss of fertility to the lands after exploitation, which would be of concern to agriculturalists in the district.

The fertility of a piece of land is determined by a number of factors: 1) richness in major plant nutrients including nitrogen, phosphorus and potassium; 2) richness in sufficient micro minerals (including boron, chlorine, cobalt, copper, iron, manganese, magnesium, molybdenum, sulfur, and zinc); 3) how much soil organic matter that improves soil structure and soil moisture retention it contains; 4) a good soil pH (usually from 6 – 6.8); 5) the range of microorganisms that support plant growth it contains; 6) the amount of topsoil it contains as a large quantity marks a fertile soil; and 7) good soil structure, creating a well-drained soil. Galamsey operators could render these lands un-cultivatable as their various activities tend to cost the farmlands most or all of the above soil characteristics. The loss of the top soil during the process would be a major indentation on the fertility of the land as major and minor nutrients are lost. Various toxic chemicals used and waste products generated during the process have the potential to contaminate the soil with heavy metals and even kill soil microorganisms, all serving to disrupt the fertility of the land. These chemicals could also serve to alter the soil pH, making the land either more acidic or basic

and hence unsuitable for production. Finally, the soil structure, feel, consistency and water retaining abilities are all liable to be lost through the various mining activities on the lands.

Moreover in the event that the exploited land would later be used for farming, the issue of heavy metal pollution of the farmlands, which could result in the crops taking up some of the metals, also becomes a big issue of concern. The biological half-lives of these heavy metals are long and have potential to accumulate in different body organs and thus produce complications like cardiovascular, kidney, nervous and bone diseases. Other severe effects include reduced growth and development, cancer, organ damage, nervous system damage, and in extreme cases, death. In the light of all these, it becomes imperative for studies to assess the levels of heavy metals and also the effects of these illegal mining activities on the fertility of farmlands in the district.

1.2   STUDY OBJECTIVES

Main Objective

The main objectives were to access the impact of illegal mining activities on various farmlands in the Prestea/Huni-Valley District of the Western region of Ghana.

1.2.1   Specific Objectives were

1. To perform soil analysis on soil samples from affected farmlands in the District and those that are unaffected by galamsey operations (virgin farmlands) and compare their fertility.

2. To quantitate the levels of five heavy metals: arsenic, copper, lead, cadmium and mercury in both virgin and galamsey farmlands.

1.3   JUSTIFICATION AND BENEFITS OF STUDY

Agriculture plays a pivotal role in the economic development of any country and for a developing nation like Ghana where it contributes a significant amount to the overal GDP, this importance cannot be undermined. With galamsey operations resulting not only in the destruction and loss of vast majority of agricultural farmlands but also having the potential to make them infertile and uncultivatable upon exploitation, the need for such a study is clear. Moreover, heavy metal poisoning of the lands could be a major public health concern,

especially in a case where the abandoned land would be used for farming activities sometime to come. The study therefore hopes to bring to bear the following benefits:

- Provide data on the extent of destruction of farmlands as well as extent of heavy metal poisoning of the farmlands in district.

- Provide evidence to support the view that galamsey operations in the long run cause a loss of fertility to the farmlands.

- Inform policy makers on the need to attach priority to addressing the issue of illegal mining to save agriculture in the district.

- Serve as a platform for authorities to educate illegal miners on the implications of their actions on agriculture productivity and the need to legalize their operations and stay clear of farmlands.
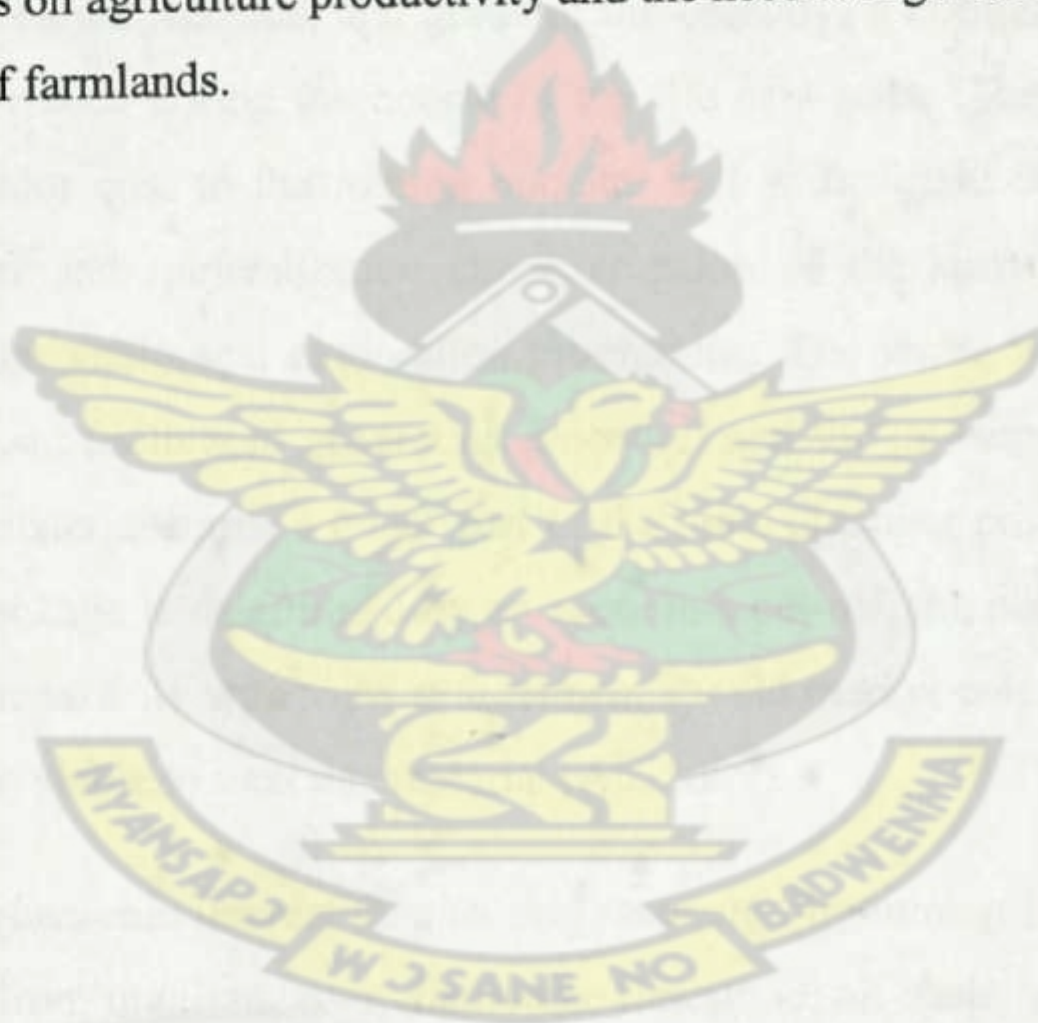
CHAPTER TWO
LITERATURE REVIEW

1.4   MINING OVERVIEW

Mining is the extraction of valuable minerals or other geological materials from the earth, from an orebody, lode,vein, (coal) seam or reef, which forms the mineralized horizon and package of economic interest to the miner. To gain access to the mineralized package within the lease area it is often necessary to mine through (to create access, shafts, addits, ramps) or remove to the side waste material which is not of immediate interest to the miner. The total movement of ore and waste, which also includes the removal of soil in some cases, is referred to as the mining process (Hartman, 1992).

Depending on the nature, attitude, and grade of the orebody, it is often the case that more waste than ore is mined during the course of the life of a mine. The waste removal and placement is a major cost to the mining operator and to facilitate detailed planning the detailed geological and mineralisation characterization of the waste material forms an essential part of the geological exploration programme. The waste is classified as either sterile or mineralised (with acid generating potential) and the movement and stacking (or dumping) of this material forms a major part of the mine planning process. In cases where the mineralised package is determined by an economic cut-off, the near grade mineralised waste is dumped separately with view to treatment should market conditions change and it becomes economic viable to treat this material (Ali, 2009).

The materials of economic interest (aka as ore) recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt and potash. Mining is required to obtain any material that cannot be grown through agricultural processes, or created artificially in a laboratory or factory. Mining in a wider sense comprises extraction of any non-renewable resource (e.g. petroleum, natural gas, or even water). Mining of stone and metal has been done since pre-historic times. Modern mining processes involve prospecting for ore bodies, analysis of the profit potential of a proposed mine, extraction of the desired materials and finally reclamation of the land to prepare it for other uses once the mine is closed (Hartman, 1992).

2.2 MINING: HISTORY AND ADVANCEMENT IN TECHNOLOGY

As one of humanity's earliest endeavors— and certainly one of its first organized industries— mining has an ancient and venerable history (Gregory, 1980). To understand modern mining practices, it is useful to trace the evolution of mining technology, which has paralleled human evolution and the advance of civilization. Mining in its simplest form began with Paleolithic humans some 450,000 years ago, evidenced by the flint implements that have been found with the bones of early humans from the Old Stone Age. Our ancestors extracted pieces from loose masses of flint or from easily accessed outcrops and, using crude methods of chipping the flint, shaped them into tools and weapons. By the New Stone Age, humans had progressed to underground mining in systematic openings 2 to 3 ft (0.6 to 0.9 m) in height and more than 30 ft (9 m) in depth (Bohuslav, 1954).

However, the oldest known underground mine, a hematite mine at Bomvu Ridge, Swaziland (Gregory, 1980), is from the Old Stone Age and believed to be about 40,000 years old. Early miners employed crude methods of ground control, ventilation, haulage, hoisting, lighting, and rock breakage. Nonetheless, mines attained depths of 800 ft (250 m) by early Egyptian times. Metallic minerals also attracted the attention of prehistoric humans. Initially, metals were used in their native form, probably obtained by washing river gravel in placer deposits (Bohuslav, 1954). With the advent of the Bronze and Iron Ages, however, humans discovered smelting and learned to reduce ores into pure metals or alloys, which greatly improved their ability to use these metals.

The first challenge for early miners was to break the ore and loosen it from the surrounding rock mass. Often, their crude tools made of bone, wood, and stone were no match for the harder rock, unless the rock contained crevices or cracks that could be opened by wedging or prying. As a result, they soon devised a revolutionary technique called fire setting, whereby they first heated the rock to expand it and then doused it with cold water to contract and break it. This was one of the first great advances in the science of rock breakage and had a greater impact than any other discovery until dynamite was invented by Alfred Nobel in 1867 (Anon, 1979).

Mining technology, like that of all industry, languished during the Dark Ages. Notably, a political development in 1185 improved the standing of mining and the status of miners, when the bishop of Trent granted a charter to miners in his domain. It gave miners legal as well as social rights, including the right to stake mineral claims. A milestone in the history

of mining, the edict has had long-term consequences that persist to this day. The greatest impact on the need for and use of minerals, however, was provided by the Industrial Revolution at the close of the eighteenth century. Along with the soaring demand for minerals came spectacular improvements in mining technology, especially in scientific concepts and mechanization that have continued to this day.

2.3   STAGES IN THE LIFE OF MINE

The overall sequence of activities in modern mining is often compared with the five stages in the life of a mine: prospecting, exploration, development, exploitation, and reclamation. Prospecting and exploration, precursors to actual mining, are linked and sometimes combined. Geologists and mining engineers often share responsibility for these two stages— geologists more involved with the former, mining engineers more with the latter. Likewise, development and exploitation are closely related stages; they are usually considered to constitute mining proper and are the main province of the mining engineer. Reclamation has been added to these stages since the first edition, to reflect the times. Closure and reclamation of the mine site has become a necessary part of the mine life cycle because of the demands of society for a cleaner environment and stricter laws regulating the abandonment of a mine. The overall process of developing a mine with the future uses of the land in mind is termed sustainable development. An explanation of the various stages is provided below (Hartman, 1992).

2.3.1   *Prospecting*

Prospecting, the first stage in the utilization of a mineral deposit is the search for ores or other valuable minerals (coal or non metallic). Because mineral deposits may be located either at or below the surface of the earth, both direct and indirect prospecting techniques are employed. The direct method of discovery, normally limited to surface deposits, consists of visual examination of either the exposure (outcrop) of the deposit or the loose fragments (float) that have weathered away from the outcrop. Geologic studies of the entire area augment this simple, direct technique. By means of aerial photography, geologic maps, and structural assessment of an area, the geologist gathers evidence by direct methods to locate mineral deposits. Precise mapping and structural analysis plus microscopic studies of samples also enable the geologist to locate the hidden as well as surface mineralization. The most valuable scientific tool employed in the indirect search for hidden mineral deposits is geophysics, the science of detecting anomalies using physical measurements of

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gravitational, seismic, magnetic, electrical, electromagnetic, and radiometric variables of the earth. The methods are applied from the air, using aircraft and satellites; on the surface of the earth; and beneath the earth, using methods that probe below the topography. Geochemistry, the quantitative analysis of soil, rock, and water samples, and geobotany, the analysis of plant growth patterns, can also be employed as prospecting tools.

2.3.2 Exploration

The second stage in the life of a mine, exploration, determines as accurately as possible the size and value of a mineral deposit, utilizing techniques similar to but more refined than those used in prospecting. The line of demarcation between prospecting and exploration is not sharp; in fact, a distinction may not be possible in some cases. Exploration generally shifts to surface and subsurface locations, using a variety of measurements to obtain a more positive picture of the extent and grade of the ore body. Representative samples may be subjected to chemical, metallurgical, X ray, spectrographic, or radiometric evaluation techniques that are meant to enhance the investigator's knowledge of the mineral deposit(Young, 1946). Samples are obtained by chipping outcrops, trenching, tunneling, and drilling; in addition, borehole logs may be provided to study the geologic and structural makeup of the deposit. Rotary, percussion, or diamond drills can be used for exploration purposes.

However, diamond drills are favored because the cores they yield provide knowledge of the geologic structure. The core is normally split along its axis; one half is analyzed, and the other half is retained intact for further geologic study. An evaluation of the samples enables the geologist or mining engineer to calculate the tonnage and grade, or richness, of the mineral deposit.

2.3.3 Development

In the third stage, development, the work of opening a mineral deposit for exploitation is performed. With it begins the actual mining of the deposit, now called the ore. Access to the deposit must be gained either (1) by stripping the overburden, which is the soil and/or rock covering the deposit, to expose the near-surface ore for mining or (2) by excavating openings from the surface to access more deeply buried deposits to prepare for underground mining(Hartman, 1987). In either case, certain preliminary development work, such as acquiring water and mineral rights, buying surface lands, arranging for financing, and

preparing permit applications and an environmental impact statement (EIS), will generally be required before any development takes place. When these steps have been achieved, the provision of a number of requirements— access roads, power sources, mineral transportation systems, mineral processing facilities, waste disposal areas, offices, and other support facilities— must precede actual mining in most cases. Stripping of the overburden will then proceed if the minerals are to be mined at the surface.

Economic considerations determine the stripping ratio, the ratio of waste removed to ore recovered; it may range from as high as 45 yd/ton - (38 m/tonne) for coal mines to as low as 1.0 yd/ton - (0.8 m/tonne) in metal mines. Some nonmetallic mines have no overburden to remove; the mineral is simply excavated at the surface. Development for underground mining is generally more complex and expensive. It requires careful planning and layout of access openings for efficient mining, safety, and permanence. The principal openings may be shafts, slopes, or adits; each must be planned to allow passage of workers, machines, ore, waste, air, water, and utilities. Many metal mines are located along steeply dipping deposits and thus are opened from shafts, while drifts, winzes, and raises serve the production areas. Many coal and nonmetallic mines are found in nearly horizontal deposits. Their primary openings may be drifts or entries, which may be distinctly different from those of metal mines (Hartman, 1992).

2.3.4 Exploitation

Exploitation, the fourth stage of mining, is associated with the actual recovery of minerals from the earth in quantity. Although development may continue, the emphasis in the production stage is on production. Usually only enough development is done prior to exploitation to ensure that production, once started, can continue uninterrupted throughout the life of the mine. The mining method selected for exploitation is determined mainly by the characteristics of the mineral deposit and the limits imposed by safety, technology, environmental concerns, and economics. Geologic conditions, such as the dip, shape, and strength of the ore and the surrounding rock, play a key role in selecting the method. Traditional exploitation methods fall into two broad categories based on locale: surface or underground. Surface mining includes mechanical excavation methods such as open pit and open cast (strip mining), and aqueous methods such as placer and solution mining. Underground mining is usually classified in three categories of methods: unsupported, supported, and caving(Young, 1946).

2.3.4.1 Surface mining

Surface mining is the predominant exploitation procedure worldwide, producing in the United States about 85% of all minerals, excluding petroleum and natural gas. Almost all metallic ores (98%), about 97% of the nonmetallic ores, and 61% of the coal in the United States are mined using surface methods(Derry and Booth, 1978), and most of these are mined by open pit or open cast methods. In open pit mining, a mechanical extraction method, a thick deposit is generally mined in benches or steps, although thin deposits may require only a single bench or face. Open pit or open cast mining is usually employed to exploit a near-surface deposit or one that has a low stripping ratio. It often necessitates a large capital investment but generally results in high productivity, low operating cost, and good safety conditions

The aqueous extraction methods depend on water or another liquid (e.g., dilute sulfuric acid, weak cyanide solution, or ammonium carbonate) to extract the mineral. Placer mining is used to exploit loosely consolidated deposits like common sand and gravel or gravels containing gold, tin, diamonds, platinum, titanium, or coal. Hydraulicking utilizes a high-pressure stream of water that is directed against the mineral deposit (normally but not always a placer), undercutting it, and causing its removal by the erosive actions of the water. Dredging performed from floating vessels, accomplishes the extraction of the minerals mechanically or hydraulically. Solution mining includes both borehole mining, such as the methods used to extract sodium chloride or sulfur, and leaching, either through drill holes or in dumps or heaps on the surface. Placer and solution mining are among the most economical of all mining methods but can only be applied to limited categories of mineral deposits (Young, 1946).

2.3.4.2 Sub-surface mining

This consists of digging tunnels or shafts into the earth to reach buried ore deposits. Ore, for processing, and waste rock, for disposal, are brought to the surface through the tunnels and shafts. Sub-surface mining can be classified by the type of access shafts used, the extraction method or the technique used to reach the mineral deposit. Drift mining utilizes horizontal access tunnels, slope mining uses diagonally sloping access shafts and shaft mining consists of vertical access shafts. Mining in hard and soft rock formations require different techniques (Hartman, 1992).

2.3.4.3 Underground mining

Underground methods— unsupported, supported, and caving— are differentiated by the type of wall and roof supports used, the configuration and size of production openings, and the direction in which mining operations progress. The unsupported methods of mining are used to extract mineral deposits that are roughly tabular (plus flat or steeply dipping) and are generally associated with strong ore and surrounding rock (Hustrulid, 1982). These methods are termed unsupported because they do not use any artificial pillars to assist in the support of the openings. However, generous amounts of roof bolting and localized support measures are often used.

Room-and-pillar mining is the most common unsupported method, used primarily for flat-lying seams or bedded deposits like coal, trona, limestone, and salt. Support of the roof is provided by natural pillars of the mineral that are left standing in a systematic pattern. Stope-and-pillar mining (a stope is a production opening in a metal mine) is a similar method used in noncoal mines where thicker, more irregular ore bodies occur; the pillars are spaced randomly and located in low-grade ore so that the high-grade ore can be extracted.

These two methods account for almost all of the underground mining in horizontal deposits in the United States and a very high proportion of the underground tonnage as well.

Two other methods applied to steeply dipping deposits are also included in the unsupported category. In shrinkage stoping, mining progresses upward, with horizontal slices of ore being blasted along the length of the stope. A portion of the broken ore is allowed to accumulate in the stope to provide a working platform for the miners and is thereafter withdrawn from the stope through chutes. Sublevel stoping differs from shrinkage stoping by providing sublevels from which vertical slices are blasted. In this manner, the stope is mined horizontally from one end to the other. Shrinkage stoping is more suitable than sublevel stoping for stronger ore and weaker wall rock.

Supported mining methods are often used in mines with weak rock structure. Cut-and-fill stoping is the most common of these methods and is used primarily in steeply dipping metal deposits. The cut-and-fill method is practiced both in the overhand (upward) and in the underhand (downward) directions. As each horizontal slice is taken, the voids are filled with a variety of fill types to support the walls. The fill can be rock waste, tailings, cemented tailings, or other suitable materials. Cut-and-fill mining is one of the more popular methods

used for vein deposits and has recently grown in use. Square-set stopping also involves backfilling mine voids; however, it relies mainly on timber sets to support the walls during mining. This mining method is rapidly disappearing in North America because of the high cost of labor. However, it still finds occasional use in mining high-grade ores or in countries where labor costs are low. Stull stopping is a supported mining method using timber or rock bolts in tabular, pitching ore bodies. It is one of the methods that can be applied to ore bodies that have dips between 10° and 45°. It often utilizes artificial pillars of waste to support the roof (Hamrin, 1982).

Caving methods are varied and versatile and involve caving the ore and/or the overlying rock. Subsidence of the surface normally occurs afterward. Longwall mining is a caving method particularly well adapted to horizontal seams, usually coal, at some depth. In this method, a face of considerable length (a long face or wall) is maintained, and as the mining progresses, the overlying strata are caved, thus promoting the breakage of the coal itself. A different method, sublevel caving, is employed for a dipping tabular or massive deposit. As mining progresses downward, each new level is caved into the mine openings, with the ore materials being recovered while the rock remains behind.

Block caving is a large-scale or bulk mining method that is highly productive, low in cost, and used primarily on massive deposits that must be mined underground. It is most applicable to weak or moderately strong ore bodies that readily break up when caved. Both block caving and longwall mining are widely used because of their high productivity. In addition to these conventional methods, innovative methods of mining are also evolving. These are applicable to unusual deposits or may employ unusual techniques or equipment. Examples include automation, rapid excavation, underground gasification or liquifaction, and deep-sea mining (Hartman, 1992).

2.3.5 Reclamation

The final stage in the operation of most mines is reclamation, the process of closing a mine and recontouring, revegetating, and restoring the water and land values. The best time to begin the reclamation process of a mine is before the first excavations are initiated. In other words, mine planning engineers should plan the mine so that the reclamation process is considered and the overall cost of mining plus reclamation is minimized, not just the cost of mining itself. The new philosophy in the mining industry is sustainability, that is, the meeting of economic and environmental needs of the present while enhancing the ability of

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future generations to meet their own needs (Hartman, 1987). In planning for the reclamation of any given mine, there are many concerns that must be addressed. The first of these is the safety of the mine site, particularly if the area is open to the general public. The removal of office buildings, processing facilities, transportation equipment, utilities, and other surface structures must generally be accomplished. The mining company is then required to seal all mine shafts, adits, and other openings that may present physical hazards. Any existing highwalls or other geologic structures may require mitigation to prevent injuries or death due to geologic failures.

The second major issue to be addressed during reclamation of a mine site is restoration of the land surface, the water quality, and the waste disposal areas so that long-term water pollution, soil erosion, dust generation, or vegetation problems do not occur. The restoration of native plants is often a very important part of this process, as the plants help build a stable soil structure and naturalize the area. It may be necessary to carefully place any rock or tailings with acid-producing properties in locations where rainfall has little effect on the material and acid production is minimized. The same may be true of certain heavy metals that pollute streams. Planning of the waste dumps, tailings ponds, and other disturbed areas will help prevent pollution problems, but remediation work may also be necessary to complete the reclamation stage of mining and satisfy the regulatory agencies.

The final concern of the mine planning engineer may be the subsequent use of the land after mining is completed. Old mine sites have been converted to wildlife refuges, shopping malls, golf courses, airports, lakes, underground storage facilities, real estate developments, solid waste disposal areas, and other uses that can benefit society.

2.4   UNIT OPERATIONS OF MINING

During the development and exploitation stages of mining when natural materials are extracted from the earth, remarkably similar unit operations are normally employed. The unit operations of mining are the basic steps used to produce mineral from the deposit, and the auxiliary operations that are used to support them. The steps contributing directly to mineral extraction are production operations, which constitute the production cycle of operations. The ancillary steps that support the production cycle are termed auxiliary operations. The production cycle employs unit operations that are normally grouped into

rock breakage and materials handling. Breakage generally consists of drilling and blasting, and materials handling encompasses loading or excavation and haulage (horizontal transport) and sometimes hoisting (vertical or inclined transport). Thus, the basic production cycle consists of these unit operations:

Production cycle = drill + blast + load + haul

Although production operations tend to be separate and cyclic in nature, the trend in modern mining and tunneling is to eliminate or combine functions and to increase continuity of extraction. For example, in coal and other soft rock mines, continuous miners break and load the mineral to eliminate drilling and blasting; boring machines perform the same tasks in medium-hard rock. The cycle of operations in surface and underground mining differs primarily by the scale of the equipment. Specialized machines have evolved to meet the unique needs of the two regimes.

In modern surface mining, blast holes of 3 to 15 in. (75 to 380 mm) in diameter are produced by rotary or percussion drills for the placement of explosives when consolidated rock must be removed. The explosive charge is then inserted and detonated to reduce the overburden or ore to a size range suitable for excavation. The broken material is loaded by shovel, dragline, or wheel loader into haulage units— generally trucks— for transport. Railroad cars are also used for haulage, and belt conveyors are often used after the material is crushed. Soil and coal are often moved in the same manner, though blasting is sometimes unnecessary. In the quarrying of dimension stone, the blocks are often freed without blasting, using wire saws or other mechanical devices.

In underground mining, the production cycle is similar, although the equipment used may be scaled down in size. Smaller drill holes are used, trucks are sometimes replaced by shuttle cars, and belt conveyors are more prevalent. Coal, salt, potash, and trona are often mined without the use of explosives or mined after undercutting the face to reduce the consumption of explosives. In addition to the operations of the production cycle, certain auxiliary operations must be performed in many cases. Underground, these usually include roof support, ventilation and air-conditioning, power supply, pumping, maintenance, lighting, communications, and delivery of compressed air, water, and supplies to the working sections. In surface mining, the primary auxiliary operations include those

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providing slope stability, pumping, power supply, maintenance, waste disposal, and supply of material to the production centers (Hartman, 1992).

2.5 THE GHANAIAN MINING INDUSTRY

Ghana's mining tradition, particularly regarding gold, dates back to the fifteenth century, but has since had a rather ragged history. British and a few other foreign investors controlled the industry during the colonial period. Developments in the mining industry at this stage were responses to economic and political developments in Britain and Europe in general rather than to market conditions. The industry was very vibrant during the pre-independence period. Ghana accounted for 36 % of total world gold output (8,153,426 fine ounces) between 1493 and 1600 (Akabza and Draimani, 2001), but its share of world mineral output dwindled over subsequent years.

The post-independence period was marked by state ownership of mineral resources. The period up to 1986 was generally characterised by stagnation of the industry, except for a few spikes recorded immediately after independence and in the early 1970s. The sluggish production, particularly in the gold sector, could be attributed to market conditions, investor uncertainty about the safety of their investment under Ghanaian self-rule and the effects of state intervention in the industry. As part of the country's economic recovery programme (ERP) launched in 1983, the mining sector underwent significant reforms beginning in 1986.

2.5.1 Pre-independence period

While gold mining by indigenous people is said to pre-date Christian times and Ghana's modern mining history spans over six centuries, private Ghanaian gold miners were banned after 1933 from operating mines due to the promulgation of the Mercury Law. Large-scale mining by British and other foreign investors began in the late 19th century. British mining interests were a significant source of influence on the Colonial Office in London and its representatives in the territory and shaped the formulation and implementation of mineral policy in the colony (Aboagye, 2001). The thrust of policy in the sector was aimed, first at establishing a legal and administrative framework that would facilitate mining operations and secondly, ensuring the self-sufficiency of the British Empire. For instance, the development of minerals such as bauxite and manganese in Ghana was a function of the needs of Britain and carried out with the active participation of British state. Although a

concession for mining bauxite in the Awaso area was obtained in 1926, production only started in 1940-41. This was when other sources of bauxite were cut off from the Allied forces in the early part of World War II. British Aluminium Company Limited, acting as agents for the British Ministry of Aircraft Production, started exploitation of the Ayawaso deposit. Similarly, exploitation of manganese in Ghana started in 1916 at the request of the Wartime Ministry of Munitions, as manganese was in high demand for war purposes (Akabza and Draimani, 2001).

Mineral production during this period had its ups and downs. The period from 1480 to 1954 was characterised by two major periods of peak production referred to as the "Jungle Booms" and three periods of depressed production, attributed to various reasons including the influence of the two World Wars. Ghana accounted for 36% of total world gold output (8,153,424 fine ounces) between 1493 and 1600, but this share dwindled over the years as a result of new producers. Total production up to 1934 was about 30 million fine ounces of gold representing 2.7 % of worldwide production (Aboagye, 2001). The First and Second World War periods were characterised by low production. Rapid closure of small and medium mines that were starved of supplies because of the war affected output. In addition, the drafting of men and miners who could handle explosives to the warfront and the internment of German concessionaires by the British were some of the reasons accounting for the low production during the period. The depressed gold production in 1918–1929 was attributed to labour scarcity. The booming cocoa and construction industries and the emergence of the manganese and diamond mines affected the labour supply. But the growing number of Ghanaians who preferred to work their small mines also affected the labour availability.

In fact the preference of Ghanaians to work in their own mines rather than work for the Europeans encouraged the Colonial Office to pass the Mercury Ordinance of 1932, making it illegal for Ghanaians to use mercury for mining. This marked the beginning of the criminalisation of indigenous, small-scale gold mining and the edging out of Ghanaian gold producers, until 1989 when the Small-scale Mining Law was enacted to give legal status to the sector again. The banning of indigenous gold mining did boost large-scale mining as more labour was freed for the latter and the period 1933 to 1942 saw increased mine output. The emergence of major new producing countries and the growing struggle for independence creating political risk and investor disquiet were responsible for the territory's

dwindling share of world production from 1943 to 1954. State intervention immediately after independence was to ensure that mines with considerable labour force threatening closure did not do so for obvious reasons(Aryee, 2001).

2.5.2 *The Post-Independence period*

Generally, the vicissitudes in Ghana's mineral industry mirror trends in the global industry. The period between 1965 and 1980 was characterized by the declaration of permanent sovereignty over natural resources by developing countries, primarily through large-scale nationalisation of mineral extractive facilities, the renegotiation of existing arrangements and the creation of state enterprises and numerous commodity producer associations (Akabza and Draimani, 2001). Ghana's mining industry was state controlled from 1957 to 1986. After independence, the government set up the State Gold Mining Corporation (SGMC) and the Ghana National Manganese Marketing Corporation (GNMC). SGMC was established in 1961 to acquire five gold mines (Bibiani, Tarkwa, Prestea, Konongo and Dunkwa mines) from British companies. In 1972, the government took majority shares (55%) in Ashanti Goldfields Corporation (AGC), Ghana Bauxite Company (BAC) and Ghana Consolidated Diamonds Company. The Ghana National Manganese Corporation (GNMC) took over manganese operations at Nsuta from the African Manganese Group (AMG), a British subsidiary of Union Carbide.

The government's cardinal objectives in the acquisition of these mines has been summarised as the protection of employment and the access to foreign currency generated by the mines (Aryee, 2001). The policy at the time was, therefore, aimed at maximizing government revenue, control of resources and employment generation. Thus, state mines were subject to government intervention for purposes often unrelated to efficiency or economic probity. The mining sector was, therefore, constrained by lack of investment and exploration. The state-owned mining enterprises were under-capitalised and became increasingly obsolescent. Lack of investment, maintenance and modernisation left these state-run mines uncompetitive. Apart from AGC and GNMC, which were operating profitably, the SGMC and BAC were operating at a loss and SGMC had closed the Bibiani and Konongo mines, which were making serious losses.

From 1960 to 1980, various modifications were made to the mining sector code aimed at attracting private participation, but they failed to attract significant foreign private investment. The changes were characterised by high taxes and other duties along with

significant state control of the industry. The mining industry stagnated and up to 1985, there were no significant new investments in Ghana's mining sector output in almost all the mines declined and the sector contributed relatively little to gross national earning (Aboagye, 2001). The mining sector accounted for about 15% of export earnings from the mid-1970s to 1982, of which the gold subsector contributed over 80%.

The dynamics in Ghana's mining sector are in direct consonance with worldwide trends in the sector. The global mining industry has undergone vigorous changes in the last 15 years. Improved exploration, mining and processing technology have revolutionized the entire mining industry worldwide, particularly in the domain of gold. The development of processes such as cyanide heap-leach and bio-oxidation have made viable the processing of low- grade material which hitherto was considered waste. The revolution in processing technology also gave impetus to an evolution of mining and exploration methods. These have made possible more efficient processing of more complex ores such as sulphides and oxides. It has also resulted in an upsurge in exploration and mining activity worldwide.

In the area of gold, traditional underground mining is being abandoned in favour of surface mining. These developments have had negative dimensions in terms of environmental impact. Apart from these technological innovations, which account for the upsurge in mining activities globally, the most fundamental development in the industry from the early 1980s to date has been in the area of the mineral policies of mineral-rich countries, particularly in the developing world.

During the late 1980s, the mineral industry worldwide experienced major changes. State ownership of mines was de-emphasized. Many mineral-rich developing countries were encouraged to put in place a policy framework that would encourage private participation. International private investor demands for participation in the mining sector were well articulated by various groups including the World Bank and the International Monetary Fund (IMF). For a country to attract private investment, therefore, it must offer, in addition to a promising geological environment, a conducive policy, legislative and administrative framework more conducive to business, and a thorough privatization programme (Akabza and Draimani, 2001).

The main purposes of the privatisation programme have been: to reduce the role of the state in the economy and to improve business competitiveness and efficiency; to reduce the fiscal deficit by using the proceeds from the sales to retire external and domestic debt, and to

generate new cash flows through investment and tax revenues. In response to this global demand for policy changes to attract international mining investment, Ghana shifted its focus from direct state investment in the mining sector to promotion and regulation of private companies. Within the framework of the country's economic recovery programme of 1983, and more specifically under its structural adjustment programme, the mining sector was a major target for reforms to address the concerns of investors and financiers, to arrest and reverse the fall in the industry and to ensure growth. The policy changes have achieved the desired results with respect to investor perception of the investment environment and the volume and value of mineral output. The country fast became a citadel of commerce and mining in West Africa. Internationally, Ghana is known now to be among a few selected African countries with the most attractive geological and investment environment (Akabza and Draimani, 2001).

Comparative geological ranking of African countries placed Ghana third after South Africa and Zimbabwe. For the most attractive African countries from the general perspective of mining investment, Ghana is ranked third after Botswana and Zimbabwe respectively (Aboagye, 2001). In a political and commercial risk assessment of African countries, Ghana was categorized good enough to risk investment alongside Zimbabwe and Morocco. A survey by International Investment Conference Inc. indicated that the country moved from 7th position in 1992 to 6th in 1994 on the list of emerging markets. The explosion of local and foreign mining and exploration companies in Ghana confirms these findings.

The renewed investor confidence in Ghana's minerals industry is reflecting in the ballooning volume and value of minerals produced. Gold production, which dwindled from a peak of 915,317 ounces in 1960 to 282,299 ounces in 1984, rebounded to 998,195 ounces in 1992, exceeding the 1960 peak value. Output reached an all-time-record high of 1,706,229 ounces in 1995 and has since exceed that figure. Bauxite production similarly has been on the increase. Production showered from 44,169 tonnes in 1984 to 530,267.2 tonnes in 1995. Gold in particular has assumed a leading role in foreign exchange earnings. In 1994, gold exports amounted to $549 million, representing 45% of total export revenue ($1,215 million), beating cocoa (25% of total exports) down to second place for the third year running. Employment in the minerals sector also surged, at least up to the close of 1995. The total labour force of the sector rose from 15,069 in 1987 to 22,500 in 1995 (Akabza and Draimani, 2001).

2.6 STRUCTURE OF THE GHANAIAN MINING SECTOR

Ghana has the potential to produce a variety of minerals including limestone, silica sand, kaolin, stone, salt., The main minerals produced by large-scale companies are gold, diamond, bauxite and manganese, while industrial minerals such as kaolin, limestone and silica sand are mainly produced by small-scale operators. While foreigners are the main owners of the large mining companies -- the government and private Ghanaian investors account for less than 15 per cent of the shares in these mines -- small-scale mining activity is statutorily restricted to Ghanaians. Gold contributes more than 90% of the total value of minerals won in the country and has attracted the largest number of large and small-scale operators. Both foreign and local companies are actively involved in exploration of gold in the country. By October 2000, 224 local and foreign companies held mineral rights for gold exploration and exploitation, while over 600 registered small-scale miners, along with an estimated 200,000 informal miners, popularly called "galamsey operators", were scattered on prospecting grounds throughout the country. Of the $612.9 million in total mineral export earnings in 1997, gold accounted for $579.2 million, or 94.5%, while the remaining 5.4% came from diamonds, bauxite and manganese (Hilson G. and Potter C, 2003).

2.6.1 Large-Scale Mining in Ghana

There are over 25 large mining companies in Ghana operating 16 gold mines, and one bauxite, one diamond and one manganese mine. Currently, with the exception of Ashanti Goldfields Company's Obuasi mine and the Prestea Gold Resources Limited, all the other mines are surface operations. The Obuasi mine of Ashanti Goldfields Corporation (AGC), which started in 1890, is by far the largest and oldest operation in the country. The mine accounts for more than 50% of Ghana's total annual gold production and AGC itself is the largest company in the country. It has gone multinational, with mines in Guinea, Mali, Tanzania and Zimbabwe, and exploration projects in about 15 African countries (Akabza and Draimani, 2001). A breakdown of the various large-scale gold mining companies is shown in Table 2.1.

Table 2-1 Major large scale mining companies in Ghana

Company	Commodity mined	Mines	Type of mine
AGC	Gold	Obuasi	UG& OP
		Anyanfuri[a]	OP
		Bibiani[b]	OP
		Iduapriem[c]	OP
		Prestea Sankofa[d]	Tailings
		Asikam	Alluvial
Abosso Goldfields Ltd.	Gold	Damang (near Tarkwa)	OP
Goldfields (Gh) Ltd.	Gold	Tarkwa	OP
Teberebie Goldfields Ltd	Gold	Teberebie	OP
GAG	Gold	Iduapriem	OP
Prestea Gold Resources	Gold	Prestea	UG
Billinton Bogoso	Gold	Bogoso	OP
Bonte Gold Mines Ltd.	Gold	Akrokerri	Alluvial
Dunkwa Continental Goldfields Ltd.	Gold	Dunkwa	Alluvial

2.5.4 The Small-Scale mining sector

According to the World Bank Group, "Small-scale mining is largely a poverty-driven activity, typically practiced in the poorest and most remote rural areas of a country by a largely itinerant, poorly educated populace with few employment alternatives". The World Bank also estimates that while some 13 million small scale miners are operating under harsh and risky conditions with minimal incomes in about 30 countries, as many as 80–100 million individuals depend on the activity for their livelihoods worldwide. Two groups of miners characterize this sector of the mining industry: 1) the artisanal miners who use only rudimentary/artisanal implements and 2) the more sophisticated mining activities operating at a relatively low level of production and which generally require limited capital investment (Aryee et al., 2003).

2.5.4.1 Historical perspectives of small-scale and artisanal mining in Ghana

During pre-colonial times, mainly gold and diamonds were mined on a small scale. In fact, gold was traded with the Moors and the Phoenicians on the trans-Saharan trade routes before the advent of the Portuguese and other European incursions, which began in 1471. Artisanal mining and processing methods were employed to work both hard rock/lode and

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alluvial gold deposits. Lode gold was mined by excavating pits to levels where "a dark coloured stone which is interspersed with gold" was reached. The gold was then recovered "by grinding the stone to powder", and then "washing it". Alluvial gold was mined by collecting gravel from the beds of streams and washing sediments clean of sand and earth. The Chief whose land was mined for gold was generally entitled to one-third of the gold won, and therefore sought to promote proper organization of the activity (Hilson and Potter, 2003).

Furthermore, in view of the opulent use of gold in the attire as well as customary practices of the traditional chieftaincy institution, close watch was kept over small-scale gold mines operating within their lands; control and regulation (by Chiefs) of such operations has existed for over two centuries. As a result, artisanal or small-scale mining continued in Ghana even after the introduction of modern exploration and mining methods to the country by the Frenchman Piere Bonnat and others circa 1870. Enterprising natives, who had neither the capital nor technical ability to venture into large-scale modern mining, were also compelled to operate at the small-scale artisanal level. In fact, small-scale miners discovered almost all deposits subsequently worked by large-scale operators.

Various legislation, which prohibited or limited certain small-scale mining activities, stunted the growth of the small-scale gold mining sector vis-à-vis the large scale sector from about 1910 onwards. This in turn led to the domination of gold mining in Ghana by English owned large-scale mining companies, and nearly a complete eradication of the small-scale mining sector. In fact, prior to 1989, artisanal activities, together with the marketing of gold from such workings, were considered illegal. Nevertheless, small-scale gold miners—referred to locally as "galamsey"—had flourished, and winnings were mainly smuggled for sale outside the country through a well-oriented black market. Despite contributing nothing economically, operations caused significant environmental damage. Outputs in turn enriched neighbouring countries, which were found to be exporting gold despite lacking significant gold deposits. The increasing awareness of the fact that the continued marginalisation of the small-scale gold mining sector was detrimental to the economy led to a study into the phenomenon, which resulted in its regularization through the enactment of the Small-Scale Gold Mining Law, PNDC L 218, in May 1989. Concurrently, the state agency responsible for marketing diamonds—the Diamond Marketing Corporation (DMC)—had its mandate expanded and was re-named the Precious

Minerals Marketing Corporation (PMMC) to provide a ready market for both gold and diamond produced by resident small-scale miners. Diamonds were first discovered in Ghana in 1919 (at the time, Ghana was known as "The Gold Coast") within the stream gravels of the Birim River. Additional deposits were later discovered in what is today known as the Birim Diamond Field and the Bonsa Diamond Field. While mechanized diamond winning has taken place in Ghana for some time, the activities of small scale miners, who use simple hand tools, led to the discovery of the various diamond fields; these operators continue to contribute significantly to Ghanaian diamond output (Hilson and Potter, 2003).

In addition to the regularization of small-scale gold mining and implementation of an accompanying marketing framework in 1989, procedures for diamond marketing, which had long been legalized, were streamlined. This combination of changes has enabled the sector to make significant contributions to national mineral exports and foreign exchange earnings. From its regularization in 1989 to 2000, some 870,000 ounces of gold valued at more than US$ 280 million, and some 4.9 million karats of diamonds, valued at more than US$ 110 million and representing 69% of Ghana's total diamond production, has been mined by Ghanaian small scale miners. Furthermore, the sector, which is expanding rapidly, has provided a number of native Ghanaians with employment. It is estimated that about 80,000 locals, including women, are currently involved in the small-scale mining of gold and diamonds alone (Aryee, 2001).

2.6.2.2 *Small-scale gold and diamond mining operations in Ghana*

The intensive small-scale mining of precious minerals is concentrated along the northeast–southwest gold belt of the country. Both legal and illegal miners operate along this belt. Legal workings operate under a license granted by the government of Ghana on concessions registered in their names, and in a majority of cases, are well organized and have access to extension services. The Minerals Commission, which is responsible for assisting the Minister of Mines with small-scale licensing procedures and the monitoring of operations, has established seven small-scale mining district centres to facilitate the provision of technical extension services. These centres shown in Figure 2.2 below, are manned by experienced mining engineers and provide assistance within small-scale mining areas in close proximity to their respective locations in Tarkwa, Asankragwa, Bibiani, AssinFoso, AkimOda, Dunkwaon-Offin, and Bolgatanga (Aryee *et al.*, 2003).

KEY

- ○ Mining District Centres
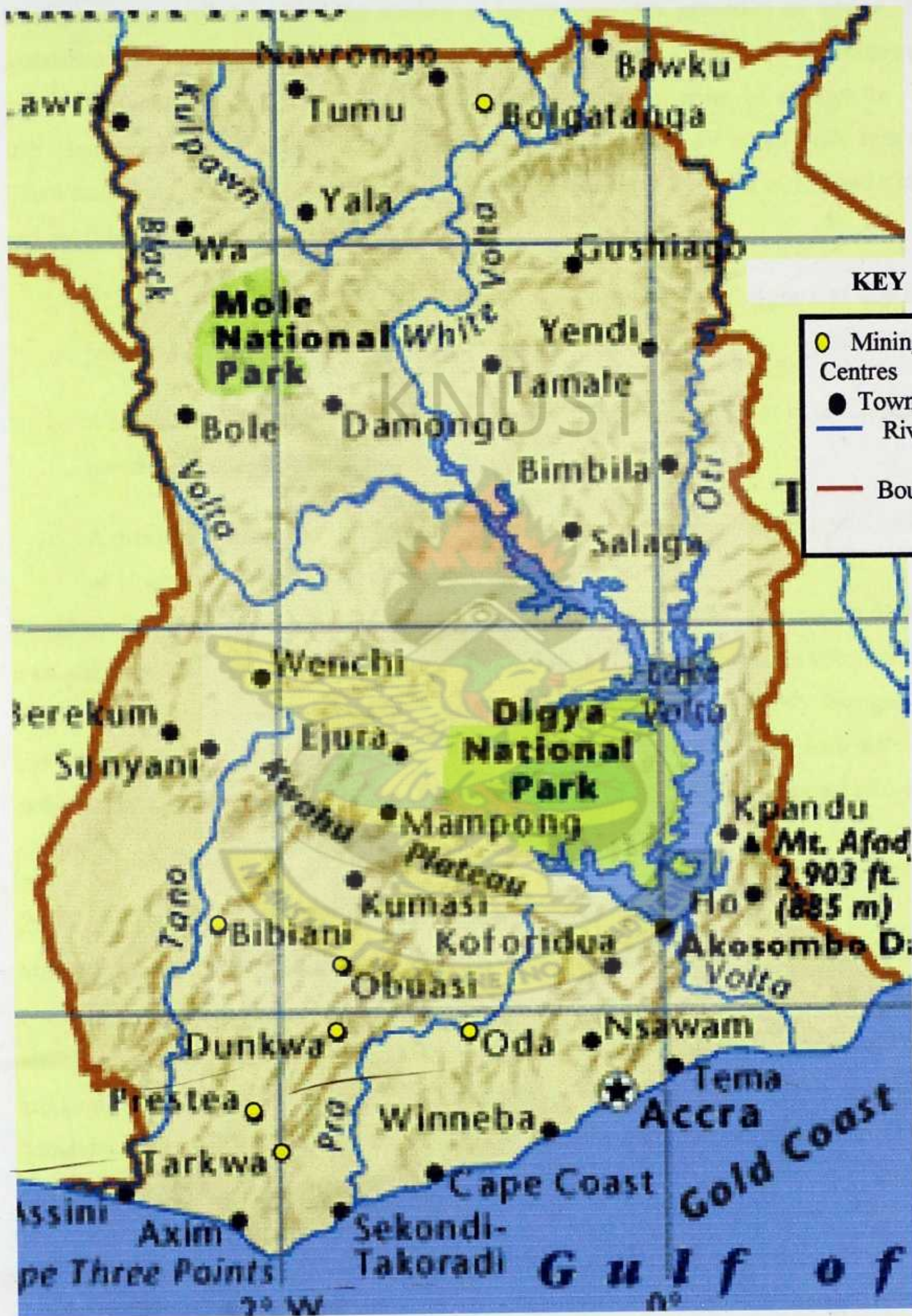- ● Towns
- —— Rivers
- —— Boundary

Figure 2-1 Small-Scale mining district support centres in Ghana

The services provided include the sharing of information, the provision of advice, and assistance and training in best practices for mining, processing, marketing, environmental sustainability, health and safety. They also serve as an initial point of contact for any individual or group of individuals wishing to acquire a license for small scale mining. Small-scale gold mining licenses may be granted to Ghanaians 18 years of age and older, and are subject to the following conditions:

- o A maximum allocation of 1.2 hectares of land in the case of a grant to any one person or group of persons not exceeding four in number ;

- o A maximum allocation of 2.0 hectares of land in the case of a grant to any group of persons not exceeding nine in number; and

- o A maximum allocation of 10 hectares in the case of a grant to a co-operative society of 10 or more persons and registered companies.

Illegal operators, on the other hand, work without a licence, have no concessions of their own and operate uncontrollably within the concessions of large-scale mining companies or in areas prohibited for mining such as forest reserves. Such miners are highly disorganized and operate in a "hit and run" manner, often initiating confrontations with both state law enforcement agencies and the security personnel of large-scale mining companies (Aryee *et al.*, 2003).

2.6.2.3 *Mining methods of small-scale miners in Ghana*

Mining methods employed by small-scale miners of precious minerals vary according to the type of deposit being exploited and its location. In view of the poor financial base of small-scale miners, a great majority rely solely on traditional/manual methods of mining, which are largely artisanal, featuring simple equipment like shovels, pick-axes, pans, chisels and hammers. The methods used in the small-scale mining of precious minerals in Ghana, however, can be categorized into the following three groups:

- • shallow alluvial mining;
- • deep alluvial mining; and
- • hard rock (lode) mining

Shallow alluvial mining techniques, which are popularly called "dig and wash", are used to mine shallow alluvial deposits usually found in valleys or low lying areas. Such deposits have depths not exceeding three metres. Vegetation is initially cleared and the soil excavated until the gold-rich layer is reached (Hilson and Potter, 2003). The mineralized material is removed and transported to nearby streams for sluicing to recover the gold. It should be noted that in view of the relative ease of reaching these deposits and treating such ores, a significant proportion of the industry's operations are of this type. For similar reasons, illegal workings are predominantly of this type.

Deep alluvial mining techniques are used to mine deep alluvial deposits found along the banks of major rivers such as the Ankobra, Tano, and Offin and certain older river courses. These methods involve excavating a pit and digging until the gold bearing gravel horizon, which is typically located at depths of 7 to 12 metres, is reached. Terraces or benches are constructed along the sides of pits to prevent collapse. The gold bearing gravel is then removed and sluiced to recover the gold. Hard rock mining techniques are adapted to mine gold bearing reefs, which can be located close to the surface or deep-seated. Holes are sunk to intercept the reefs and when accomplished, the reefs are worked along the strike. Where such reefs are weathered, small-scale miners use chisels and hammers to break ore. In cases where ore is hard, explosives are commonly used, despite being prohibited throughout Ghana.

2.6.2.4 *Processing methods of small-scale miners in Ghana*

Small-scale gold miners invariably prefer free milling ores (not sulphuric ores), and therefore gravity concentration, using sluicing, is the main method for processing. Current regulations do not permit the use of cyanide or other leaching techniques. In any case, these are not likely to be widely adopted by the small-scale miners of Ghana should they be introduced, because of the longer time these methods need for the recovery of the mineral from ores. In the case of alluvial ores, the traditional ore processing method, which usually yields a recovery rate of approximately 60%, involves the sluicing of mined material in a sluice box to obtain gold concentrate. Mercury is added to the concentrate and mixed to form a gold amalgam, which is then heated to separate the gold. When processing hard rock ores, traditional or manual methods featuring artisanal implements are typically used. This is largely due to a lack of capital to purchase the requisite crushing and milling equipment to facilitate the process. The manual method of gold extraction from hard rock ore involves

"pounding" (crushing and grinding) using locally designed metal mortars and pestles. The resultant powder is mixed with water and sluiced to obtain a gold concentrate, which is later amalgamated with mercury (Aryee *et al.*, 2003).

In the case of diamonds, a mining method similar to the shallow alluvial mining technique described earlier is adopted. In short, mined material is transferred on to a jig and washed. As washing progresses, the diamonds are picked by hand. It is also worth mentioning that an increasing number of Ghanaian small-scale miners have, in recent years, received financial and technical support from both foreign and local investors, registered as "Mine Support Service Companies". This has facilitated a transition from artisanal or traditional mining to semi-mechanized and mechanized mining methods in some mining districts, particularly Tarkwa. Where the deposit is alluvial in nature, mechanized operations commonly feature sizing trommels and Knelson concentrators and sluice boxes, all of which are used to process the material. In hard rock operations, on the other hand, jaw crushers, hammer mills, ball mills and modified corn mills are also used for communition.

2.7 LAND/SOIL FERTILITY

2.7.1 Overview

The fertility of soil can be considered in different ways, depending on land use. In intensively managed agricultural and horticultural systems, and even in forestry, soil fertility can be defined in terms of the value of products produced relevant to inputs used (including economic aspects of nutrient budgeting). Alternatively, the emphasis may be on quality or productivity. In this regard, the fertility of soil is related to its capacity to produce a product. In many natural ecosystems, the value of land use may not be clearly defined, and a different definition of soil fertility may be more suitable. Hence the fertility of soil is related to its capacity to support a particular natural community of plants. Yet still, another view might emphasise the concept of sustainability; i.e. the fertility of a soil is related to its capacity to maintain consistent output with minimal input(McCauley *et al.*, 2005).

Thus, the concept of soil fertility is most useful when it is used in a specific context. However, in all contexts, soil fertility depends on physical, chemical and biological characteristics. When soil fertility is considered in terms of the highest practical level of productivity, the focus is mostly on physical and chemical aspects of soil. It is important to note that some aspects of the biological component of soil fertility can be overridden by addition of fertilisers, but this is not a simple phenomenon, because increased plant growth

associated with addition of fertiliser can increase other aspects of the biological activity in soil(Zhang and Raun, 2006). When sustainability of the soil resource is emphasised in the context of soil fertility, biological components may become more relevant because long-term productivity is taken into account. A change in focus from the highest practical level of productivity to a lower, profitable and persistent level of production has the potential to depend to a greater extent on soil biological processes(Gardiner and Miller, 2004).

In a sustainable agricultural or horticultural system, soil fertility can be considered in terms of the amount of input relative to the amount of output over a long period, using a budgeting approach. This definition is different to one that defines fertility in relation to a maximum level of productivity in the short-term, or at one point in time. A definition that focuses on short-term productivity is based on the capacity of soil to immediately provide plant nutrients. A definition of soil fertility that is inclusive of sustainable land must consider the three components of soil fertility (biological, chemical and physical) equally.

2.7.1 Components of soil fertility

There are three main components of soil fertility - physical, chemical and biological(Abbott and Murphy, 2003). The level of soil fertility results from the inherent characteristics of the soil and the interactions that occur between these three components. Most characteristics that contribute to the fertility of soil, such as soil pH and the susceptibility of the soil to compaction are dependent on the constituents of the original parent rock. Subsequent events, including the growth of plants and addition of fertiliser, modify the soil characteristics and alter its fertility. For instance, the original soil pH can be modified by legumes which increase soil acidity (i.e. decrease soil pH).

Pedology is the study of the formation of soil and the physical process of soil formation plays a major role in soil chemical fertility. For example, the relationship between pedological characteristics of soil and soil chemical fertility are clearly demonstrated for the lateritic soils of jarrah forests in south-western Australia(Robson and Gilkes, 1981). The soils formed on these laterite soils have low levels of chemical fertility (especially phosphate, calcium and magnesium) because of the chemical characteristics of the parent rock. These low levels of nutrients lead to either low or slow productivity of plants and to low levels of organic matter returned to the soil. Overall, biological activity is low because of the low level of organic matter, and many biological processes proceed at a slow rate. It

is useful to understand the origins of soil because it helps in predicting how soil disturbance influences the three components of soil fertility.

The biological components of a soil which influence its fertility include many different types of organisms: microorganisms (bacteria and fungi), animals (microfauna, mesofauna and macrofauna) and plants. These organisms range in size from less than a micrometre to more than a metre. Most are only visible with a microscope. These examples illustrate the considerable difference in dimensions of organisms that inhabit the soil. The size range depends on the species. Earthworms common in agricultural soils fall into the range of 5 to 15 cm in length. In contrast, most bacteria are of a much smaller size, about one micrometre. When bacteria are grown on agar plates in a laboratory they are usually slightly larger than the same organism would be in the soil(Brady and Weil, 2002). This is partly because artificial growing media contain much greater quantities of nutrients than might naturally occur in the soil. The three components of soil fertility and the various factors that determine them are illustrated below.
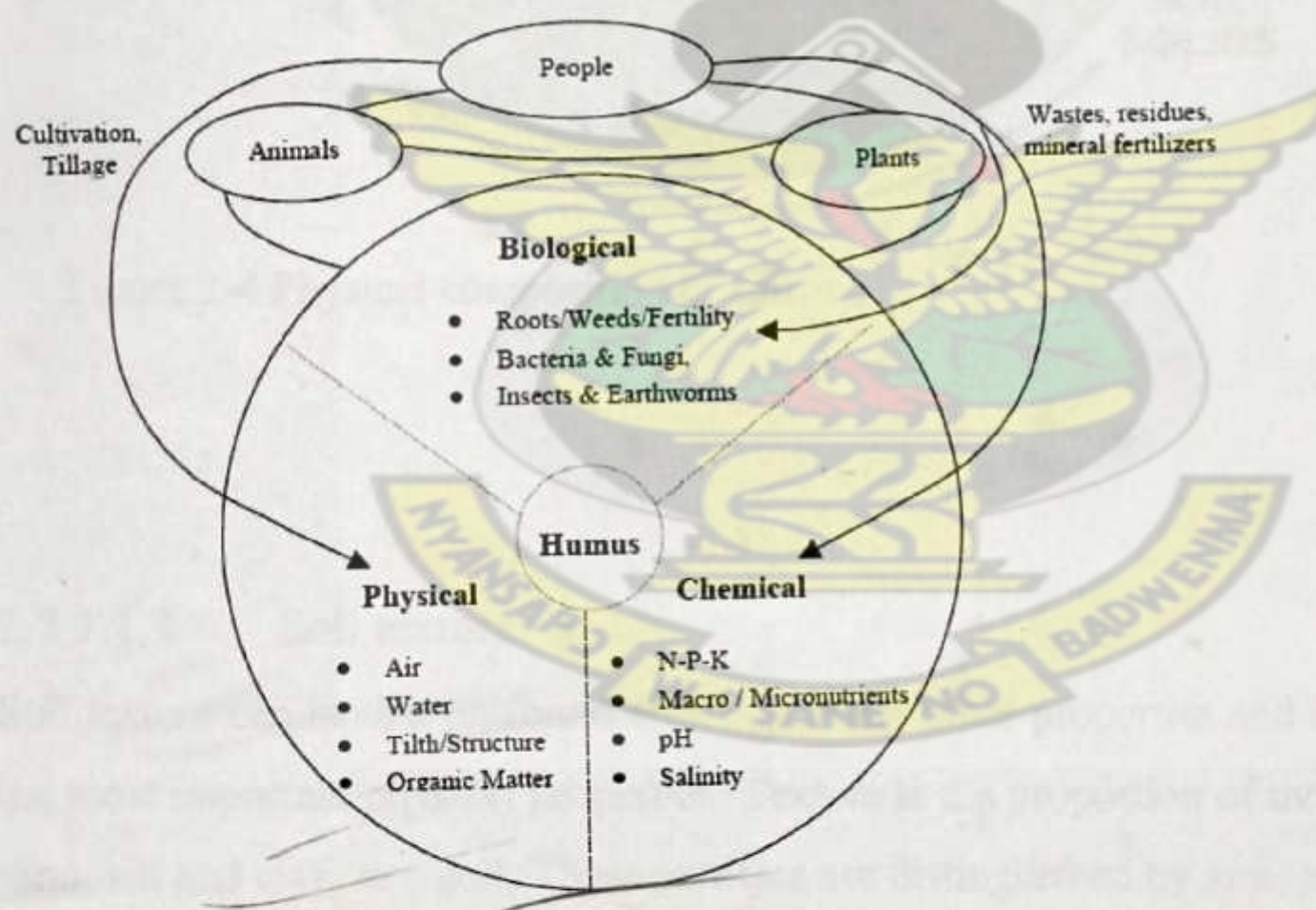
Figure 2-2 The various components of soil fertility and factors that affect them

2.7.2.1 Physical properties

Soil is comprised of minerals, soil organic matter (SOM), water, and air (shown in the figure below). The composition and proportion of these components greatly influence soil physical properties, including texture, structure, and porosity, the fraction of pore space in a

soil. In turn, these properties affect air and water movement in the soil, and thus the soil's ability to function (McCauley *et al.*, 2005).
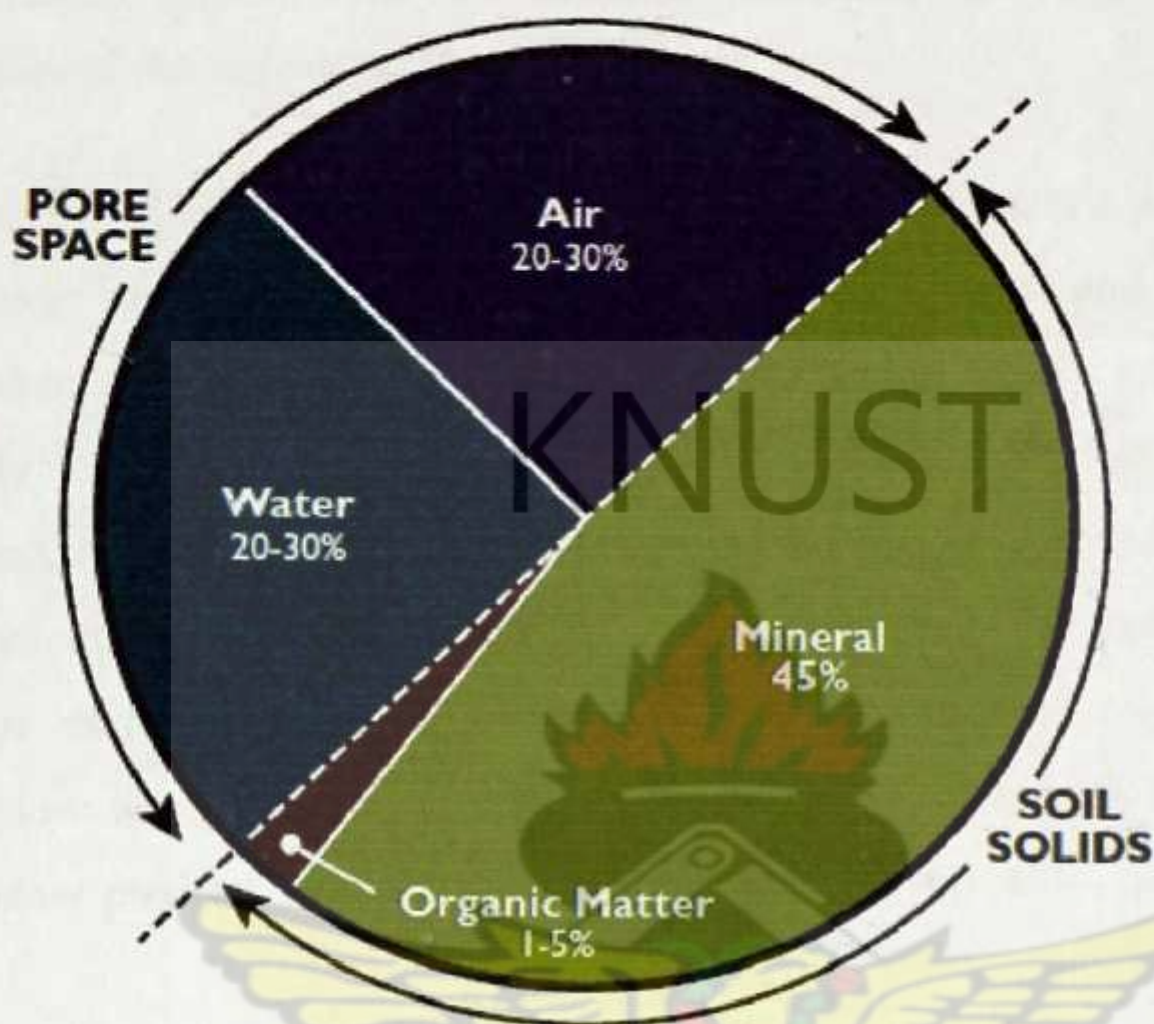
Figure 2-4 Physical composition of soil

2.7.2.1.1 Soil texture

Soil texture can have a profound effect on many other properties and is considered among the most important physical properties. Texture is the proportion of three mineral particles, sand, silt and clay, in a soil. These particles are distinguished by size, and make up the fine mineral fraction (Shown in the table below).

Soil particle	Diameter
Sand	0.05 – 2.0
Silt	0.002 – 0.05
Clay	<0.002

Table 2-2 Sizes of the various soil particles

Particles over 2 mm in diameter (the 'coarse mineral fraction') are not considered in texture, though in certain cases they may affect water retention and other properties. The relative amount of various particle sizes in a soil defines its texture, i.e., whether it is a clay, loam, sandy loam or other textural category. Texture is the result of 'weathering,' the physical and chemical breakdown of rocks and minerals. Because of differences in composition and structure, materials will weather at different rates, affecting a soil's texture. For example, shale, an easily weathered rock, forms clay-rich soils, whereas granite, a slow weathering rock, usually forms sandy, coarse soils. Since weathering is a relatively slow process, texture remains fairly constant and is not altered by management practice.

2.7.2.1.2   Soil structure

Soil structure is the arrangement and binding together of soil particles into larger clusters, called aggregates or 'peds.' Aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil. 'Granular' structure consists of loosely packed spheroidal peds that are glued together mostly by organic substances. Granular structure is characteristic of many topsoils, particularly those with high SOM content and biological activity (Gardiner and Miller, 2004). As soil swells (wets or freezes) and then shrinks (dries or thaws), cracks form around soil masses, creating peds. Peds are held together and in place through the adhesion of organic substances, iron oxides, clays or carbonates. Cracks and channels between peds are important for water, air, and solute transport and deep water drainage. Finer soils usually have a stronger, more defined structure than coarser soils due to shrink/swell processes predominating in clay-rich soils and more cohesive strength between particles.

2.7.2.1.3   Soil porosity

Many important soil processes take place in soil pores (the air or water-filled spaces between particles). Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Coarse-textured soils have many large (macro) pores because of the loose arrangement of larger particles with one another. Fine-textured soils are more tightly arranged and have more small (micro) pores. Macropores in fine-textured soils exist between aggregates. Because fine-textured soils have both macro- and micropores, they generally have a greater total porosity, or sum of all pores, than coarse-textured soils. Unlike texture, porosity and structure are not constant and can be altered by management, water and chemical processes. Long-term cultivation tends to lower total porosity because of a decrease in SOM and large peds (Brady and Weil, 2002). Surface crusting and compaction decrease porosity and inhibit water entry into the soil, possibly increasing surface runoff and erosion. Calcareous and salt-affected soils can also alter porosity and structure. In general, increasing SOM levels, reducing the extent of soil disturbance, and minimizing compaction and erosion will increase soil porosity and improve structure.

2.7.2.2 Chemical properties

The chemical properties of soil encompass soil, pH as well as the elements and ions that necessary for plant growth(Zhang and Raun, 2006).

2.7.2.2.1   Soil nutrients

Plants require at least 16 elements for normal growth and for completion of their life cycle. Those used in the largest amounts, carbon, hydrogen and oxygen, are non-mineral elements supplied by air and water. Carbon is the backbone of all organic molecules in the plant and is the basic building block for growth. After absorption of carbon dioxide (CO_2) by the leaves of the plant, carbon is transformed into carbohydrates by combining with carbon, hydrogen, and oxygen through the process of photosynthesis. Metabolic processes within the plant transform carbohydrates into amino acids and proteins and other essential components (Zhang and Raun, 2006).

The other 13 elements are taken up by plants only in mineral form from the soil or must be added as fertilizers. Plants need relatively large amounts of nitrogen, phosphorus, and potassium. These nutrients are referred to as primary nutrients, and are the ones most frequently supplied to plants in fertilizers. The three secondary elements, calcium,

magnesium, and sulfur, are required in smaller amounts than the primary nutrients. Calcium and magnesium are usually supplied with liming materials, and sulfur with fertilizer materials. Contaminants in rainfall also supply 10 to 20 pounds of nitrogen and sulfur per acre each year, depending on local air quality (Gardiner and Miller, 2004).

The micronutrients consist of seven essential elements: boron, copper, chlorine, iron, manganese, molybdenum, and zinc. These elements occur in very small amounts in both soils and plants, but their role is equally as important as the primary or secondary nutrients. A deficiency of one or more of the micronutrients can lead to severe depression in growth, yield, and crop quality. Some soils do not contain sufficient amounts of these nutrients to meet the plant's requirements for rapid growth and good production. In such cases, supplemental micronutrient applications in the form of commercial fertilizers or foliar sprays must be made. Thus the soil supplies 13 of the 15 elements required for nutrition of higher plants. These elements must be available, continuously, and in balanced proportions to support photosynthesis and other metabolic processes of plants.

2.7.2.2.2 *Cation exchange*

Silicate clays and organic matter typically possess net negative charge because of cation substitutions in the crystalline structures of clay and the loss of hydrogen cations from functional groups of organic matter. Positively-charged cations are attracted to these negatively-charged particles, just as opposite poles of magnets attract one another. Cation exchange is the ability of soil clays and organic matter to adsorb and exchange cations with those in soil solution (water in soil pore space). A dynamic equilibrium exists between adsorbed cations and those in soil solution. Cation adsorption is reversible if other cations in soil solution are sufficiently concentrated to displace those attracted to the negative charge on clay and organic matter surfaces. The quantity of cation exchange is measured per unit of soil weight and is termed cation exchange capacity. Organic colloids exhibit much greater cation exchange capacity than silicate clays. Various clays also exhibit different exchange capacities. Thus, cation exchange capacity of soils is dependent upon both organic matter content and content and type of silicate clays (McCauley *et al.*, 2005). Cation exchange capacity is an important phenomenon for two reasons:

- Exchangeable cations such as calcium, magnesium, and potassium are readily available for plant uptake.

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- Cations adsorbed to exchange sites are more resistant to leaching, or downward movement in soils with water.

Movement of cations below the rooting depth of plants is associated with weathering of soils. Greater cation exchange capacities help decrease these losses. Pesticides or organics with positively charged functional groups are also attracted to cation exchange sites and may be removed from the soil solution, making them less subject to loss and potential pollution. Calcium ($Ca2+$) is normally the predominant exchangeable cation in soils, even in acid, weathered soils. In highly weathered soils, such as oxisols, aluminum ($Al3+$) may become the dominant exchangeable cation (Brady and Weil, 2002).

The energy of retention of cations on negatively charged exchange sites varies with the particular cation. The order of retention is: aluminum > calcium > magnesium > potassium > sodium > hydrogen. Cations with increasing positive charge and decreasing hydrated size are most tightly held. Calcium ions, for example, can rather easily replace sodium ions from exchange sites. This difference in replaceability is the basis for the application of gypsum ($CaSO4$) to reclaim sodic soils (those with > 15% of the cation exchange capacity occupied by sodium ions). Sodic soils exhibit poor structural characteristics and low infiltration of water.

The cations of calcium, magnesium, potassium, and sodium produce an alkaline reaction in water and are termed bases or basic cations. Aluminum and hydrogen ions produce acidity in water and are called acidic cations. The percentage of the cation exchange capacity occupied by basic cations is called percent base saturation. The greater the percent base saturation, the higher the soil pH (McCauley et al., 2005).

2.7.2.2.3 Soil pH

Soil pH is probably the most commonly measured soil chemical property and is also one of the more informative. Like the temperature of the human body, soil pH implies certain characteristics that might be associated with a soil. Since pH (the negative log of the hydrogen ion activity in solution) is an inverse, or negative, function, soil pH decreases as hydrogen ion, or acidity, increases in soil solution. Soil pH increases as acidity decreases.

A soil pH of 7 is considered neutral. Soil pH values greater than 7 signify alkaline conditions, whereas those with values less than 7 indicate acidic conditions. Soil pH typically ranges from 4 to 8.5, but can be as low as 2 in materials associated with pyrite

oxidation and acid mine drainage. In comparison, the pH of a typical cola soft drink is about 3. Soil pH has a profound influence on plant growth. Soil pH affects the quantity, activity, and types of microorganisms in soils which in turn influence decomposition of crop residues, manures, sludges and other organics.

2.7.2.3 Soil biological properties

The soil environment is teeming with biological life and is one of the most abundant and diverse ecosystems on earth. Soil biota, including flora (plants), fauna (animals) and microorganisms, perform functions that contribute to the soil's development, structure and productivity (Abbott and Murphy, 2003). General characteristics and functions of these groups are presented below.

2.7.2.3.1   Soil flora

Plants act on the soil environment by aiding in structure and porosity, and in supplying SOM via shoot and root residue. Root channels can remain open for some time after the root decomposes, allowing an avenue for water and air movement. Roots also act to stabilize soil through aggregation and intact root systems can decrease soil loss. The 'rhizosphere,' the narrow zone of soil directly surrounding plant roots, is the most biologically active region of the soil. It contains sloughed root cells and secreted chemicals (i.e., sugars, organic acids) that provide organisms with food (Abbott and Murphy, 2003).

2.7.2.3.2   Soil fauna

Soil fauna work as soil engineers, initiating the breakdown of dead plant and animal material, ingesting and processing large amounts of soil, burrowing 'biopores' for water and air movement, mixing soil layers, and increasing aggregation. Important soil fauna include earthworms, insects, nematodes, arthropods and rodents. Earthworms are considered one of the most important soil fauna. Through the process of burrowing, they provide channels that increase a soil's porosity, WHC, and water infiltration(Lee, 1985). They also increase further biotic activity by breaking down large amounts of SOM through digestion and supplying nutrient-rich secretions in their casts(Savin et al., 2004). Furthermore, earthworms are able to build soil by moving between 1 to 100 tons of subsoil per acre per year to the surface, possibly helping offset losses by erosion(Magdoff, 2000).

Microorganisms (microbes) are invisible to the naked eye. However, their effects on numerous soil properties are far-ranging. Microorganisms represent the largest and most diverse biotic group in soil, with an estimated one million to one billion microorganisms per one gram of agricultural top soil(Tugel and Lewandowski, 1999). Microbes aid soil structure by physically surrounding particles and 'gluing' them together through the secretion of organic compounds, mainly sugars. This contributes to the formation of granular structure in the A horizon where microbial populations are greatest. Soil microbes include bacteria, protozoa, algae, fungi and actinomycetes. Bacteria are the smallest and most diverse soil microbes.

Bacteria are important in SOM decomposition, nutrient transformations and small clay aggregation. Some bacteria carry out very special roles in the soil, such as Rhizobia, the nitrogen-fixing bacteria associated with legume roots. Protozoa (e.g., amoebas, ciliates, flagellates) are mobile organisms that feed on other microbes and SOM. Algae, like plants, photosynthesize and are found near the soil surface. Fungi are a diverse group of microbes that are extremely important in the breakdown of SOM and large aggregate stability. Many fungi have long 'hyphae' or 'mycelia' (thin thread-like extensions) that can extend yards to miles underneath the soil surface and physically bind soil particle. Actinomycetes are a microbial group that are classified as bacteria, but have hyphae similar to fungi. They are important for SOM breakdown, particularly the more resistant fractions, and give soil much of its 'earthy' odor. Bacteria dominate in agricultural and grassland soils, whereas fungi are more prevalent in forest and acid soils (Tugel and Lewandowski, 1999). An important relationship found in almost all soils and plants, including many crop species, are mycorrhizae. Mycorrhizae are a plant-fungal symbiosis (a relationship between two interacting species) in which fungi infect and live in, or on, a plant root.

2.8   HEAVY METALS

By definition, a heavy metal has a specific gravity of about 5.0 or greater and is usually poisonous. The term heavy metal, however, is often broadly applied to include other potentially hazardous elements, even if they do not meet the strict chemical definition(Alloway, 1990). Heavy metals are naturally occurring elements, and are present in varying concentrations in all ecosystems. There is a huge number of heavy metals. They

are found in elemental form and in a variety of other chemical compounds. Those that are volatile and those that become attached to fine particles can be widely transported on very large scales. Each form or compound has different properties which also affect what happens to it in food web, and how toxic it is. Human activities have drastically changed the biochemical cycles and balance of some heavy metals. The main anthropogenic sources of heavy metals are various industrial processes, mining, foundries, smelters, combustion of fossil fuel and gasoline, and waste incinerators. The major heavy metals of concern according to the European Monitoring and Evaluation Program (EMEP) are Hg, Cd and Pb, because they are the most toxic and have known serious effects on e.g. human health.

2.8.1 Cadmium

This is a heavy metal of major environmental concern because of its high mobility and the small concentration at which it can adversely affect plants and animal metabolism. Furthermore it has adverse impact on soil biological activity(Kabata-Pendias and Pendias, 1984). Cadmium is released as soluble Cd2+ ion during weathering. Under both acidic and alkaline conditions cadmium is adsorbed to surfaces of clay minerals, thereby reducing the mobility of the cadmium ions. Diet is the major source of cadmium intake because there is cadmium bio-accumulation in the food chain, especially in plants and seafood. Toxicity of cadmium results from cadmium substitution for zinc in enzymes(Stoessel, 2004). The critical toxic endpoint after ingestion is kidney damage(Davies *et al.*, 2005), because of bioaccumulation in the liver and kidney. Cd poisoning may result in the Cd substitution for Ca in bones producing itaiitai, a degenerate bone disease.

2.8.2 Lead

Lead has an average range in soils of 17–26 g/kg (Stoessel, 2004). It is the most immobile of all the common heavy metals. It is strongly sorbed by soils under neutral to basic conditions, being particularly attracted to sulphur groups in humans. Lead introduced at the soil's surface will complex with organic matter causing lead to be bound in the soil within the top few centimetres, where organic matter content is highest. Lead poisoning has dominated the environmental agenda for several decades. Nonetheless, environmental lead remained a mere curiosity until the 1960s. Lead does not undergo biomagnifications in food chain and also not toxic to plants (Stoessel, 2004). Some of the knowneffects on higher plants include dark green leaves, stunted foliage and increased amounts of shoots(Ferguson,

1990). It is not known to be of any known function in the human body(Essa, 1999). The inorganic forms of lead in soil have the same toxic endpoints. The common symptom of lead poisoning is anaemia because lead interferes with the formation of haemoglobin. It prevents iron uptake (Stoessel, 2004). High levels of lead may produce permanent brain damage and kidney dysfunction. Over time lead will substitute Ca in bone which acts to store the lead. Then in old age the lead is reactivated by slow dissolution of the bone.

2.8.3 Copper

Anomalous Cu concentration in soils is generally from mineralization. Cu is very mobile in weathering environment. This is the reason why it can hardly be found in excess in soils. What is generally experienced is Cu deficiency in soils. Copper has been found in all forms of animal and plant life and in every part of human body. It is an essential part of several enzymes and is essential for the synthesis of haemoglobin. Cu deficiency in soils can generally lead to serious reduction in yield in cereals(Thornton and Webb, 1979). Cu deficiency in humans may cause anaemia, poor growth, degeneration of the nervous system and bone demineralisation leading to osteoporosis and bone fractures(Lech et al., 2004).

2.8.4 Mercury

Mercury is an element that occurs naturally in the environment, usually in combination with other elements as mercury compounds or salts. Metallic mercury is a shiny, silver-white metal that is a liquid at room temperature. If heated, it enters the atmosphere as a colorless, odorless gas. Mercury combines with other elements to form inorganic mercury compounds, some of which are soluble in water. It also combines with carbon to form organic mercury compounds, such as methyl mercury. Because it is an element, mercury does not degrade nor can it be destroyed. Metallic mercury is used to produce chlorine gas and caustic soda and to extract gold from ores. It is used in thermometers, dental fillings, and batteries. Mercury can be taken into the body primarily by breathing air or eating food. How much mercury enters the body and what happens depends on the form of mercury and the route of exposure (that is, through air, food, or skin)(Alloway, 1990). When vapors of metallic mercury are inhaled, as much as 80% is absorbed. Following ingestion, absorption is less than 0.01% for metallic mercury, less than 10% for inorganic mercury, and greater than 95% for organic mercury. Mercury can also be absorbed through the skin, but the amount is small compared to breathing or swallowing it. Once in the body, metallic mercury and organic mercury compounds easily reach most tissues, including the brain;

mercury also reaches the fetus of a pregnant woman. Mercury accumulates in the kidneys. In the brain, metallic mercury and methylmercury can be converted to an inorganic form that is then trapped in the brain. Exposure to high levels of mercury can damage the brain, kidneys, and developing fetus. The nervous system is very sensitive to all forms of mercury, although the brain is most sensitive to metallic mercury and methylmercury because they enter the brain more easily than inorganic mercury salts. Exposure can cause tremors; memory loss; and changes in personality, vision, and hearing(Alloway, 1995).

2.8.5 *Arsenic*

Arsenic is a metalloid widely distributed in the earth's crust and present at an average concentration of 2 mg/kg. It occurs in trace quantities in all rock, soil, water and air. Arsenic can exist in four valency states: -3, 0, $+3$ and $+5$. Under reducing conditions, arsenite (As(III)) is the dominant form; arsenate (As(V)) is generally the stable form in oxygenated environments. Elemental arsenic is not soluble in water.

Arsenic salts exhibit a wide range of solubilities depending on pH and the ionic environment(WHO, 2000). Arsenic is a component in manufacture of bronze materials, fireworks, shot, agricultural chemicals, laser materials, glass, semiconductor materials, wood preservatives, copper and lead alloys and insecticides (most of which are obsolete). Soluble inorganic arsenic is acutely toxic, and ingestion of large doses leads to gastrointestinal symptoms, disturbances of cardiovascular and nervous system functions, and eventually death. In survivors, bone marrow depression, haemolysis, hepatomegaly, melanosis, polyneuropathy and encephalopathy may be observed. Long-term exposure to arsenic in drinking-water is causally related to increased risks of cancer in the skin, lungs, bladder and kidney, as well as other skin changes such as hyperkeratosis and pigmentation changes. These effects have been demonstrated in many studies using different study designs. Exposure-response relationships and high risks have been observed for each of these end-points. The effects have been most thoroughly studied in Taiwan but there is considerable evidence from studies on populations in other countries as well. Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with ingestion of drinking-water at concentrations ≤ 50 μg arsenic/litre(WHO, 2000).

CHAPTER 3
MATERIALS AND METHODS

3.1   STUDY DESIGN

Four farmlands that were currently being used for galamsey operations were chosen from two communities (Prestea and Abosso) in the District for the study, with two farmlands from each community. A control farmland which had not seen any galamsey activities was chosen from another community (Bompieso) in the district. The farmlands were labeled as A, B, C, D and Control; with A and B in Prestea and C and D in Abosso. Soil samples were taken from each farmland for laboratory analysis for heavy metals and fertility. A dept of upto 25cm below ground was dug with a cutlass and chisel and 200g soil sample was taken from a mixed portion of the dug up soil.

3.2   STUDY DISTRICT – GEOGRAPHY AND MINING OPERATIONS

The Prestea/Huni Valley district used to be under the Wassa West District before a recent political re-alignment split the district into two. The district whose capital town is Bogoso has a population of about 159,304 and a land size of 1514.7km². The geographical coordinates of the district are 5° 28' 0" North, 1° 55' 0". The district is bounded to the north by the Wassa Amenfi District and the south by the Ahanta West District. It lies within the South-Western Equatorial Zone and has a fairly uniform temperature, ranging between 26°C in August and 30°C in March. The area falls within the forest dissected plateau physiographic region. The rock structure is made up of Precambrian rocks of Birimian and Tarkwain formations. These underline the forest disserted plateau. The land rises from about 240 meters to 300 metres above sea level with undulating scarps ranging between 150 meters to 300 meters above sea level. (source: Prestea/Huni-Valley Map, Social Studies for J.S.S book 1, page 75-83)
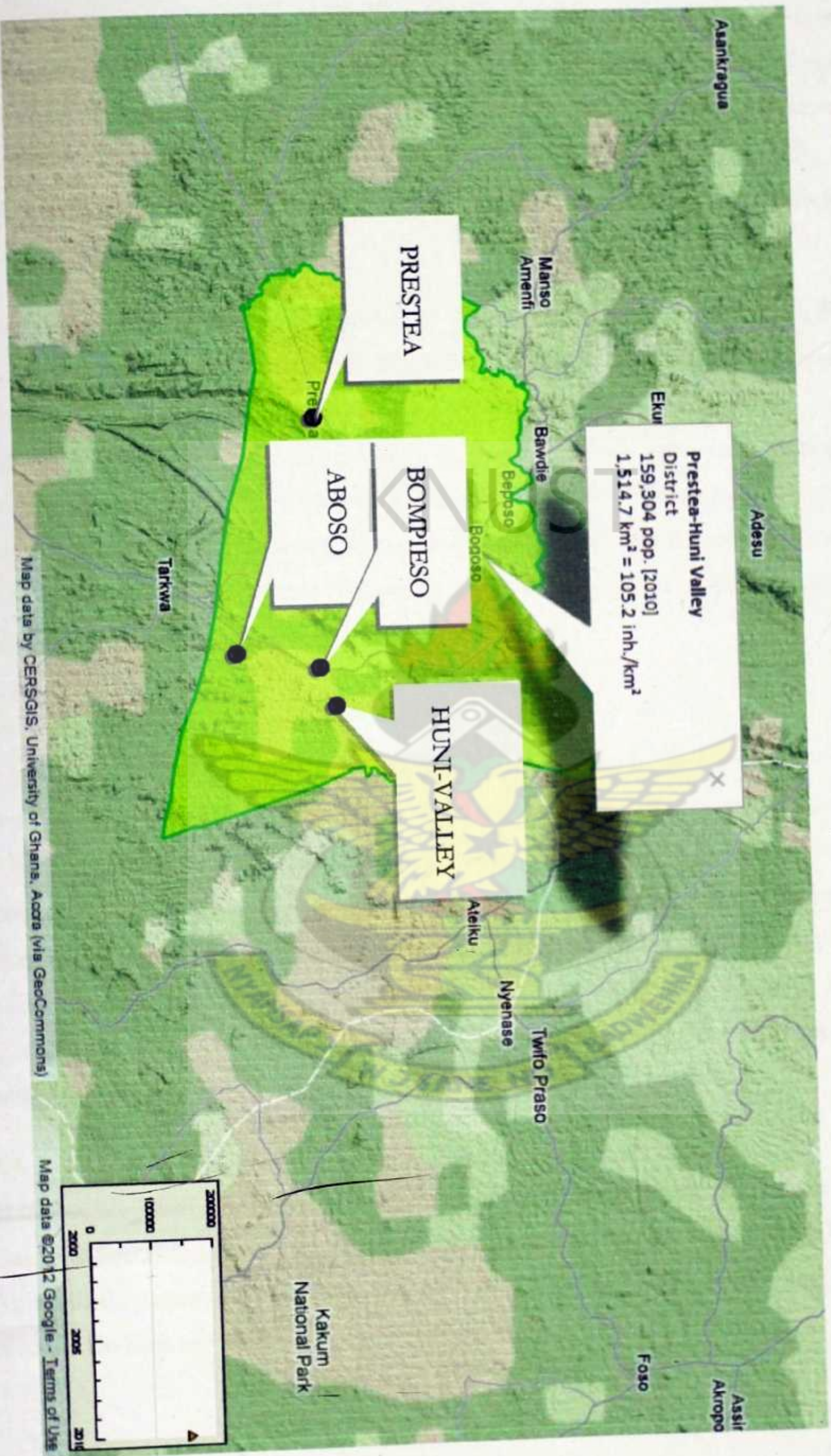
Figure 3.1   Map showing Prestea-Huni Valley District

A map of the district is shown in the figure 3. The vegetation of the district consists of tropical rain forest characterized by rich undergrowth of climbers and shrubs of varying heights. The trees, which generally reach heights of between 15 and 45 metres are distributed mostly at the summit of hills where mining has not yet reached. The huge agricultural and mining potential in the district is as a result of the high vegetation in the area.

Mining activities together with agriculture are the main occupations that engage a majority of inhabitants of the district. The three major large scale mining companies in the district are the Golden Star Resources at Bogoso, the Sankofa Goldfield at Prestea and the Aboso Goldfields Ltd. operating at Damang. These companies engage the services of more than 50% of residents. They have operated surface mining since the early 1990's to date and have had extensive experience in the practice of compensation and resettlement of individuals and communities in the district. A high number of galamsey operators also operate within the district.

3.3   SAMPLING

Sampling for all farmlands (A – D and Control) were done in the same manner. For each farmland, a depth of up to 25cm below ground level was dug with cutlass and chisel and 200g soil sample was taken from a mixed portion of the dug up soil. For each farmland, a composite sampling method was used, where various soil samples were taken from various portions of the land and mixed together before the final sample was taken. This ensured that the results obtained were representative of the lands in use. Each sample was rid of any debris and rocks before transferring into sterile polythene rubber carriers and sent for laboratory analysis.

3.4   LABORATORY ANALYSIS

The laboratory analyses were done at the Soil Science Laboratory of the Department of Crop and Soil Sciences of the College of Agriculture and Natural Resources, KNUST. All methods employed were in accordance with ISO guidelines on soil analysis as described in each test method.

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3.4.1 Pre-treatment of samples

These methods were conducted in accordance with ISO guidelines on soil pre-treatment before physio-chemical analysis(ISO, 1994c). The types of soil sample used for analysis were mineral soil samples.

To prepare the mineral soil samples, removal of living material (such as mosses, roots, etc.) and objects bigger than 2 cm, was done on the collected samples before air-drying at a temperature of 40 °C until the loss in mass of the sample was not greater than 5 % per 24 h. The size of larger clods (greater than 15 mm) was broken down to accelerate the drying process. Living macroscopic roots and all other materials, mineral and organic, with a diameter larger than 2 mm, were then removed from the samples by dry or wet sieving. The fraction smaller than 2 mm was used for the soil analysis. No further grinding was done except for the analysis of total Organic Carbon, total Nitrogen and Total Elements. The sample materials for storage were kept without preservative under normal room conditions with minimal temperature and humidity fluctuations, shielded from incident light.

3.4.2 Moisture content determination

3.4.2.1 Procedure

The moisture can with the lid was oven-dried at 105°C to a constant weight. The can was allowed to cool and its weight recorded. 10g of soil was then weighed into the can with the lid in place and weighed. The lidded can with the soil was then placed in the oven and dried for 24 hours to a constant weight, before allowing cooling and its weight taken.

3.4.2.2 Calculation

$$\% \text{ Soil Moisture content} = \frac{W3 - W1}{W2 - W1} \times 100$$

Where W1 = Weight of empty can + Lid

W2 = Weight of can + Lid + fresh soil

W3 = Weight of can + Lid + oven − dried soil

3.4.3 Particle size distribution (ISO 11465, 1993)

3.4.3.1 Procedure

A quantity of air-dried soil sample (51.0 g) was weighed into a 1 L screw lid shaking bottle before 100ml of distilled water was added and the mixture swirled to wet the soil. 30% Hydrogen peroxide (20 ml) was then added after which 5% sodium hexametaphosphate (20 ml) was also added. Two drops of methanol was added and the mixture swirled gently to minimize foaming, after which it was shaken on a mechanical shaker for two hours. The contents were then transferred to a 1000 ml sedimentation cylinder or tube and water was used to wash all soil particles into the sedimentation tube, before making up to the mark with distilled water. The first hydrometer reading after 40 seconds as well as temperature reading was read with a thermometer. The sample was then allowed to stand undisturbed for 3 hours and the second hydrometer and temperature readings were taken.

3.4.3.2 Calculation

$\% \text{ Sand} = 100 - [H_1 + 0.2 (T_1 - 20) - 2] \times 2$

$\% \text{ Clay} = [H_2 + 0.2 (T_2 - 20) - 2] \times 2$

$\% \text{ Silt} = 100 - (\% \text{ Sand} + \% \text{ Clay})$

Where

$H1 = 1^{st}$ hydrometer reading

$T1 = 1^{st}$ thermometer reading

$H2 = 2^{nd}$ hydrometer reading

$T2 = 2^{nd}$ thermometer reading

3.4.4 Soil pH (ISO, 1994a)

3.4.4.1 Procedure

A representative sample (at least a volume of 5g) of the air-dried soil (fraction < 2 mm) was taken. The test sample was placed in the sample bottle and then five times its volume of calcium chloride solution (pH-$CaCl_2$) or water (pH-H_2O) was added. The suspension was shaken and mixed vigorously, for 5 min, using the mechanical shaker after which the mixture was allowed to stand for 2 hours. The pH meter was next calibrated using buffer solutions of pH 4 and 7 before the pH of the suspension was read and the results recorded.

3.4.5 Organic carbon content

3.4.5.1 Procedure

A quantity of air-dried soil sample (5.0g) was weighed into a crucible and an excess 100 ml of hydrochloric acid (4M) was added and mixed. After 4 hours, the crucible was oven- titrimetry dried for 16 hours a temperature of 60 °C to 70 °C. A quantity of this dried soil sample (2g) was weighed into a crucible and analysis of total carbon content was determined by the apparatus.

3.4.5.2 Calculation

The total carbon content (on basis of air-dried soil) is obtained by:

$$wc_o = 1000 \times \frac{m2}{m1} \times 0.2727$$

where

w_{C_o}	=	Organic carbon content (g/kg) on basis of air-dried soil
m_1	=	Mass (g) of test portion
m_2	=	Mass (g) of released CO_2
0.2727 =		Conversion factor for CO_2 to C

3.4.6 Total nitrogen content (ISO 11261, 1995)

3.4.6.1 Procedure

A test portion from 0.2g (expected N-content 0.5%) to 1g (expected N-content of 0.1%) of the air-dried soil sample was placed in the digestion flask. Salycylic/sulfuric acid (4ml) was added and the flask swirled until the acid was thoroughly mixed with the soil. The mixture was allowed to stand (or overnight). Sodium thiosulfate (0.5g) was added through a dry funnel with a long stem that reaches down into the bulb of the digestion flask. The mixture was then heated cautiously on the digestion stand until frothing had ceased. The flask was cooled and 1.1g of the catalyst mixture was added before heating until the digestion mixture became clear.

The mixture was boiled gently for up to 5 h so that the sulfuric acid could condense about 1/3 of the way up to the neck of the flask. It was also ensured that the temperature of the solution did not exceed 400°C. The flask was allowed to cool down after the digestion and about 20ml of water was slowly while shaking. The flask was then swirled to bring any insoluble material into suspension and the contents were

transferred the distillation apparatus. Rinsing was done three times with water to complete the transfer. Boric acid (5ml) was added to a 100 ml conical flask and the flask was placed under the condenser of the distillation apparatus, making sure that the end of the condenser dipped into the solution. The sodium hydroxide (2ml) was added to the funnel of the apparatus and the alkali was run slowly into the distillation chamber. About 40 ml of the condensate was distilled and the end of the condenser was rinsed. A few drops of indicator was added to the distillate and then titrated with sulfuric acid to a violet endpoint.

3.4.6.2 Calculation

The total nitrogen content is calculated by use of the following formula:

$$w_N = \frac{(V_1 - V_0) \times c(H^+) \times M_N}{m} \times \frac{100 + w_{H_2O}}{100}$$

Where:

w_N = The total nitrogen content (mg/g = g/kg)

V_1 = Volume of the sulfuric acid used in the titration of the sample (ml)

V_0 = Volume of the sulfuric acid used in the titration of the blank sample (ml)

$c(H^+)$ = Concentration of H+ in the sulfuric acid (moles/litre)

M_N = The molar mass of nitrogen (= 14 g/mol)

m = Mass of the air-dried soil sample (g)

wH_2O = Water content of the soil sample, based on oven-dried soil (% by mass)

3.4.7 Exchangeable cations (Ca, Mg, K, Na, Al) and exchangeable acidity (H)(ISO, 1994b; ISO, 1994d)

3.4.7.1 Procedure

A quantity of air-dried soil sample (2.5g) was weighed and placed in a 50ml centrifuge tube. Barium chloride solution (30ml) was added and shaken for 2 hours. The mixture was centrifuged at 3000 rpm for 10 min and the supernatant liquid was transferred to a 100 ml volumetric flask. The volumetric flask was made up to the mark with barium chloride solution and mix and then the extract was mixed and filtered. A portion of the

extract was retained for the analysis of Ca, Mg, K, Na and Al using the flame photometry.

For exchangeable acidity, a portion of the extract (25 ml) was pipetted into a container of sufficient capacity to also receive the electrodes of the pH-meter. The electrodes of the meter were inserted in the container and titration with the sodium hydroxide (0.05M) solution was done until a pH value of 7.8 was reached and remained stable for 30 second. The procedure was repeated for a blank 0.1M $BaCl_2$ solution extract.

3.4.7.2 Calculation

The total exchangeable acidity on basis of air-dried soil is given by:

$$E_A = \frac{(V_a - V_B).C_{NaOH}.100.V}{V_s.m}$$

where

E_A: total exchangeable acidity (cmol/kg) of the soil on basis of air-dried soil

V_A: volume NaOH (ml) used for the test sample

V_B: volume NaOH (ml) used for the blank

C_{NaOH}: concentration of NaOH (mol/l)

V_S: volume (ml) pipetted for analysis

m : mass (g) of the laboratory sample

V : final volume (ml) of the extract

For Ca, Mg, K, Na and Al, calculation was done according to apparatus and taking into account equivalent weights of each element in g/mol.

3.4.8 Heavy metal determination (Cu, As, Cd, Hg, Pb)

3.4.8.1 Procedure

10 ml of 1:1 HNO_3 was added to 2 g of air-dried soil in a 150 ml beaker. The sample was placed on a hot plate, covered with a watch glass, and heated (reflux) at 95°C for 15 minutes. The digest was cooled and 5 ml of concentrated HNO_3 was added. Refluxing for an additional 30 minutes at 95°C was done and this step was repeated before reducing the solution to about 5 ml without boiling (by only partially covering the beaker). The digest was cooled again and 2 ml of deionized water added before 3 ml of 30% H_2O_2. With the beaker covered, the sample was heated gently to start the peroxide reaction. The sample was removed from the hot plate if effervescence became

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excessively vigorous. Addition of 30% H_2O_2 was continued in 1 ml increments, followed by gentle heating until the effervescence subsided. 5 ml of concentrated HCl was added as well as 10 ml of deionized water and the sample was refluxed for an additional 15 minutes without boiling. Cooling was done and the sample was filter through a Whatman No. 42 filter paper. Dilution to 50 ml with deionised water was next done before analysis of the sample for the respective metal was done with the AAS.

CHARPTER 4

RESULTS

For each galamsey farmland A, B, C and D as well as non-galamsey land CT A and CT B, the soil fertility test as well as heavy metal determination was done.

4.1 SOIL FERTILITY ANALYSIS

The soil pH levels of all lands are illustrated in Figure 4. All galamsey lands had slightly alkaline pH levels that were also higher than that of the control lands. The pH of control lands were about neutral.
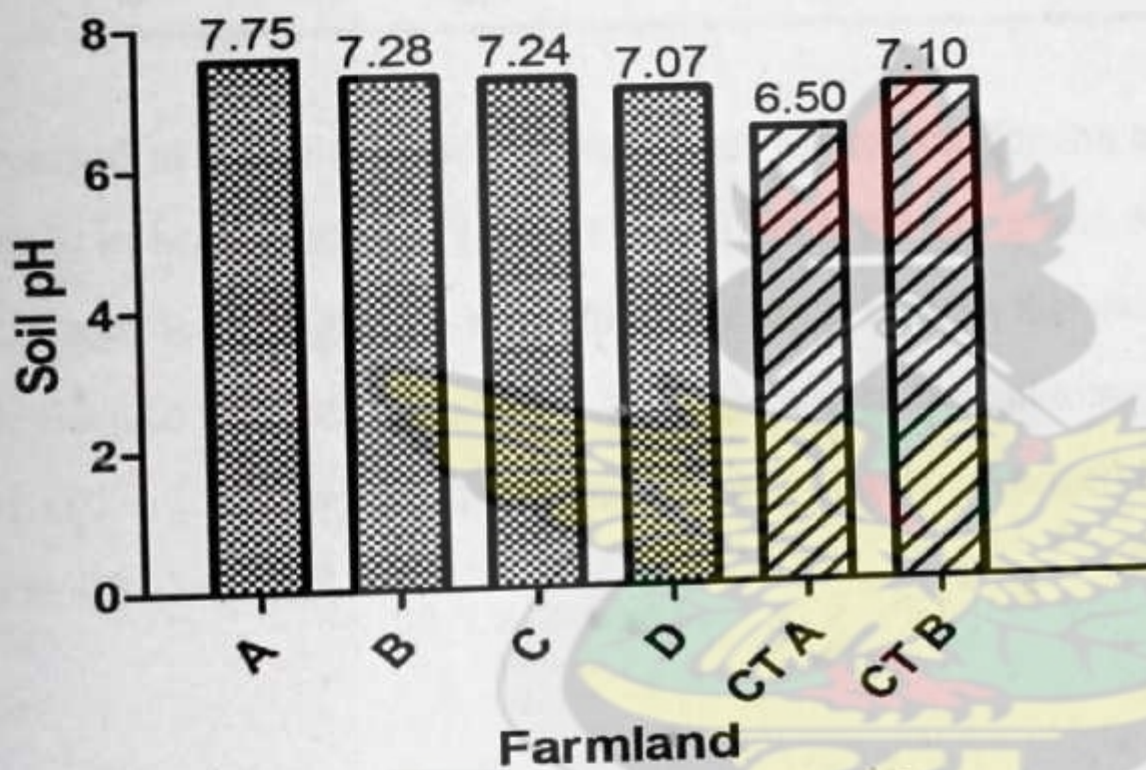
Figure 4.1 pH of soils from the various studied farmlands

The levels of organic carbon, organic matter, soil total nitrogen and available phosphorus are presented in Table 4.1 below. For all parameters, the non-galamsey lands had higher levels than the galamsey lands. For organic carbon and matter, the range for the galamsey lands were between 0.1 - 0.5% whereas for the non-galamsey lands, it ranged between 2.3 – 4.5%. Levels of soil total nitrogen ranged between 0.04 – 0.05% for galamsey lands and 1.7 – 2.1% for non-galamsey lands.

Table 4.1 Soil levels of organic carbon, organic matter, total nitrogen and available phosphorous in the galamsey verses control lands

Farmland	Organic carbon (%)	Organic matter (%)	Total Nitrogen (%)
A	0.1	0.17	0.04
B	0.34	0.59	0.04
C	0.26	0.45	0.04
D	0.3	0.52	0.05
CT A	3.1	2.3	1.7
CT B	4.5	2.6	2.1

Presented in Table 4.1 and Figure 4.1 are the results for the soil levels of exchangeable cations in both groups of lands. Overall, with the exception of Aluminum, the levels of all cations were higher in non-galamsey lands than in the galamsey lands. The range of soil calcium was between 0.008 and 3.8cmol/kg for galamsey lands with a mean ± S.D of 1.802 ± 1.346, whereas for non-galamsey lands, it ranged between 11.5 – 18.1 with a mean ± S.D of 14.8 ± 3.3.
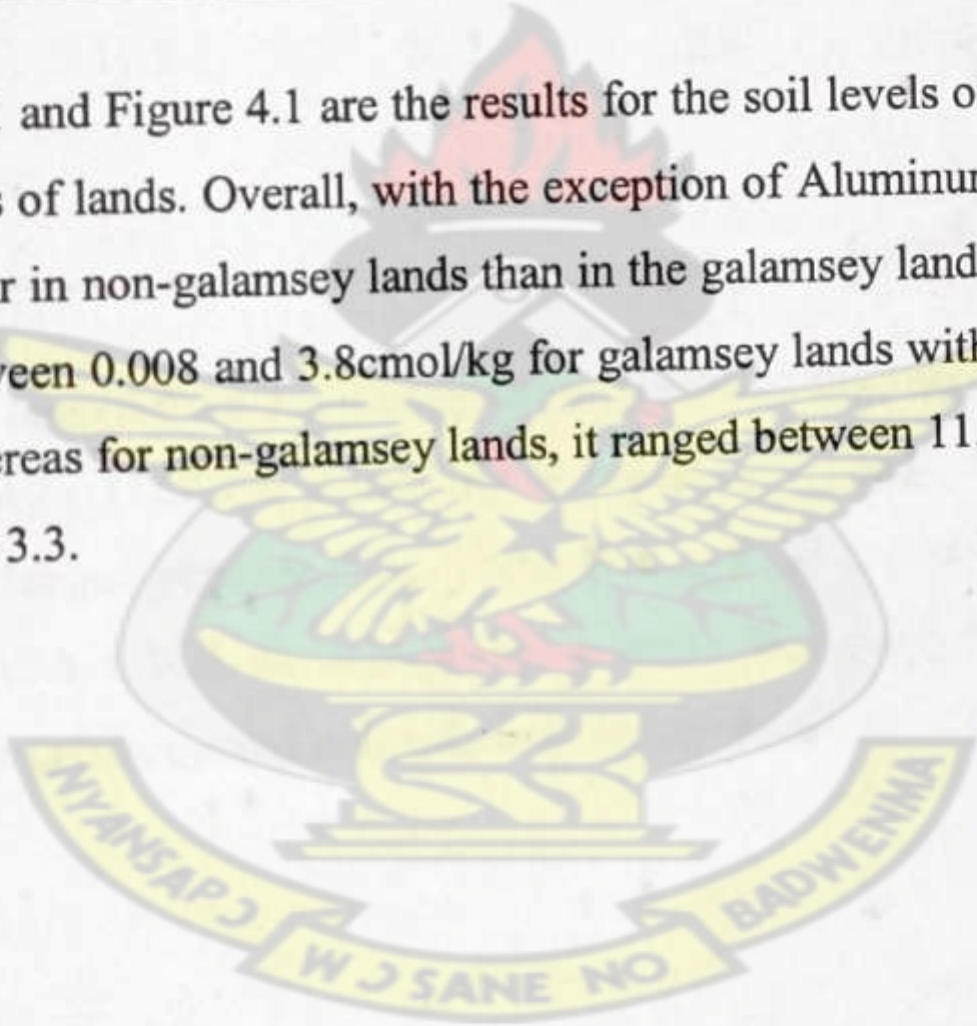
Table 4.2 Levels of exchangeable cations in the farmlands

Farmland	Excheancheable cations (cmol/kg)				
	Ca	Mg	K	Na	Al
A	0.008	3.2	0.04	0.04	0.3
B	3.8	12.6	0.04	0.06	0.2
C	1.8	4.2	0.04	0.06	0.3
D	1.6	5.1	0.08	0.08	0.3
CT A	11.5	10.2	2.5	1.1	0.1
CT B	18.1	15.5	3.1	0.9	0.08

Levels of magnesium ranged from 3. – 12.6cmol/kg (6.275 ± 3.713) for galamsey lands and 10.2 – 15.5cmol/kg (12.85 ± 2.650) for non-galamsey lands. For potassium, galamsey land levels ranged between 0.04 – 0.08cmol/kg (0.05 ± 0.017) for galamsey lands and 2.5 – 3.1 (2.8 ± 0.3) for non-galamsey lands. The mean ± S.D levels of sodium cations in the galamsey and non-galamsey lands were 0.06 ± 0.014 and 1.0 ± 0.1 respectively.
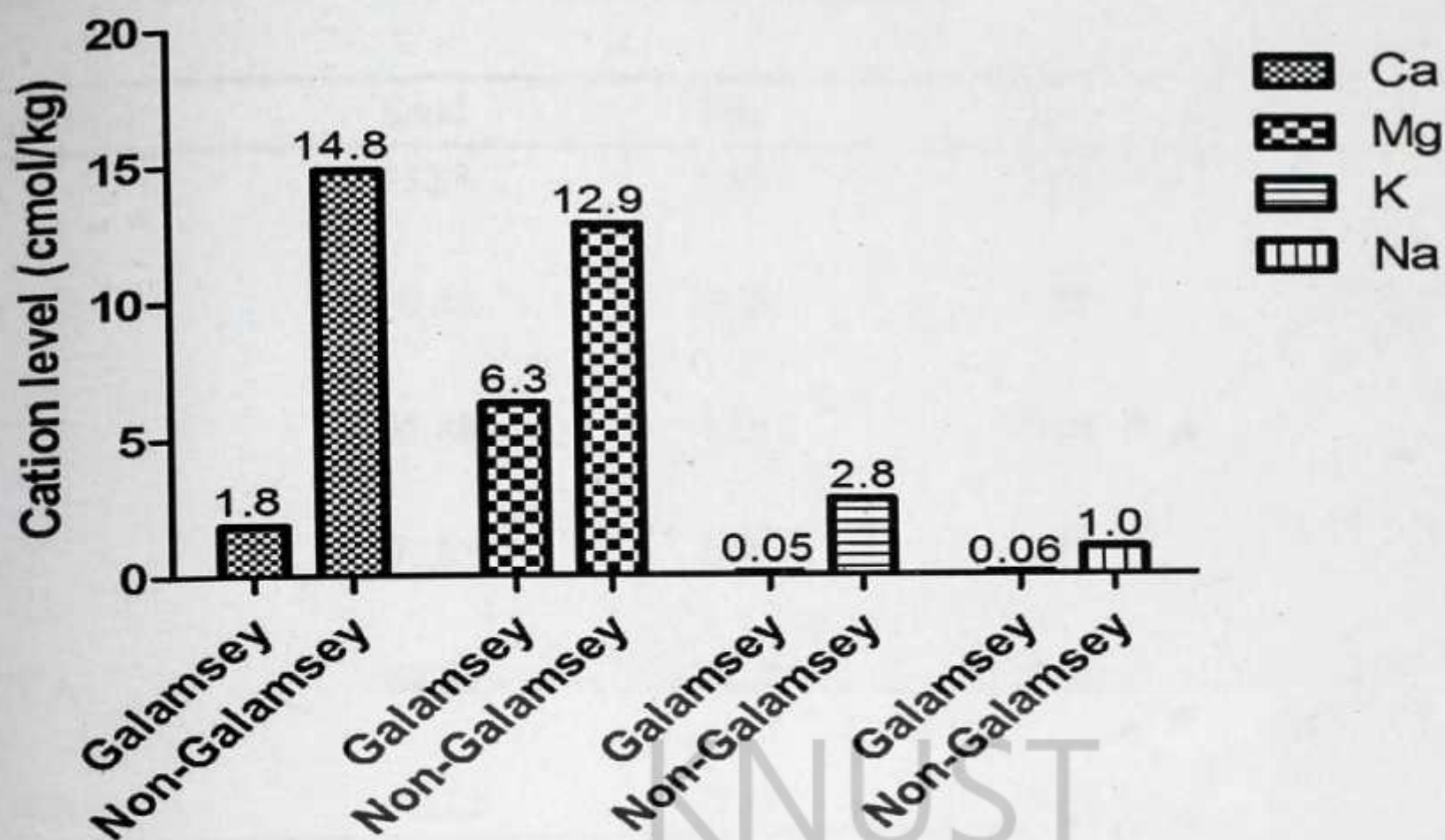
Figure 4.2 Cation exchange capacity of soils in galamsey vs. non-galamsey lands

Particle size analysis result for all the farmlands are presented in Table 4.3 below. For the galamsey lands, all had higher percentage sand content (greater than 90%) with the exception of land B (79.88%). Comparatively, the non-galamsey lands had lower percentage sand contents, the highest being 70.12% (CT B). A high sand content correlated with a low silt content and hence all non-galamsey lands had comparatively higher silt percentage than the galamsey lands. Land D had the lowest silt level of 1.36% and land B the highest level of 19.88%. The lowest percentage silt content for the non-galamsey lands was 29.43% (CT B). Soils that had a high sand content, had a higher clay content. The lowest percentage clay content for the galamsey lands that had a higher sand content (A, C and D) was 0.64% (land A). Land B had a percentage clay content of 0.24%. For the non-galamsey lands, the highest percentage clay content was observed in land CT B (0.45%). The soil types present in the various lands was then determined using the percentage contents calculated. All the galamsey lands were remarked to be sandy, with the exception of land B which was remarked loamy sandy. Conversely, all non-galamsey lands were remarked to be loamy based on their low sand, high silt and low clay contents.

Table 4-3 Particle size analysis of soils from the farmlands

Farmland	Sand	Silt	Clay
A	93.88	5.48	0.64
B	79.88	19.88	0.24
C	95.88	3.16	0.96
D	97.88	1.36	0.76
CT A	64.55	35.33	0.12
CT B	70.12	29.43	0.45

5   SOIL HEAVY METALS

Presented in Table 4.4 and Figure 4.3 are the results obtained for the heavy metal analysis of soil from all the lands. Generally, the levels of each metal in the galamsey lands were excessively higher than that in the non-galamsey lands. Levels of arsenic ranged between 79.7 and 86.3mg/kg for galamsey lands and 5.2 and 8.5mg/kg for non-galamsey lands. For copper, the levels ranged from 420 – 611mg/kg for galamsey lands and 21 – 45mg/kg for non-galamsey lands. With lead, non-galamsey land levels ranged from 36 – 61mg/kg whereas galamsey land levels were between 425 and 440mg/kg. Mercury levels were ranged between 886 and 911mg/kg for galamsey lands and 23 – 35mg/kg for non-galamsey lands. Lastly, levels of cadmium were between 88 – 94mg/kg for galamsey lands and 1.4 – 4.2mg/kg for the non-galamsey lands.

Table 4-4 Levels of heavy metals in the farmlands

Farmland	Heavy Metal (mg/kg)				
	As	Cu	Pb	Hg	Cd
FARM A	86.3	520	431	911	91
FARM B	80.5	435	432	886	88
FARM C	85.3	611	440	895	94
FARM D	79.7	420	425	901	90
CT A	5.2	45	61	35	1.4
CT B	8.5	21	36	23	4.2

The mean $\pm$ S.D levels of each metal in the galamsey lands were as follows: 82.95 ± 2.9 for arsenic; 496.5 ± 76.3 for copper; 432 ± 5.3 for lead; 898.25 ± 9.1 for mercury; and 90.75 ± 2.2 for cadmium. For the control lands, the mean S.D levels of each metal were: 6.85 ± 1.65 for arsenic; 33.0 ± 12.0 for copper; 48.5 ± 12.5 for lead; 29.0 ± 6.0 for mercury; and 2.8 ± 1.4 for cadmium.
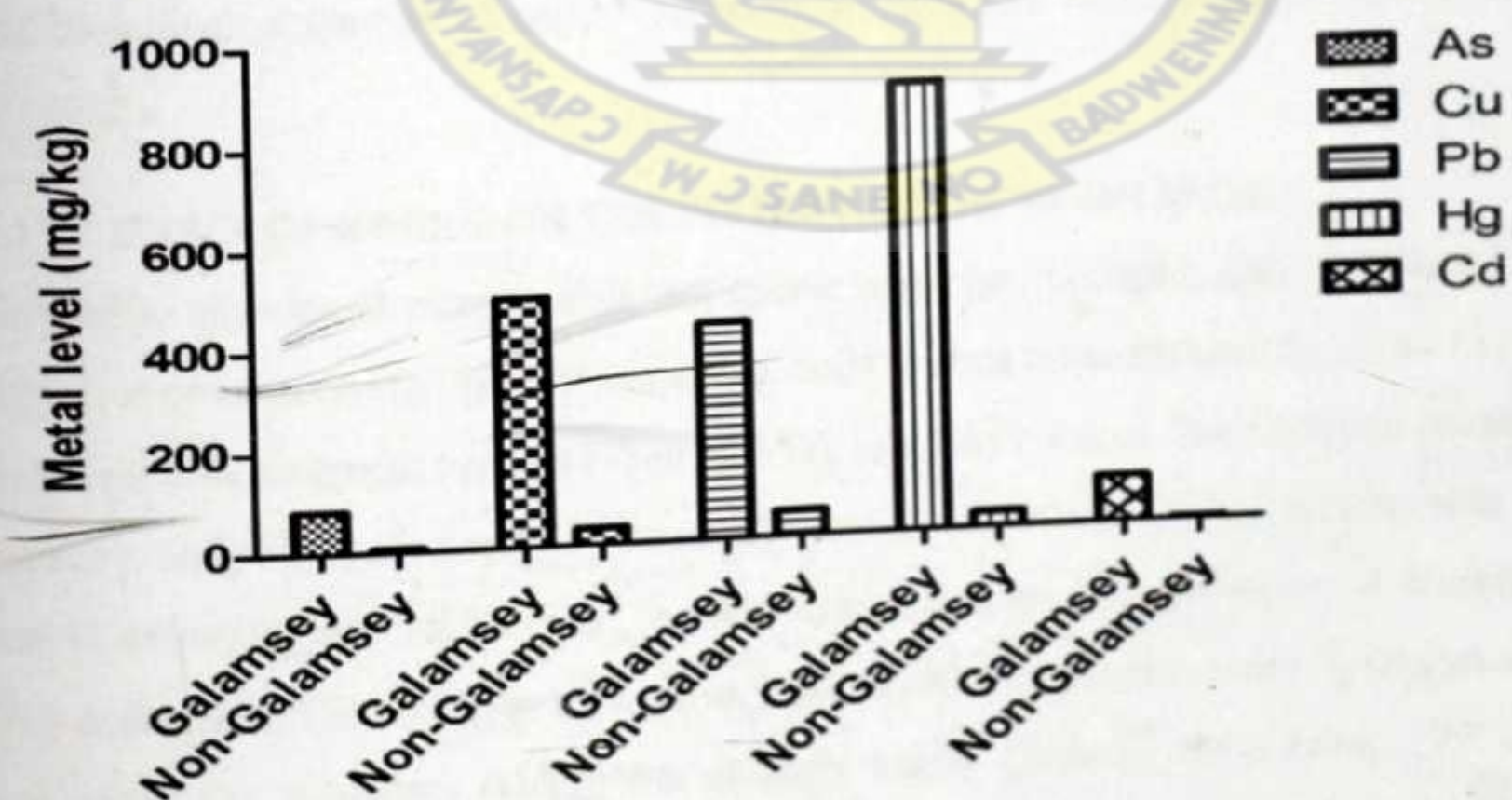

Figure 4-3 Mean heavy metal levels of the galamsey vs. non-galamsey lands

CHAPTER 5

DISCUSSION

Mining and processing has led to socio-economic and infrastructural development of many countries; however, the major negative impacts on mining activities on the physical, biological and hydrological environments cannot be ignored. The importance of the environment to sustainable development in any society is not in doubt. There must be a healthy, rich and adequately protected environment in order to have a healthy, prosperous society. In a country like Ghana, the environment could provide the foundation for all development efforts if protected and managed in a meticulous manner.

The role of illegal mining activities in the whole environmental degradation process can hence not be overemphasized. Such illegal miners, because they may have no title to the land they are working, there is no incentive for sustainable land management (Siswanto et al., 2012). Such artisanal miners employ very simple technologies both in the mining and processing of the metal ore. In addition, usually there is no planning for rehabilitation after the closure of the mining activities. Environmental destruction is the most visible outcome of artisanal mining. Problems include acid mine drainage, deforestation, soil erosion, river silting and the pollution of soil and water with toxic compounds. Degradation on mined land include landscape changes, physical, chemicals and biological properties of soils, microclimate, flora and fauna changes (Siswanto et al., 2012).

5.1   EFFECT OF MINING ON SOIL FERTILITY OF THE FARMLANDS

Generally, abandoned mining sites are coarse and open textured, and therefore, it is subject to erosion due to unstable materials. Soils in such areas are usually characterized by a high rock fragment content (35 to >70 %), low clay content, low moisture retention capacity, and high bulk density. Chemically, most soils in such illegal mining sites are low in nutrients, pH, but elevated in metal concentrations. The presence of aluminum (Al) and/or iron (Fe) sulfates as well as, hydroxysulfates release more hydrogen ions and cause the substrates to become strongly acidic (Seoane and Leiros, 1997). In addition to the acidity issue, such soils are often characterized by high salinity, which is derived from the parent rock characterized by the presence of soluble salts in water or

soil, which can cause a decrease in the relative growth rate and water uptake in shoots and roots. Furthermore, saline conditions affects nitrogen (N) metabolism such as N uptake. These conditions can also significantly decrease dry matter production; the concentration of potassium (K+), calcium (Ca2+) in leaves; and increase the sodium (Na+) and chloride (Cl-) content in leaves (Nathawar et al., 2007).

Soils in galamsey-operated lands in this study were battling serious fertility problems. The levels of essential nutrients were very low and comparing with the levels on the non-galamsey lands, the picture of low fertility in these soils was clear. Soil fertility markers determined in this study included pH, organic carbon and organic matter content, available phosphorus, total nitrogen and measures of cation exchange. The organic carbon as well as organic matter content of the galamsey lands was hugely low compared to that of non-galamsey lands. Percent organic matter and carbon content is a measurement of the amount of plant and animal residue in the soil.

The color of the soil is usually closely related to its organic matter content, with darker soils being higher in organic matter. The organic matter serves as a reserve for many essential nutrients, especially nitrogen. Bacterial activity releases some of this reserve nitrogen, making it available to the plant. Percent organic carbon and matter levels for optimum plant growth usually are expected to be > 2% (Horneck et al., 2011); clearly galamsey-operated lands in the two mining communities failed this minimum requirement. Soil pH is one of the most indicative measurements of the general chemical status of soil.

Most crops grow best with the soil pH is between 6.0 and 7.5. With this guideline, the pH characteristics of the galamsey-operated lands were desirable, though they were still higher than that recorded for the non-galamsey lands. Total nitrogen analysis measures N in all organic and inorganic forms. Plant-available forms of nitrogen are nitrate (NO_3^--N) and ammonium (NH_4^+-N). Soil concentrations of NO_3^--N and NH_4^+-N depend on biological activity, and therefore fluctuate with changes in conditions such as temperature and moisture. Just like percent organic carbon and matter, percent total nitrogen levels in a fertile soil is expected to be > 2% (Horneck et al., 2011). The very low levels of total nitrogen recorded for galamsey lands in the study compared to the control lands shows clearly the deficiency of these lands for crop production.

Soil phosphorus test measures the phosphorus which is readily available to plants (if the weak Bray test is used), or readily available phosphorus plus a part of the active reserve phosphorus in soil (if the strong Bray test is used). In both instances, levels are expected to be between 10 – 20mg/kg (weak Bray) and greater than 30mg/kg (strong Bray)(Yost and Uchida, 2000). Levels of available phosphorus determined in this study were way low than these expected levels and when compared with the control lands, the deficiency in phosphorus of these lands is very clear. Cation Exchange Capacity (CEC) measures the soil's ability to hold nutrients such as potassium, magnesium, and calcium, as well as the other positively charged ions such as sodium and hydrogen. The CEC of a soil is dependent upon the amounts and types of clay minerals and organic matter present. Soil cation exchange capacity is a useful indicator of soil fertility because it shows the soil's ability to supply three important plant nutrients: calcium, magnesium and potassium(Anderson *et al.*, 2010).

Calcium deficiencies are rare when the soil pH is adequate, but yet still, calcium was found to be very deficient in the galamsey lands in this study. Calcium levels are expected to be > 10cmol/kg for optimum cation exchange capacity and hence soil fertility. Magnesium levels of galamsey operated lands were however close to acceptable as levels were approaching the 8cmol/kg lower limit of the cation; with one of the lands even having as a high a content as 12.6cmol/kg. Potassium is the third most important plant nutrient along with nitrogen and phosphorus. Soil K exists in three forms: unavailable, slowly available (exchangeable), and available (in solution). The exchangeable form becomes available when the potassium in solution is removed by the crops. Excessive soil potassium levels can result in elevated K levels in grass forage crops, which may be detrimental to animal health, and hence levels of the cation for optimum soil fertility is quoted with a lower limit of 0.7cmol/kg and an upper limit of 3.0cmol/kg (Horneck *et al.*, 2011).

Notwithstanding this however, galamsey-operated lands in the study had notably very low levels of the cation, the highest being a value of 0.04cmol/kg. Comparing this to the control lands whose minimum level was 1.9cmol/kg brings to bear the likely role the mining could be playing in the infertility of the mining lands. Aluminum (Al^{3+}) and sodium (Na^+) cations are not plant nutrients, so are not wanted by the plant and not necessary for plant growth (Horneck *et al.*, 2011). High levels of sodium are

detrimental to soil structure, soil permeability, and plant growth. Non-galamsey lands though had higher levels of sodium than the galamsey lands, could not be branded to contain levels of the cation detrimental to plant growth.

Aluminum is not present as a cation when soil pH is over 5 because it is precipitated out of the soil solution. It is only at pH levels below 5 that it may become available as a cation, and under 4.5 may even become available in toxic levels, displacing other cations from the clay or humus colloids. As pH of the lands were acceptable and way above 5, the effect of the cation as a soil fertility indicator can be neglected, coupled with the very low levels of the cation.

Particle size analysis results of the galamsey lands shows that all the lands contain sandy soil, with the exception of one that had loamy sandy soil. This observation was not a surprising one since organic matter and carbon content of these soils were excessively low. The high sand levels in these lands could also be the major contributing factor for the low cation exchange capacity of the soils from the galamsey lands. CEC varies according to the type of soil. Humus, the end product of decomposed organic matter, has the highest CEC value because organic matter colloids have large quantities of negative charges. Humus has a CEC two to five times greater than montmorillonite clay and up to 30 times greater than kaolinite clay, so is very important in improving soil fertility (Hoskins, 1997).

Sand has no capacity to exchange cations because it has no electrical charge, implying that sandy soils would have very low CEC, as clearly observed in this study regarding galamsy-operated lands. Conversely, the control lands that had seen no galamsey activities had high CEC, attributable to the high content of organic matter, with evidence provided by the loamy properties of the soil from these lands. The implication of these findings on the fertility of the galamsey lands are that very high amounts of fertilizers would be required if these lands have to ever be used for farming activities, as the level of nutrients can no way support any plant's grow.

5.2   HEAVY METAL POLLUTION OF THE FARMLANDS

Gold mining has contributed significantly to the socioeconomic life of Ghana for the past hundred years(Akabza and Draimani, 2001). However, gold mining in recent times has become unpopular as it is regarded as a significant source of various heavy metal

contamination of the environment owing to activities such as mineral exploitation, ore transportation, smelting and refining, disposal of the tailings and waste waters around mines(Armah et al., 2010). Excess heavy metal accumulation in soils is toxic to humans and other animals. Exposure to heavy metals is normally chronic (exposure over a longer period of time), due to food chain transfer. Acute (immediate) poisoning from heavy metals is rare through ingestion or dermal contact, but is possible. Chronic health problems associated with long-term heavy metal exposures include mental lapse (lead), kidney, liver and gastrointestinal tract problems (cadmium) and skin poisoning (arsenic). Heavy metal pollution within mining communities of Ghana has been extensively studied (Carboo and Serfor-Armah, 1997; Akabza and Draimani, 2001; Hilson, 2002; Adimado and Amegbey, 2003; Essumang et al., 2007; Yidana et al., 2007). The levels of heavy metal poisoning of the five metals determined in this study, for the galamsey lands are very alarming.

All the metals were above the allowed threshold limits and compared to the non-galamsey lands were in very high levels. According to the Environmental Protection Agency (EPA), non-contaminated soils must meet some typical background levels as far as heavy metals are concerned. Recommended levels are as follow: arsenic: 3 – 12 ppm; cadmium: 0.1 – 1.0 ppm; copper: 1 – 50 ppm; lead: 10 - 70 ppm; and mercury: 1 – 30 ppm (USEPA, 2008). Clearly the levels of the five metals observed in the various lands do not meet these threshold requirements and these lands are hence heavily polluted. The imminent health threat of this finding is clear and one that would require urgent attention. If these lands have to be used for farming in the near future, there is likelihood for crop yields to take up some of these metals which would be ingested by consumers. Even breathing of dust coming from such soils may also pose a health risk.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Farmlands in the mining communities of the district are heavily polluted with heavy metals and the fertility of the lands is very low. The pHs of soil in the galamsey lands though slightly alkaline were comparable with that of the non-galamsey lands. The percentage contents of organic matter, organic carbon and total nitrogen in the galamsey lands were very low compared to the non-galamsey lands and were below the required levels for optimum soil fertility. Moreover, the levels of phosphorus and the exchangeable cations were low in the galamsey lands compared to the non-galamsey lands and did not meet the required levels for optimum soil fertility.

Particle size analysis showed that soils in the galamsey lands were mainly sandy and hence would support very little plant growth. The mean levels of the five heavy metals used in the study namely arsenic, copper, cadmium, mercury and lead were all high in galamsey lands compared to the levels in the non-galamsey lands and were above the allowable threshold of each metal set by regulatory bodies. The results imply that for these lands to be cultivable and inhabitable, a lot of work and money have to be invested.

6.2 RECOMMENDATIONS FOR FURTHER WORK

Further studies to determine the levels of heavy metals in crop yields emanating from these farmlands would be necessary to confirm if consumers are at risk of heavy metal pollution.

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