UNIVERSITY OF CAPE COAST

ECOLOGICAL IMPACTS OF SMALL-SCALE MINING IN THE DUNKWA EAST MUNICIPALITY OF GHANA

BY

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DECLARATION

Candidate`s Declaration

I hereby declare that this thesis is the result of my own research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate`s Signature --- Date ----------------------

Name: Paul Kwame Essandoh

Supervisors` Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

Rehabilitation of mined land is crucial for ensuring improved livelihoods of communities in mining areas of developing countries like Ghana. The study assessed the impacts of small-scale mining on forest cover; concentration and distribution of soil nutrients and heavy metals. The vegetation data was obtained from 1000 (20 m × 20 m) plots and the soil samples collected from 120 (50 m × 50 m) plots. A total of 157 species (140 genera and 54 families) and 209 species (185 genera and 73 families) were identified in the mined and unmined areas respectively. Small-scale mining activities significantly ($p< 0.05$) reduced species diversity, and richness of species of higher conservation and economic values. Plant families, Euphorbiaceae, Rubiaceae and Asteraceae were the top-most contributors to species diversity while Asteraceae, Poaceae and Euphorbiaceae were dominant in both the unmined and mined areas. Species-wise, *Pteridium aquilinum*, *Tridax procumbens* and *Waltheria indica* in the unmined area and *Chromolaena odorata*, *Sporobolus pyramidalis* and *Euphorbia hirta* in the mined area were dominant. Nutrient (Ca, Mg, Na, N, P, K, and OC) concentrations and EC varied significantly ($p < 0.05$) between unmined and mined soils. There were no significant variations ($p< 0.05$) in the concentrations of heavy metals between both soils. Despite the generally poor (33.8%) soil quality in the study area, mining activities further reduced (24.2%) it. Soils from mined sites with unfilled /partially filled pits had higher levels of K, Mg and Na. As mined sites fallow period increased, concentrations of OC and Cd increased, while Ca, Mg, pH, Cu, Pb, As and value of EC decreased. The spatial patterns of Cu, As and Pb were generally dot-like in the unmined and mined areas, except Cd which had hot spots in Nyamebekyere. Mg, K and Na showed dot-like distribution in both areas, reducing further in the mined areas. Ca and P had patch-like distribution in both areas with higher levels in the unmined areas while N showed uniform patch-like distribution in both areas. Though educational attainment, religious beliefs and experience in mining significantly explained the opinions of small-scale miners on the effects of mining on the environment, the associations were not significant (Cramer`s V less than 0.3). The number of years that mined land remained fallow should be factored into the mined land rehabilitation processes. Plant species restoration is required in the mined area.

KEY WORDS

Small-scale mining

Flora/ vegetation

Mined/ Unmined areas

Filled/ Unfilled pits

Fallow mined land

Soil quality

Perception of miners

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DEDICATION

To my family

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LIST OF ACRONYMS

AK - Mined Akropong Site
UAK - Unmined Akropong Site
DK - Mined Dunkwa Site
UDK - Unmined Dunkwa Site
PKK - Mined Pokukrom Site
UPK - Unmined Pokukrom Site
KKW - Mined Kyekyewere Site
NB - Unmined Nyamebekyere Site
UBU - Unmined Buabenso Site
FAO - Food and Agriculture Organization
WHO - World Health Organization
GSS - Ghana Statistical Service
MC - Minerals Commission of Ghana

CHAPTER ONE
INTRODUCTION

Background to the study

Gold has provided enormous support to Ghana`s economy in terms of capital formation and fiscal payment (Lawson & Bentil, 2014) and also accounts for about 80% of all mineral revenues (Kuranchie-Mensah & Amponsah-Tawiah, 2016). Apart from employing more people especially in the rural poor communities (Arthur, Agyemang-Duah, Gyasi, Yeboah, & Otieku (2016), small-scale mining contributed between 20% - 35% of the estimated one million five hundred thousand ounces of gold produced in Ghana in 2014 (MinCom, 2015). According to Benkenstein (2012), the contribution of small-scale mining to gold production in Ghana increased sharply from 9% in 2000 to 23% in 2010. Notwithstanding the support of small-scale mining to Ghana`s growth and development, mining activities have impacted negatively on the environment rendering soils and water in most mined sites not suitable for many purposes (Kpan, Opoku, & Anukwah, 2014)

Despite the enormous contribution of small-scale mining to the livelihoods of most poor rural communities, the relatively regulated rehabilitation of large scale mined sites has not been replicated in small-scale mined sites. This often leads to degraded sites after mining has ceased. The degradation of the site is characterized by unfilled pits, poor landscaping, and depleted and fragmented plant cover rendering the sites not suitable for members of the community who are mostly farmers to re-use the land. Thus, there is the need to know the functional relationship between small-scale mining activities and natural resources so as to help reduce the impacts of small-scale mining on the environment. Policy makers need better environmental knowledge of the impacts of small-scale mining so as to provide suitable solutions to mitigate these impacts for the sustainable development of land and vegetation resources (Meaza, Ali, Tesfamariam, & Abebe, 2017). As noted by Owen & Kemp (2016), scientific information is critical for developing appropriate policy responses to environmental impacts emanating from small-scale mining activities.

Mining is a prehistoric activity and presently can be found in many countries (Elgstrand & Vingard, 2013). Mining processes include exploration for minerals, extraction of minerals, preparation, crushing, grinding and concentration or washing of the extracted materials (Elgstrand & Vingard, 2013). Industrial development has accelerated worldwide in recent years with associated increase in the demand for raw materials and expatriates (Elgstrand & Vingard, 2013). This has triggered worldwide increase in extraction of minerals such as gold and this is improving the economic development of many countries including Ghana (Arthur *et al.*, 2016).

The global mining boom in the early 1980`s brought in a lot of foreign investment to the mining sector in Africa leading to marked economic growth and development of most mineral-rich countries (Edwards *et al.*, 2014). Despite this boom, only 5% of the estimated 30% mineral resources deposit in Africa has been exploited (Edwards *et al.*, 2014). This large mineral resource deposit has been an attraction for further injection of capital to the African economy (Zhang & Wilkes, 2010).

Presently, there are two types of gold mines in Ghana; the large-scale mines and the small-scale mines. Patel, Rogan, Cuba, & Bebbington (2016) reported that there were over 13 large-scale mining companies and 300 legally registered small-scale mining companies in Ghana. The general characteristics of large scale mining show that they are large in terms of physical size and capacity and owned by multinationals (Garvin, McGee, Smoyer-Tomic, & Aubyn, 2009). However, small-scale mining activities are characterized by the use of individuals or groups of persons who operate with minimal or no mechanization (Bansah, Barnes-Sakyi-Addo, & Dumakpor-Dupey, 2016). The Ghana Minerals and Mining Act (Act 703) defines small-scale gold mining as an activity that is not operated with large expenditure and is owned by an individual or group of persons not exceeding nine in number or by a co-operative society consisting of 10 or more persons (Bansah *et al.*, 2016). Thus the operations of small-scale mining in Ghana involve use of rudimentary equipment as well as use of advanced activities which require limited capital investment and production at relatively low level (Calys-Tagoe, Ovadje, Clarke, Basu, & Robins, 2015).

Large scale-mining employs about seven million people worldwide and about 20,000 people in Ghana; and it is estimated that proceeds from large-scale gold mining contributes about 45% of Ghana`s total foreign exchange earnings (Garvin *et al.*, 2009). Small-scale mining while employing about one hundred million people in eighty countries, also accounted for about 20% of total gold produced worldwide (Intergovernmental Forum on Mining, 2017). The increased number of people in artisanal and small-scale mining in Africa has been attributed to varied reasons which include the decline in the viability of agriculture; sustaining socio-economic activities of most rural people in mineral rich communities; and as a way of getting high profits and enhancing the economic status of small-scale miners (Opoku-Antwi, Amofah, & Nyamaah-Koffuor, 2012). Small-scale mining in most developing countries, has contributed positively to the overall improvement of the economy and generation of several employment forms (Hilson & McQuilken, 2014).

However, the methods of extraction and other activities of the small-scale miners tend to degrade the environment (Edwards *et al.*, 2014) leading to environmental impacts such as deforestation, alteration, fragmentation and isolation of habitats, soil, air and water pollution and destruction of the pathways of water bodies. If not controlled, the additive effect of the degradation of small-scale mined environments may cause more damage than large-scale mining (Calys-Tagoe *et al.*, 2015). The liberalization of the gold mining industry coupled with the tax incentives from the government promoted foreign investment in mining in Ghana. Notwithstanding this support, about 95% of small-scale miners operated illegally in Ghana (Amankwah & Anim-Sackey, 2003). Out of the 250,000 small-scale mining workers in Ghana, only 30% had been duly registered to operate formally (Aubynn *et al.*, 2010). Notwithstanding the benefits of mining to the local communities and governments, small-scale mining tend to be poorly regulated and the use of inappropriate technologies often result in environmental and ecological degradation of small-scale mined areas (Macdonald, Lund, Blanchette, & Mccullough, 2014; Rajaee *et al.*, 2015).

The Dunkwa East Municipal Assembly, located in the Central Region of Ghana, is noted for extensive small-scale mining activities (Kpan *et al.*, 2014; Kwaansa-Ansah, Basu, & Nriagu, 2010). However, the environmental and ecological impacts of mining have not been thoroughly studied. Few studies, though, have been carried out to; study the incidence of heavy metal pollution of water bodies and soils of some towns in the Dunkwa East Municipality (Kpan *et al.*, 2014); assess the radiological exposure to members of the community as a result of small-scale mining activities (Marfo, 2014) and assess the dwindling economic benefits as a result of the participation of foreign investors especially the Chinese in small-scale mining (Crawford, Agyeyomah, Botchwey, & Mba, 2015). This study seeks to provide data on soils and vegetation of small-scale mined areas to serve as input for target specific interventions needed for effective and sustainable management of small-scale mined sites in the Dunkwa East Municipality.

Most of the inhabitants have leased their lands to the miners for immediate economic benefits without considering the long term ecological and environmental damage; and others engage in small-scale mining to increase their incomes and improve their livelihoods since agriculture, their mainstay, is associated with low incomes (Arthur *et al.*, 2016). Most people living in the mined communities in the Dunkwa East Municipality cannot effectively re-use their lands for cultivation of crops after operations of the mines have been brought to an end. This often leads to conflicts and further deepens the woes of most inhabitants in the community who are mostly farmers. For any future use of small-scale mined sites, there is the need to assess the destructive effects of small-scale mining activities in order to properly evaluate and rehabilitate the degraded mined sites.

Statement of the Problem

Mining of gold has been recorded as one of the activities that destroys the environment through the discovery, extraction and processing of the mineral resource (Edwards *et al.*, 2014; Kpan *et al.*, 2014; Meaza *et al.*, 2017; Tetteh, 2010b). The laws and regulations by the government of Ghana for managing the mining environment are geared towards large-scale mining, and the law enforcement in the small-scale mining sector has been relatively poor (Bansah *et al.*, 2016). .

The Dunkwa East Municipality in Ghana has traditionally been the home for exploitation of mineral resources (Kpan *et al.*, 2014; Kwaansa-Ansah *et al.*, 2010). Many of the small-scale miners have formalized their activities by obtaining their concessions directly from the District Mineral Commission. As reported by Ghana Statistical Service [GSS] (2010), small-scale mining goes on in almost all the towns in the Dunkwa East Municipality and the large numbers of small-scale mining sites, closeness of the mining sites to another and the methods used in extracting the mineral tend to compound the destruction of the environment in the study area (Edwards *et al.*, 2014)

Larger portion of revenues accrued from small-scale mining by law goes to the state to the detriment of local community members who are directly affected by the activities of small-scale mining. To further compound the situation, chiefs, opinion leaders and land owners have joined the fray in releasing land to small-scale miners for immediate economic benefits without considering the unavailability of agricultural lands to most of the people in the mined communities. The ever increasing numbers of small-scale mining activities in the Dunkwa East Municipality has resulted in unhealthy competition for land resource between the miners and community members (Kwaansa-Ansah *et al.*, 2010; McQuilken, 2016). Moreover, the rehabilitation of small-scale mined sites which essentially has been refilling of pits and leveling of the landscape has not been vigorously followed by the small-scale miners in the study area. Despite all these challenges, alternative livelihood strategies are not available or they are in not in good standing to support the marginalized and vulnerable people, who incidentally are farmers in the municipality.

. The earlier studies on small-scale mining (illegal or galamsey) in the Dunkwa East Municipality have focused on radiological impact of small-scale mining activities on the people in the mined communities (Marfo, 2014) and heavy metal pollution of water and soils in mined areas in some selected towns in the study area (Kpan *et al.*, 2014). Not much work has been done to study the impacts of small-scale mining on the flora and soil resources of the study area resulting in paucity of data.

The government of Ghana banned small-scale gold mining for almost two years (2017-2019) ostensibly in reaction to increasing environmental degradation. This ban brought an economic challenge to the miners, mining community members and Ghana as a whole. For the resolution of the economic and environmental challenges, there is the need to effectively rehabilitate the old small-scale mined sites alongside the new ones so that small-scale mining and small holder farming in the study area could coexist.

Whether natural recovery, assisted recovery or a combination of these two methods is used for rehabilitation of mined sites, this may take many years to complete the recovery process (Tetteh, 2010a; Tetteh, 2010b). However, the re-entry of mined sites in the study area is critical for the survival of community members who are mostly farmers hence, the need for measured and targeted rehabilitation of small-scale mined sites.

Purpose of the study

The study sought to reveal the extent of vegetation/forest cover loss and its effect on floral quality and also to provide inputs for flora restoration; determine the levels and distribution of soil nutrients, physico-chemical parameters and heavy metals content in time and space in the mined environment. It further sought to assess how different land-use types, the length of fallow period after mining and the pits condition (filled and unfilled pits) affected the contents and distribution of nutrients and heavy metals in soil. This research also assessed the extent to which small-scale miner`s knowledge on impacts of mining could contribute to policy formulation.

Objectives

1. To assess the impacts of small-scale mining on the vegetation/ forest cover of the affected areas in the Dunkwa- East Municipality.
2. To determine the effects that small-scale mining activities, the length of fallow of mined land and pit condition (filled and un-filled pits) have on the concentrations and distribution of nutrients and heavy metals in the soil.
3. To assess the geochemical distribution of heavy metals and nutrients of mined and unmined soils in the study area.
4. To evaluate the perception of small-scale miners on environmental effects of gold mining in the Dunkwa East Municipality.

Hypotheses

H_0: The floristic composition and diversity of native species are similar in the mined and unmined areas.

H_0: The concentrations and spatial distribution of heavy metals and nutrients are identical in the mined and unmined soils.

H_0: The length of fallow of mined land and pit condition (filled or un-filled) affect the levels and distribution of nutrients in the soil.

H_0: Gold miners` knowledge on environmental effect of small-scale mining is independent of educational attainment, ethnicity and gender of gold miners

Significance of the study

This study advances knowledge by increasing the understanding of the impacts of small-scale mining activities on vegetation and soil resources. The quantification of these impacts bring to fore the real extent of degradation to stimulate appropriate response. Additionally, the study would contribute to knowledge on gold mining in the specific study context. This could inform policy makers to adhere to the current leveling of small-scale mined sites and filling of the pits or make interventions needed to make the mined site suitable for re-use. The report of this study would be a useful document that could be used by policy makers to assess the perceptions of miners on rehabilitation of small-scale mined sites and could in form future policy directions and help address policy inadequacies.

The research community and stakeholders in the mining sector would be able to utilize the findings to ensure that their interventions are sensitive to the aspirations of the community. The report of this study would be a good document that would be used to address the major challenges of the ever increasing small-scale mined sites which are presently not being utilized by the community members. It would serve as a reference data and a guideline for teaching and future research into small-scale mining to help improve efficiency in the preparation of the mined area for alternative use.

Delimitation of the study

The study was located in the Dunkwa East Municipality of the Central Region of Ghana. The fundamental motivation is that the Municipality hosts numerous small-scale mining sites found in almost every town or village in the Dunkwa East Municipality. The now defunct Dunkwa Goldfield Limited, formerly owned by the Government of Ghana, was located in the study area for the extraction of alluvial gold because the locality has been known to be rich in gold deposits.

Mining is an integral and important industrial activity in the Municipality (Kpan *et al.*, 2014; Kwaansa-Ansah *et al.*, 2010). The study area lies in a gold belt and this has resulted in the invasion of the Municipality by small-scale miners. Due to these developments, a District Mineral Commission office overseeing about 350 small-scale mining groups has been set up in Dunkwa-on-Offin, the Municipal capital town. This has facilitated access to information on small-scale mining and easy interactions with the miners. The study area provides a unique opportunity for studies on the impacts of small-scale mining and better understanding of the perceptions of small-scale miners on mining.

Limitations to the study

Miners have strong negative perceptions about strangers to their concession sites. This together with the sensitive nature of small-scale mining in the study area, often lead to behaviour put up by the miners being frightening and life threatening.

Almost all the information collected using questionnaire for the survey aspect of the study is subject to reporting and recall biases. For example, information demanded from the respondents such as age of respondents, how long the miners have been in small-scale mining etc., were events in the past and demanded recall. Respondents were sometimes reluctant to contribute to the study as they were research fatiqued or reacting to the perceived sensitive nature of small-scale mining. Community members are apprehensive that information they provide could be used wrongly against them and this situation sometimes make them reluctant to open up.

No attempt was made to include lower plants (non-vascular plants) in the study since these plants usually pose a problem for many to visualise as plants. The study focused only on the broader concept of plants as herbs, shrubs and trees.

Organization of the study

This study is organized into six chapters. The first chapter deals with introduction of the study and covers the research background, the statement of the problem, purpose of the study, research objectives, hypotheses, and significance of the study, delimitation and limitation of the study. The second chapter provides information on literature review which covers historical overview of mining, legal regimes, nature and contribution of small-scale mining, mining and environmental security, mining and the forest, vegetation, land and soils of mined areas, and rehabilitation of mined environments. Chapter three deals with the research methods which details the background information of the study area, sampling procedures, methods and techniques for data collection, data collection instrument and procedures, data processing and analysis. Chapter four of study presents the findings from the research while chapter five focuses on the discussions of the findings. Chapter six covers the summary, conclusions and recommendations from the research.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This section of the study reviewed the historical background of gold mining in Ghana and also examined the development of small-scale mining in Ghana. It assessed the laws and regulatory framework governing small-scale mining and the socio-economic impacts of small-scale mining. The study also examined the impacts of small-scale mining on land, soil and vegetation and heavy metals in affected areas. This section also assessed environmental effects of mining and rehabilitation of mined sites.

History of gold mining in Ghana

Ghana`s participation in the gold mining industry has come a long way. As reported by Kesse (1985), the Gold Coast historically has been associated with gold and the trade in gold dates back many years before the Phoenicians and Cartaginians sailed around the West Coast in the 5th and 6th centuries B. C. Thus, the people in the Gold Coast had been involved in the gold industry before Europeans from Portugal and Britain arrived in the Gold Coast between 1453 and 1622.

In the earlier activities of mining in West Africa, three sources of gold were identified (Peters, 1986). The first source of gold was from unconsolidated sediments in the river beds, along the rivers and streams and at the sea shores. The second source of gold was from the alluvial terraces and old river and stream valleys where the sediments which bear the gold can be unconsolidated, partially or completely consolidated. The third source of gold was derived from a hard rock made up of metamorphosed sediments or volcanic /plutonic rocks, quartz veins etc.

Most of the local people on the coast of West Africa were into agriculture and hunting. The use of iron and stone tools became popular and as Posnansky (1977) stated “iron was concomitant of agriculture over most of Guinea forest and was instrumental in allowing populations to expand geographically and numerically”.

The area where today`s Ghana is located was a neolithic settlement (Clark, 1967). The Ntereso town on the White Volta was a mesolithic /Neolithic fishing community and the people were introduced to iron by immigrants from Arounae in the Sahara (Clark, 1967). When the gather-hunter populations in West Africa started gold collection and gold mining, any bright object was obtained and initially used as an ornament. Upon the collection of many of these "bright objects", they were turned into implements (Rickard, 1934; Sutherland, 1952). When hunters came across nuggets of gold, they were used for making tools, weapons and necklaces (Rickard, 1934). These gather-hunters gradually turned into miners and when they noticed that pieces of the gold that they were gathering were half buried in the sand of river beds, they used sticks and wooden spears to stir the sand and most often discovered more pieces of gold (Rickard, 1934). They then started sifting the sand with the aid of water and this led to further discoveries of more gold and better cleansing of the gold nuggets (Anin, 1990). These activities of the local inhabitants invariably led to the discovery of simple mining technique. Upon using this technique over a period, the miners observed that gold could be separated from the sand by the" difference in simple gravity" between gold and sand. This prompted the miners to wash the alluvial detritus with effective motion in a wooden pan, the batea of the South American aborigines or in a calabash for effective separation (Rickard, 1934). As reported by Sutherland (1952) and Peters (1986), the Neolithic miner used gold mainly for adornment as un-alloyed gold was considered to be too soft for other uses.

Later on, Neolithic miners in West Africa found out that gold could also be used as an economic medium for exchange of goods and services. This experience was thought to have emanated from the interactions of the miners with people from outside their jurisdiction (Peters, 1986). When the Neolithic gather-hunter turned into a miner was able to strike a deal through batter, where gold could be exchanged for copper, bronze or iron tool, the miner realized another importance of gold (Peters, 1986). This batter trading system led to rising demand for gold. Castles and Forts were built as trading links between West Africa and the Europeans, West Indies and the American continent (de Moraes Farias, 1974).

In the Gold Coast, Barbot (1732) had explained that miners in the lower Ankobra river obtained alluvial gold by plunging and diving under the most rapid streams with a brass basin or wooden bowl on their heads. They then collect any gold pieces found in the sediments into the bowls or basins. When the bowls or basins are full, the miners come to the bank of the river. The other supporting miners after washing the gold, use chicken-feather and small pointed sticks to remove impurities on the gold (Terray, 1983). Gold mining at that time was mainly financed through the Abusa system where the Chief of the area who principally was considered the land owner, received one third of the proceeds from the mines, the operator of the mine also took one third and the last third of the proceeds shared by the workers (Terray, 1983). The Ashantis in the Gold Coast increasingly got involved in mining of high grade gold ore from hard rock using slaves for the crashing of the rocks, washing of the rocks and then obtained most of the gold through panning (Terray, 1983). Around this period where there was a search of improvement of techniques used in the extraction of gold, some local indigenous people in the Gold Coast in West Africa have succeeded in extracting gold from under-ground operations (Wilson, 1856).

The development of modern mining in the Gold Coast can be put under three different periods. The first period which was from 1880 to 1901 was characterized by lack of road and railway transport. This led the miners to use heads of porters for transporting most of the machines needed for mining causing delays and frustrations. It was later in 1892 that an English fitter, Mr Higson discovered that it was easier for some machines like rings to be rolled instead of dismantling them to be carried with the head (Allen, 1958). Between 1875 and 1885, mining companies such as the Effuenta Gold Mining Company, Wassaw Gold Mining Company and the Gold Coast Mining Company were established in the Tarkwa-Abosso area for mining of gold. Marie- Joseph Bonnat was largely thought to be the first non- indigenous person to introduce modern approaches to mining in the Gold Coast and was accordingly called the father of modern mining in Ghana (Peters, Kessee, & Acquah, 1992). The African Gold Coast Company was granted a concession for 100 pounds in the Tarkwa area. This concession later became the Tarkwa mines and Bonnat became the deputy director of the company. Through his skills he was able to acquire other mines such as the Abosso concession in April 1879. Other British companies made efforts to increase gold production in southern Gold Coast. About twenty-five mining companies between 1878 and 1883 tried to raise capital to invest in the gold mining industry in the Gold Coast (Peters *et al*., 1992). The early companies to follow Bonnat to the Tarkwa area invested in mining companies which were located or found in the vicinity of Eduapriem, Tamso, Detchikrom and Effuenta, Abosso, Adja Bippo, Cinnamon Bippo, Chida and Damang. Gold mining concessions which have been registered in Cape Coast between May 1878 and June 1882, were one hundred and nine (Peters, 1986). Other concessions that had sprouted in the Ahanta and Nzema areas included Ahanko, Izrah and Apatim concessions (Peters *et al*., 1992; Peters, 1986). By the end of 1881, about 71 mining concessions had been purchased in the Gold Coast but surprisingly only 5 mines were in operation partially due to operational cost. Notwithstanding these adverse effects on the growth of mines during that period, 20 more mining companies were formed between 1885 and 1893 (Peters, 1986). Through the MacArthur Forest Cyanidation Process for Chemical Extraction, a new technology for the extraction of gold was introduced into the Gold Coast in 1895. This new technology initially did not bring any appreciable increase in the total output of gold production in the Gold Coast. The gold production levels between 1880 and 1901 did not go beyond 24,300 ounces per year. These levels were far below what was obtained in many of the years of the pre-modern mining era (Silver, 1981). The export of gold from the Gold Coast between 1880 and 1901 showed that gold from the European managed mines contributed two thirds of the total annual production (Silver, 1981). Gold output fell to about 6000 ounces in 1901 when the operations of the European Gold Mining Companies had virtually come to a halt (Silver, 1981). The concessions in Tarkwa which were originally granted to Bonnat were worked on by the Abosso Mines Ltd, and those belonging to Dr Horton and others were taken over by Amalgamated Banlket Area Ltd. The Ariston Gold Mines in Prestea, Bibiani Mining Company and Ashanti

Goldfields Corporation started work in 1885, 1891 and 1897 respectively (Allen, 1958).

During the second period of modern gold mining in the Gold Coast, the railway lines from Sekondi to Tarkwa (1901), to Obuasi (1903) and Prestea in 1910; the ending of the Ashanti in Ghana and the Boer war in South Africa facilitated the boom in gold mining in the Gold Coast (Allen, 1958). About 400 gold mining companies were opened in the Gold Coast between 1902 and 1903 where there was intensive prospecting and exploration for gold. The Gold Coast Geological Survey which was founded in 1913 for mineral and geological survey led to the discovery of gold, bauxite and manganese deposits. As a result of these discoveries and mapping of the deposits, gold production in the Gold Coast went up. The total production of gold per year in 1901 which was 5,223 ounces moved up to 400,000 ounces in 1914 (Allen, 1958). The third period was characterized by drop in the production of gold. When England moved out of the gold standard, price of gold moved up from 84s 11½d to 135s (Allen, 1958). This resulted in the establishment of fifteen gold mining companies in 1941 in the Gold Coast producing about 885,712 ounces of gold. However, due to the effects of the second war, economic activities went down and the price of gold fell. This adversely affected gold production as the number of gold mines reduced to 10 by 1955, producing between 500,000 to 800,000ounces of gold. The Marlu Company and Taquah and Abosso Mines were closed between 1955 and 1956. Due to the closure of other mines in the Gold Coast, the number eventually reduced to seven (Allen, 1958).

By early 1930s, the Ashanti Goldfields Corporation and the Ariston Gold Mines were the quartz reef mines established in the Gold Coast (Allen, 1958). Three other quartz reef mines were later opened; these were the Bibiani, Konongo and Gold Coast Main Reef Mines with improvement in both the under- ground and open- cast operations. Alluvial mining in the Gold Coast was relatively ancient however returns from alluvial mining had not been encouraging. In response to the gold jungle of 1901-1902, 15 dredging companies including Ankobra, Ofin and Fura

Companies etc. operated and produced 20,102 ounces of gold by 1909 (Allen, 1958). The Tano Gold Dredging Company came into existence in 1936 but got liquidated in 1942. One major success story was the Breman Gold Dredging Company which began work on the Ankobra river in 1938 and later acquired the defunct Tano Dredging Company.

The unfriendly environmental conditions in West Africa, occasioned by the incidence of malaria, yellow fever, small pox and dysentery prevented most investors from bringing their capital to the Gold Coast (Peters, 1986). Later in the nineteenth century, medical solutions were found to mitigate most of the diseases that affected the Europeans in West Africa. During that period, many European business people simply used agents to acquire concessions from local chiefs, used the concessions to form companies and later floated the shares in Britain for profits. This led to what became "concession mongering" (Rosenblum, 1972). However, foreign investors in the gold mining sector in the Gold Coast kept on increasing, partially due to the mitigation measures put in place to resolve certain medical conditions and the quest of the mostly Europeans, to invest in the mining sector of the Gold Coast.

The initial problems faced by the foreign mining companies in the Gold Coast were mostly self- inflicted. These were attributed to poor management of mines and excessive drinking on the part of the foreign business men. Most of the owners of the mines lacked knowledge on the techniques for professional exploration. A mining engineer of the Guinea Coast Mining Company died 21 days reaching the coast due to excessive drinking (Peters, 1986). Overall, lack of experienced mine managers, inadequate funds and inappropriate mining equipments for the deposits in the Gold Coast which contributed to the difficulties faced by the earlier foreign miners were generally self-inflicted. However, the difficult terrain, dense vegetation covering the underlying geology, tropical climate and adverse health issues also contributed to the failure of most of the earlier mines in the Gold Coast (Peters, 1986).

Labour was listed by the foreign investors in the mining industry as one of the factors contributing to the poor mine growth in the Gold Coast. The local inhabitants disagreed with this assertion. It was identified that the problem was due to the poor managerial skills on the part of the foreign investors in convincing the local labour force to work effectively in the mines. During this period, some of the local groups like the Fantis discovered that they could use powder in blasting the ore and could make more money on their own from mining (Cameron, 1882). The Wassaws, Ashantis etc. were prepared to work in their farms or do indigenous gold mining than to work for the foreign investors (Rosenblum, 1972). The disputes between local labour and their foreign masters arose mainly from delayed payments of wages to labour. The delayed payments were attributed to inavailability of funds, delay in the transfer of funds, mailing of insufficient funds and sending unacceptable coinage (Peters, 1986). The poor treatments handed to the local labour force included "the boots, the stick, abuse and inadequate pay and dishonest dealings" (Silver, 1981). Local people in the Gold Coast gradually turned to prefer working in their farms or doing indigenous mining as compared to working for the foreign mining operators. This brought about a paradigm shift in the thinking and behaviour of foreign mine owners towards local labour. After about two decades, the foreign engineers and experts gave the green light that the local people were amongst the best workers you can get anywhere in the world, and with little training, they could have the capacity to take over highly skilled positions (Silver, 1981).

After the second war, the problem of getting labour to help the rehabilitation of closed down mines in the Gold Coast, persisted for some time. To improve the situation, the mining companies set up centres to house most of their workers, provide vehicles for transportation, built canteens and health posts and signed contracts with sections of the work force. The workers were unionized to improve working relations with management (Allen, 1958). To further boost the operations of the mines, the government amended the Tax Ordinace. The Surtax placed on gold was abolished and the Mineral Tax was introduced to replace the Export Duty Tax, so as to remove the double taxation burden on gold production. Additionally, the government of the Gold Coast gave aid to distressed mines to boost production and secure labour.

The development of gold mining in Ghana in the twentieth century has gone through ups and downs. Gold Mining Companies operating in Ghana in 1938 were eighty and by 1987 the number has gone down to four. As reported by Hilson (2002b), fifty gold mining companies were operating in Ghana in 1930, and this number reduced to eleven by 1950. This was primarily attributed to lack of government support. In the early years after independence in 1957, most of gold mining operations were carried out in Obuasi since most of the other mines located in Tarkwa, Abosso etc. were underdeveloped and lacked funds (Hilson, 2002b). To have control of mining operations in Ghana, a commission was set up in 1959 to among other things, look at mineral rights, status of unexploited concessions and the profitability of mining operations in Ghana. The recommendations from the commission indicated that the government should take over mineral rights from the communities and royalties accrued from mining should be paid to government. They also recommended that government should regulate the activities of mining and establish a monopoly on exported minerals from Ghana. The government implemented the recommendation of the commission by establishing the State Mining Coporation and by 1966, the Coporation had taken over most of the mining companies owned by foreigners. These mining companies included Amalgamated Banket Limited, Ariston Gold Mines, Breman Gold Dredging Company, Ghana Main Reef Limited, Konongo Gold Mines Limited and Bibiani Limited. Most of the mines were nationalized except those at Obuasi and Konongo (Jackson, 1992). The Minerals act (Act 123) was passed in 1962 to put all minerals in Ghana under the control of the government. Due to excessive government control and bad management, there was a decline in gold production. Gold production which was 956,947 oz in 1960 reduced to 766,252 oz in 1970 (Hilson, 2002b). The passage of the Mining Operation Decree (NRCD 132) in 1972, lack of foreign exchange and the general weakness in Ghana`s economy further promoted the decline in the activities of most mining companies (Pelig-Ba, Biney, & Antwi, 1991). The Mining Operations Law required that 55% of equity capital of mining companies be held by government in addition to the payment of compensation on 55% of total assets of any mining company. Notwithstanding these interventions by government, the decline in production of gold continued as gold production which stood at 900,000 oz in 1960 had fallen to 232,000 oz in 1982 (Hilson, 2002b). Thus, through the backing of the United Nations, Ghana nationalized many of its companies after independence in 1957. Most of the mines became state owned and after sometime, most of them faced financial difficulties due mainly to poor management and financial difficulties in Ghana at that time. To reverse the situation in the mining sector, the government of Ghana turned to the World Bank and the International Monetary Fund (Hilson, 2002b). The introduction of the Economic Recovery Programme in 1983 reversed all policies implemented in the mining sector. The recovery programme allowed for inflow of foreign resources into the mining industry. The International Development Association (IDA) of the World Bank, commissioned the US $90million Mining Sector Rehabilitation Project in 1989 for the rehabilitation and privatization of the Tarkwa, Prestea and Dunkwa mines which were state owned (Amponsah-Tawiah & Dartey-Baah, 2011). About US$4 billion was invested into the mining industry in Ghana between 1983 and 1988 (Aryee, 2001). Not surprisingly, gold output rose by 250% between 1990 and 1994 to reach 45 t/year (Sutton-Pratt, 1996). As reported by Hilson (2002b), there were 18 companies operating gold mines in Ghana and 237 mining companies, that is 154 Ghanaian and 83 foreign companies prospecting for gold in Ghana. With the promulgation of the Minerals and Mining Law in 1986, Ghana`s Mineral Commission was established to regulate the mining sector and further liberalized the mining sector. The regulatory activity of the Mineral Commission coupled with rise in the world price of gold, led to substantial new interest in Ghana by International Mining Companies (Minerals Commission [MC], 2000). Generally, gold production in Ghana has been increasing since 1980 and had reached 429,476 oz in 1989 and exceeded 2 million ounces annually since 1987 (Hilson, 2002b). With this encouraging prospect, Ghana was named among the top 10 emerging markets for mining in 1995 (Ayee, Søreide, Shukla, & Le, 2011).

Notwithstanding the difficulties faced especially by foreign investors in the mining industry from the pre-colonial period, through the colonial days to the present, mining has brought a lot of good economic returns. The active involvement of the European mine managers in the Tarkwa mines improved the average earnings of the local miner from 1 shilling to 1 shilling 6 pence, rising to 2- 10 shillings in some mines (Peters, 1986) and this trend notwithstanding the difficulties, has continued over the years. With improved economic benefits to the foreign investor and the labour force in the mining industry, and the recognition by the pre-colonial and post-colonial governments of Ghana of the importance of mining to the economy of Ghana, various interventions have been put in place to promote the gold mining industry in Ghana. This has resulted in increase in the gold mining companies in Ghana. In addition to the old established mining companies already in Ghana, 17 new mining companies have been established since 1988 (MC, 2000).

Review of small-scale mining in Ghana

Small-scale mining industry in Ghana which has been with us for many years, has been treated as an informal sector activity and until the 1980s, the activities of small-scale mining have remained unregulated and received little support and policy directions from government or its agencies.

In Ghana, small-scale mining is defined to cover the level of exploitation of mineral resources where rudimentary equipments are used, and the level of production which usually involves the use of minimal capital investment. Globally, small-scale mining has been defined differently depending on the country involved and the conditions of mining existing in that country. From the end of the United Nations (UN) and Intermediate Technology Development Group (ITDG), small-scale mining is defined to contain the given production ceiling and the level of sophistication with which the minerals are exploited. United Nations define small-scale mining as any single unit mining operations having an annual production of unprocessed materials of 50,000 tons or less as measured at the entrance of the mine (Dreschler, 2001). According to the Ghana small-scale Mining Law in 1989, small-scale mining constitute any mining of minerals by individuals or group of persons not exceeding nine in number, or by a co-operative society made up of ten or more persons not using substantial expenditure. This definition has opened small-scale mining in Ghana not only to include operations using rudimentary equipments but to the use of relatively more sophisticated implements but operating on a low production levels using limited capital investment (MC, 2000). The more sophisticated small-scale mineral concession holder can employ other contractors including expatraits. The involvement of expatraits, though not intended in the laws governing small-scale mining in Ghana, has cumulatively over the years resulted in devastating degradation of the environment. The introduction of extensive mechanization and improved technologies in the small-scale mining sector has caused serious damage to the environment (Botchwey & Crawford, 2016).

The geological setting in Ghana promotes the proliferation of small-scale mining. Ghana is found within the West African craton (MC, 2000) and through various tectonic processes many areas were folded, faulted, metamorphosed and then subjected to igneous activity followed by erosion and sedimentary processes. These events resulted in a series of gold belts found in many regions of Ghana (Lunt, Kirby, & Ritchie, 1995). Two general categories of gold deposits, the Birimian and the Tarkwaian Gold deposits have been listed by geologist to occur in Ghana (Dzigbodi-Adjimah & Bansah, 1995). The Birimian rocks extend from Ghana westwards to Senegal and Mauritania, northwards into Burkina Faso. These supracrustal rocks have deposits of Proterozoic greenstone-type gold iode deposits (Hammond & Tabata, 1997). In the Birimian rock, gold deposits are usually found in the quartz-filled shear zones and in the altered rocks adjacent to the shear zones (Mumm, Oberthür, Vetter, & Blenkinsop, 1997). The Birimian rocks are usually located in the metamorphosed volcanic belts which on the average have a width of 15km to 40km and covers about one-sixth of the surface area of Ghana (Dzigbodi-Adjimah & Bansah, 1995). The Tarkwaian rocks consist of auriferous quartz-pebble conglomerates. The matrix of these conglomerates is made up of fine-grained quartz and black sands. The quartz-pebbles of the Tarkwaian gold consists mainly of vein-quartz and the remaining is made up of quartzite and phyllite (Mumm *et al.*, 1997). The bulk of gold in Ghana is obtained from the Birimian deposits. Ghana`s earth crust has a lot of paleoprotoerozoic rocks of the Birimian super group and the overlying clastic sedimentary Tarkwaian group (Mumm *et al.*, 1997). Due to erosional activities over the years, large portions of these rocks have been re-deposited as placer formation in streams and channels as sources of alluvial gold deposits. The placer gold deposits are found in many rivers that drain the Birimian and Tarkwaian rocks. Alluvial gold deposits are found in channels and river beds of Offin, Ankobra, Birim, Tano and Pra rivers in Ghana (Dzigbodi-Adjimah & Bansah, 1995).

Generally, mining methods used by small-scale miners depend on type of gold deposits to be exploited and the location of the deposits. Due to the weak financial background of most small-scale miners in Ghana, they often use simple rudimentary tools such as shovels, pans, pick-axes, chisels, hammers etc. in a manual method for extracting the gold ore. However with the present law allowing the licensed small-scale miner to obtain assistance from other contractors, the face of small-scale mining has changed with accompanying environmental concerns. The methods employed in small-scale mining in Ghana can be put under three groups; shallow alluvial mining, deep alluvial mining and hard rock (Iode) mining (Aryee, Ntibery, & Atorkui, 2003). The shallow alluvial method is used to mine low lying sites and valleys where the gold may be found just three metres into the alluvial deposits. Normally the vegetation on site is cleared and the soil is excavated till the deposit containing the gold is layer is reached. The gold deposit material is transported to a nearby stream for it to undergo sluicing to obtain the gold. The method of obtaining gold is called "dig and wash" in Ghana. The deep alluvial mining techniques are employed to get to the alluvial gold deposits along the banks of major rivers such as Offin, Ankobra, Pra etc. A pit is excavated and dug into until the gold bearing gravel horizon, which is often between 7 to 12 metres, is reached (Aryee *et al.*, 2003). To avoid collapse of the pits, benches or terraces are constructed along the sides of the pits, and the gold-bearing gravels are then removed by an escavator. The gold-bearing alluvial deposits are the sluiced to get the gold (Aryee *et al.*, 2003). In the hard rock operations, gold bearing reefs are mined. Holes are sunk to intercept the reefs and when the reefs are weathered, implements such as pick-axes, chisels, hammers etc. are used to break down the gold-containing ores. The miners sometimes use explosives to break down the rocks though use of explosives by small-scale miners is illegal in Ghana (Aryee *et al.*, 2003). For alluvial ores, the traditional or manual method of separation involves sluicing of the milled gold-ore in a sluice box to get a gold concentrate. Mercury is added to the gold concentrate to form gold amalgam. The gold amalgam is then heated to separate the gold. The manual means used by the small-scale miners in processing hard rock ores consist of first crushing and grinding the ores using mortars and pestles. The powder obtained is mixed with water and sluiced to obtain a gold concentrate which is then mixed with mercury. The amalgam is then heated to separate the gold (Aryee *et al.*, 2003). The present laws governing the small-scale mining activities in Ghana permits the miners to get technical and financial support from other investors. Small-scale mining operators who can afford have engaged the services of these Mine Support Service Companies and have their operations moved from the manual stage to semi-mechanised mining methods with the associated increased environmental degradation. In the semi-mechanised mining method, sizing trammels, knelson concentrators and suice boxes are employed to improve the efficiency of processing alluvial gold deposits (Aryee *et al.*, 2003). The milling of the hard rock is done relatively better using jaw crushers, hammer mills, ball mills and in some cases modified corn mills are used.

Laws and regulatory framework for small-scale mining

The laws and regulations governing the operations of mining in Ghana have gone through various stages over the years. Through the colonial period to the present situation, various laws have been passed at every stage to control the development of mining in Ghana. Some of the laws include the Concessions Ordinace, 1939 (Laws of Gold Coast, 1951 Revision) and Form of Schedule; Prospecting & Digging License Regulations, 1950; Mineral Regulations, 1962 (L. I. 231); Mineral Regulations, 1963 (L. I. 253) and Explosives Regulation, 1970 (L. I. 666) (Iddirisu &

Tsikata, 1998; Macdonald *et al.*, 2014; McQuilken, 2016). These laws were passed mainly to regulate activities of large scale mines in Ghana. However, the concerns of the impacts of small-scale mining on the environment, the enormous benefits that this sector is noted to be adding to the economic development of the country prompted the government to make a much needed move to legalize small-scale gold mining in Ghana.

The passage of the Mineral and Mining Law (PNDC Law 153) in 1989 by the government was to revolutionalize activities of small-scale mining in Ghana. To further promote growth and development of the small-scale mining sector, three laws were passed (Iddrisu & Tsikata, 1998; MC, 2000). These were the Mercury Law (PNDCL 217) which was to legalize the buying of mercury from authorized dealers; small-scale gold mining law (PNDCL 2018) which made provision for the registration small-scale operators, granting of gold-mining licenses to individuals or groups, the licensing of buyers to purchase gold and the establishment of district centres to assist miners; and the Precious Mineral Marketing Corporation Law (PNDCL 219) which transformed the Diamond Marketing Corporation into the Precious Mineral Marketing Corporation to allow for buying and selling of gold locally (MC, 2000). The Mining Law of 1989 was later replaced with the Mineral Act of 2006 (Act 703). This Act (703) defined small-scale mining as “mining by any method not involving substantial expenditure”. The small-scale miners were also required to submit plans for environmental management of their concessions to complete the permitting processes (Hilson, 2001; Mensah *et al.*, 2015).

The acquisition of land for small-scale operations in Ghana is done under a licensing regime operated by the government (MC, 1989). Ghana Minerals Commission assists the Minister of Mines and Natural Resources in issuing licenses to small-scale mining operators. The Mineral Commission has established District centres to assist with the permitting process for obtaining small-scale mining operating licenses and facilitate the provision of technical extension services to the small-scale miners. These district centres are closer to the small-scale miners to provide other services such as sharing of information, assistance and training, marketing, health and safety tips and the methods and procedures that are to be followed to ensure environmental sustainability. These Mineral Commission district centres can be found in Dunkwa-on-Offin, Tarkwa, Asankragwa, Assin Foso, Akim Oda and Bolgatanga in Ghana. Small-scale mining licenses may be given to Ghanaians who are 18 years and above under the following conditions; a maximum allocation of 1.2 hectares of land to any one person or group of persons not exceeding four, a maximum allocation of 2.0 hectares of land to a group of persons not exceeding nine, and a maximum allocation of 10 hectares of land to a co-operative society or registered companies of 10 or more persons (Mineral Commision [MC], 1989).

When a prospective small-scale miner notifies the District Mineral Commission Centre of his intention to mine gold in that district, the district officer or his representative evaluates the chosen site to determine suitability of the site. If the area is declared suitable, a site plan is prepared. The miner submits 10 copies of small-scale mining application forms together with the site plan of the prospective area to the Mineral Commission through its district offices. A notice of intention to allocate the site for small-scale mining is published by the District Assembly which has political jurisdiction over the area where the site is located. This publication takes a period of 21 days after which if no objections are raised over the land, the District Chief Executive gives a recommendation for the intended use of the land. When the required fees are paid, the completed forms accompanied by the permit from the Environmental Protection Agency (EPA) are sent to the Minister of Mines and Natural Resources for final approval. If the Minister after evaluating the forms and the accompanying permit approves the deal, he signs an agreement between the prospective small-scale miner and the Government of Ghana. The applicant can then send the signed agreement to the chief Inspector of Mines to obtain an operating license to work on the approved site. Usually, small-scale mining licenses are due for renewal between 3 to 5 years depending on the size of the concession (Aryee *et al.*, 2003). During the permitting process, the small-scale miner among other things, is expected to give a brief overview of the likely environmental impacts and describe the mitigation measures proposed to resolve the impacts (Hilson, 2001). However, the lack of specific environmental management system in this Environmental Impact Assessment process, the often inadequate financial and technical background of the small-scale miners and lack of supervision by EPA authorities invariably lead to poor rehabilitation of small-scale mined sites.

Ghana`s association with the extractive industry has been over 1000 years. To obtain the maximum benefits and promote sustainable development of the sector, various institutions have been established to monitor and ensure compliance of the mining laws and regulations. The key institutions for controlling mining activities include the Ministry of Mines and Natural Resources and Minerals Commission. They have direct supervisory and oversight responsibilities over the mining industry in Ghana to ensure the overall regulation and development of the minerals sector. The Ministry of Mines and Natural Resources is in charge of granting licences for mineral exploration and mining and the formulation and implementation of policies to guide the operations of mining. The functions of the Mineral Commission as stipulated in Article 269 of the 1992 Constitution enjoin the Commission to administer the Mining Acts and make mineral policy recommendations to help the industry players to abide by the mining laws and regulations, and advice the Minister of Mines and Natural Resources on the development of the extractive sector in Ghana (Mensah *et al.*, 2015). The Forestry Commission controls the regulations concerning the utilization of forest and wildlife resources in Ghana and how best to restore the habitat to its previous use. If a mining activity that has the potential to adversely affect the forest, the holder of the mineral right should obtain a permit from the Forestry Commission before embarking on any mining operation. When a potential miner is granted permission to mine in a forest reserve, he is required to submit report of his activities to a liason committee which has the supervisory role over mining in or near a forest reserve. The liason committee usually consists of members from the Ministry of Mines and Natural Resources, District Assembly hosting the mine, Environmental Protection Agency and the Forestry Commission (Mensah *et al.*, 2015). Other institutions that help to achieve the mandate of the Ministry of

Mines and Natural Resources are the Geological Survey Department which studies the mineral deposits in Ghana and the Mines Department which oversees the adherence of safety and health standards in the mining sector and the Lands Commission which provides legal advice to the Ministry of Mines and Natural Resources on lands during the licensing processes and also ensures sustainable and judicious use of land. The Environmental Protection Agency (EPA) is responsible for the enforcement of environmental regulations through the Environmental Assessment Regulations of 1999 (L. I. 1652). Concerning the mining industry, EPA helps with the processing of environmental permits and investigates claims that have the potential to affect the environment. Additionally, the EPA ensures that mineral right holders comply with the terms of the environmental permit and laws and also create awareness among the citizenry to appreciate the impacts of any activity on the health of the environment (Aryee *et al.*, 2003; Mensah *et al.*, 2015).

Environmental and socio-economic impacts of small-scale mining

The activities involved in the extraction and processing of gold-rich ores have severe impacts on the environment. The situation is further compounded by the inappropriate working practices employed by small-scale miners in the extraction of gold and the often poor or lack of rehabilitation of small-scaled mined sites. This mining induced environmental degradation have principally been found within the greenstone belts of Ghana which host the Birimian and Tarkwaian for hard rock mining and also along the paleo-placer terraces of major rivers such as Offin, Ankobra, Pra and Tano for alluvial gold deposits. These gold deposits are widespread and can be found in many towns and villages across many districts in Ghana (Lunt *et al.*, 1995). Some of the towns noted for extensive mining in Ghana include Dunkwa-on-Offin, Tarkwa, Prestea and Obuasi. Generally, Africa is known to harbour about 30% of mineral resources in the world (Edwards *et al.*, 2014) and though the extraction and sale of these resources have provided economic advancement to most of the countries that host the mineral resources, the accompanying environmental degradation has been severe (Canavesio, 2014). As reported by (Amponsah-Tawiah & Dartey-Baah, 2011), there were 17 large scale mining companies and 300 registered small-scale mining entities in the Ghanaian industry whose combined activities have compounded the impacts on the environment. Impacts of small-scale mining generally affect the lithosphere, hydrosphere and the atmosphere in general (Aryee *et al.*, 2003). Studies by various authors have all come to the conclusion that mining over the years has caused extensive damage to the environment (Armah & Gyeabour, 2013; Armah, Luginaah, Taabazuing, & Odoi, 2013; Macdonald *et al.*, 2014; Mensah *et al.*, 2015). Small-scale mining is associated with severe damage to the environment and can cause sheet, rill and gully erosion (Adeoye, 2016). However, most of the community members close to where small-scale mining is taken place are mostly not aware of the impacts or are not equipped to deal with the impact. Activities of small-scale miners such as the extraction and processing of ore deposits have been ranked as the second largest source of pollution in Africa (Kessey & Arko, 2013). Small-scale mining has been noted by many researchers as an agent that threatens sustainable development of most rural communities that hosts these mines but this has received little or no serious attention (Adeoye, 2016; Meaza *et al.*, 2017).

Mining of mineral resources in general and small-scale mining of gold in particular, have contributed immensely to the economic development of most sub-Saharan countries. To obtain the full benefits of mining and to ensure sustainable development of the sector, various governments of mineral-rich countries have put in place laws and systems that control the activities of the miners and also provide incentives to the industry players. The organization of the mining sector was achieved mainly through the proper award of contracts and license, collection of taxes and royalties and the proper management and allocation of royalties obtained from mining (Barma, Kai, Tuan, & Lorena, 2012). Thus the quality of how the mining sector is controlled by the government and how the revenues and royalties are distributed to affect the welfare of local communities will eventually determine the nature of impacts of mining on the livelihoods of the people (Chuhan-Pole, Daben, & Land, 2017).

The Ghana Mineral and Mining Law in 1986 (PNDCL 153) was formulated to open up the mining industry and create a favourable climate for the attraction of foreign capital and also provide avenue for Ghanaians to own mining concessions whiles obtaining good revenue from the extraction industry. The law among other things stipulates that the government of Ghana is entitled to 10% of the equity in all new mining companies and has the option to buy an additional 20%; corporate tax is fixed at 45% and additional profit tax is applicable if the rate of return exceeds agreed levels; an investment allowance of 5% is allowed during the first year of operation; capitalization of all pre-production expenses; favourable amortization levels of 75% in the first year and 50% afterwards; and the complete legalization of the mining of precious metals and gemstones by small-scale miners. With these improved laws and the deliberate promotion of the mining sector by the government, there was a massive foreign investments into the sector. About US$ 900million was invested in the Ghanaian mining industry between 1983 and 1993 (Hilson, 2002b) and annual gold production which was about 301,700 ounces in 1983 rose to 2357000 ounces in 1990. As reported by Hilson (2002b), about 30,000 small-scale miners operating in Ghana between 1989 and 1994 contributed gold worth US$ 68.56 million to the economy. The ever increasing contribution of gold revenue from small-scale mining and the increased generation of employment in most local communities prompted the government to help address the challenges faced by small-scale miners. The small-scale mining operators complained of lack of geological information to help prospective investors and the inadequate technical and financial support needed for effective extraction of mineral resources. They are also concerned with social conflicts arising from mining, the degradation and pollution of mined environments and the inadequate distribution of earnings of mining among all stakeholders. Small-scale mining historically has not enjoyed enough support though its contribution to revenue mobilization and the improvement of economic development in most developing countries has been increasing over the years (Hentschel, Hruschka, & Priester, 2002). In response to the complaints by the small-scale miners, the government of Ghana has rolled out various interventions to help the miners to operate efficiently (Mineral Commission [MC], 2013) and coupled with the increase in the prices of gold globally, gold production from this sector has improved. The assistance provided by the government of Ghana to the small-scale mining industry include; improvement to the access of finance by the miners through formation of co-operative savings and also pool equipments for leasing purposes; concessional landing schemes have been provided to help small-scale miners with funding from local and international sources; and the set up of institutions to obtain fair prices for the miners and provide current market information, and appropriate technical support In addition, the Mineral Commission has developed easy and standard procedures for the acquisition of land and permits for small-scale mining and also provides extension services to the miners.

The United Nations Educational and Scientific Organization [UNESCO] (2012) estimated that out of the 52,000 Ghanaians working in the mining industry, about 96% are employed by the small-scale mining sector. The contribution of small-scale gold mining to the total gold production in Ghana has been rising over the years. From a contribution of 3.2% to the total gold production in 1990, it rose to 7.2% in 2002 and came to 34.31% in 2014 (Mineral Commission [MC], 2016). The small-scale mining sector contributed 1.49 million ounces of gold to the total gold production in 2014 forming about 34.3% of all the gold produced in Ghana.

Table 1: *Comparative gold production of large and small-scale mines from 1990 to 2014*

Year	Large scale producer (oz)	Small-scale producer (oz)	Total Ghana production (oz)	Small-scale/ Total production (%)
1990	517,818	17,234	535,052	3.2
1991	825,114	15,601	840,715	1.9
1992	976,223	17,297	993,520	1.7
1993	1,222,344	35,145	1,257,489	2.8
1994	1,338,491	89,520	1,428,011	6.3
1995	1,581,506	127,025	1,708,531	7.4
1996	1,474,746	112,349	1,578,095	7.1
1997	1,677,911	107,097	1,785,008	6.0

1998	2,244,819	128,334	2,373,153	5.4
1999	2,358,423	130,833	2,489,256	5.3
2000	2,168,802	145,662	2,314,464	6.3
2001	2,184,313	185,596	2,369,909	7.8
2002	2,075,954	160,879	2,236,833	7.2
2003	2,085,070	221,063	2,306,133	9.6
2004	1,783,400	246,570	2,029,970	12.1
2005	1,913,534	225,411	2,138,945	10.5
2006	2,095,553	247,063	2,342,616	10.5
2007	2,239,678	388,594	2,628,272	14.8
2008	2,378,012	416,943	2,796,955	15.0
2009	2,564,095	555,737	3,119,832	17.8
2010	2,624,391	767,196	3,391,587	22.6
2011	2,697,612	978,611	3,676,223	27.0
2012	2,848,409	1,464,871	4,313,190	33.96
2013	2,808,405	1,441,497	4,249,902	33.92
2014	2,851,885	1,498,722	4,341,607	34.31

Source: (Mineral Commission [MC], 2016)

The mining industry in most sub-Saharan countries is a source of foreign direct investment. In 2005, the mining sector in Ghana contributed US $ 26.76 million as royalties to the government. The payment of royalties continues to be a major source of revenue to the government as this increased from $ 38.46 million in 2006 to $ 53.80 million in 2007 (International Council on Mining & Metals [ICMM] and Commonwealth Secretariat [CS], 2009). In areas with relatively high level of mining activities, poverty tends to decline faster as compared with areas not endowed with mining. As Reported by McQuilken (2016), general poverty fell faster in two mining districts, Wassa West and Adansi West as compared to the national average in Ghana. The extraction of mineral resources can raise incomes and also improve non-mine employment opportunities, reduce poverty and generally lead to the improvement of the welfare of members of the local community (Chuhan-Pole *et al.*, 2017). On examination of exports from most African countries between 2001 and 2017, it was observed that the share of natural resources in the exports has increased mainly due to the higher contribution from the extractive sector (Chuhan-Pole *et al.*, 2017). Small-scale has been associated with the growth and development of most mineral-rich countries in the developing world (Oppong & Gold, 2016) as it often employs most poor members of the local communities (Seccatore, Veiga, Origliasso, Marin, & De Tomi, 2014). With the ever increasing dwindling of agricultural lands in most third world countries, small-scale mining has become the most attractive alternative for most rural people (Hilson, 2016) and notwithstanding the adverse environmental and livelihood issues associated with small-scale mining, the sector continues to thrive in most African countries like Ghana and South Africa because of the overall economic benefits and as a major source of employment (Meaza *et al.*, 2017). Small-scale gold mining as a poverty driven activity has provided the economic leverage to make people get rich-quick (Seccatore *et al.*, 2014) and provides alternative source of livelihood for most local people. Over the years, small-scale mining activities have gone up primarily due to soaring gold prices, land shortage, population growth and poverty (Soulard, Acevedo, Stehman, & Parker, 2015). In the district and local communities that host the mining industry in Ghana, employment in agriculture tend to decline over the years though there is often increase in employment in the service and mining sectors (Chuhan-Pole *et al.*, 2017). In a study on the activities of large scale mining in some countries in Africa, Kotsadam & Tolonen (2015) observed that mining resulted in the decline of agricultural labour but with a corresponding rise in labour in the service industry.

The adverse impacts of small-scale mining activities on the environment include water and soil pollution, loss of farm lands and vegetation and the problems associated with management of mine waste (Taiwo & Awomeso, 2017). Communities that host mining industries perceive the sector to have negative impacts on the environment and health of the local inhabitants for which they do not get adequate and appropriate compensation. These events eventually result in loss of their sources of livelihoods (Chuhan-Pole *et al.*, 2017). Though sustainable growth in Africa is expected to be led by contributions from the extractive sector, the relatively slow pace of poverty reduction in most third world countries has been attributed to the natural resources-led growth (Chulan-Pole *et al.*, 2017). About 7 percent of the total Gross Domestic Product in Mali was obtained from contributions from mining activities in the year 2013 however, the sector employed only 1% of the population

(Sanoh & Coulibaly, 2015). Mining districts tend to have lower poverty rates but the benefits obtained from mining decline with distance from the mine (Aragón & Rud, 2013). Again, the welfare of the inhabitants of the mining communities will depend on how the government shares the revenues from the mining sector. In Ghana, 10% of the royalties obtained from mining is given to the mining districts (Chuhan-Pole *et al.*, 2017). The adverse effects of gold mining can be found within 10-15km of the catchment area of a mine in Africa (Kotsadam & Tolonen, 2015) and as far as 100km away from the mine site (Aragón & Rud, 2013). This contributes to the increased poor health conditions of most people who engage in small-scale mining for sustainability. Release of mercury and cyanide in most small-scale mined sites pose environmental and social problems (Nakazawa, Nagafuchi, Kawakami, & Inoue, 2015). A study by Chuhan-Pole *et al.* (2017) showed that the number of local community members engaged in agriculture dropped between 10-20% when a gold mining industry was put up in the vicinity of the local inhabitants whiles a Ghana Living Standard Survey on employment in the mining sector indicated that there is a higher probability that a man living close to a mine works in that mine.

Gold mining generally has both good and adverse effects on the environment and livelihoods of most local communities that host the mines, on the youth who do not have access to land resources and migrants to the gold mining communities (Meaza *et al.*, 2017). Although small-scale gold mining has been identified as a agent that has the potential to threaten sustainable development in most mined areas, activities of small-scale mining have not received the needed attention from governments and their agencies (Adeoye, 2016; Meaza *et al.*, 2017). When gold mining activities are not planned to ensure sustainable use of resources and maintenance of the environment, then marginalization of the livelihoods of the local farmers become eminent (Hilson, 2016).

Impacts of mining on land, soil and vegetation

Small-scale mining activities in the localities of host communities have caused severe destruction of farmlands, soil and pollution of water bodies (Eludoyin, Ojo,

Ojo, & Awotoye, 2017; Nukpezah, Abdul Rahman, & Koranteng, 2017). Surface mining directly causes deforestation, pollution and land degradation and indirectly poses social and environmental costs to the communities (Schueler, Kuemmerle, & Schröder, 2011). The degradation of the immediate environment of small-scale mining intensive areas leads to decrease in economic activities such as farming. There is often competition for land-use between miners and agriculturalist resulting in low production of food materials (Mensah *et al.*, 2015; Yelpaala & Ali, 2005). The land-use change from the activities of small-scale mining results in conflicts between argarians and small-scale miners leading to the marginalization of the livelihoods of most local community farmers (Hilson, 2016; Kumah, 2006). Small-scale mining which is very common in poor rural areas of hosts communities, is often associated with land cover and land-use change (Schueler *et al.*, 2011) resulting in once forest and shrub areas being converted to grazing areas (Schueler *et al.*, 2011). The impacts from mining operations adversely affect the equilibrium of the ecosystem through the destruction of the habitat. This puts the species under the risk of interruption of gene flow, extinction and possibly death.

The damage to landscape by small-scale mining operations has severe consequences due to the share numbers and mostly unprofessional ways adopted by the miners for the extraction and processing of gold ores. Small-scale mining in most of the third world countries is being undertaken by miners with little or no scientific knowledge in mining. For example, prospecting is largely based on the opinions of miners and the local community members. Thus, small-scale mining tends to be transient often resulting in large tracts of land with uncovered pits (Hilson, 2002a; Mensah *et al.*, 2015). As reported by Maponga & Anderson (1995), about 100,000 ha of land is cleared annually for small- scale mining operations in Zimbabwe. The high concentration of people in communities that host small-scale mining activities invariably lead to increased demand for forest resources such as fuel wood with it attendant deforestation (Hilson, 2002a; Mensah *et al.*, 2015). The large portion of land and vegetation cleared to allow for small-scale mining activities causes the creation of pits and valleys and the undulating nature of the landscape. The haphazard construction of pits for the underground operations by small-scale miners also causes substantial damage to the landscape of mined sites. The construction of trenches, clearing of vegetation for creation of access roads and the establishment of small villages and resting places lead to deforestation and also affect the local hydrological patterns in mined areas (Mensah *et al.*, 2015). Small-scale miners often do not refill pits and trenches after mining and the widespread scattering of the mine overburdens make the land not generally suitable for other uses (Mensah, 2015). In the assessment of land cover change due to surface mining in the Western Region of Ghana, the researchers observed that surface mining accounted for 58% of deforestation and there was a loss of 45% of farmland within the approved mining concession areas (Schueler *et al.*, 2011). Additionally, most of the farmers who were relocated because of mining activities went into the forest to obtain new farmlands. The study which was conducted from 1986 to 2002 in the concession areas of Darmang, Tawkwa and Bogoso-Prestea communities, showed there was widespread land cover change in the concession. The total land area used for surface mining in 1986, which was only 2% of the concession, had risen to 41.9% of the concession area in 2002 (Schueler *et al.*, 2011). Within this period, the Begoso-Prestea mining operations occurred on 7.6% (449 ha) of the concession area whiles mining in the concession in Tarkwa increased from 2% (25.5 ha) to 23% (2,667 ha). In Darmang, mining accounted for the largest land cover change as 54% (1,099 ha) of the concession area which was mainly farmlands had been converted to mining site (Schueler *et al.*, 2011). Generally, the study revealed that farmland loss accounted for largest land cover change. About 45% (4,935.3 ha) of farmland in all the three concession areas have been converted to miming pits between 1986 and 2002 (Schueler *et al.*, 2011). Surface mining is a major driver for forest loss as deforestation due to mining led to a loss of 3167.6 ha of land cover in the study area. The Land-use systems in most communities in Ghana face a lot of difficulties especially when small-scale mining activities are involved. Gold mining in the local communities often lead to conflicts about the use of land. To help resolve this threatening impasse between miners and the local inhabitants, the Ghanaian government and other stakeholders in the mining industry provide resettlement package and alternative livelihood programmes for the affected community members (Banchirigah & Hilson, 2010). However, these well intended programmes are often not properly and effectively implemented in some communities as the packages are not extended to members affected by small-scale mining. Due to their share numbers and closeness of their mine sites, and the surface mining methods employed, activities used in small-scale mining result in large use of land with associated degradation.

The customary land tenure in Ghana has impact on small-scale mining. This land tenure system gives the chiefs and family heads power to grant land concessions. In this system, chiefs have the jurisdiction to speak and negotiate on behalf of the local communities in any decisions concerning the release of land for purposes such as small-scale mining. These developments in the land tenure system often lead to community upheaval in mining communities. Apart from the government providing land to the small-scale miners for the purposes of mining, they can also obtain land from chiefs and family heads and later regularize it through the Mineral Commission (MinCom, 2015). The adverse effects of mining are mostly not understood by local landowners during negotiations for compensation. This apparently lack of knowledge on mining usually leads to unsatisfactory compensation paid to landowners (Armah & Gyeabour, 2013; Schueler *et al.*, 2011). To ensure sustainable development, the use of any land in Ghana must be taken through the national land use planning guidelines (Lands Commission [LC], 2014). The guidelines stipulate that lands that are outside forest reserves and wildlife estates can be used for agriculture, human settlement, lumbering and mining; no lumbering can be done on hills and mountain slopes of at least 30^0 gradient but agriculture, human settlement and mining can be carried out on hills provided the appropriate technology is used to mitigate any environmental and ecological consequences; lands with primary forest cover should not be cleared for mining or crop plantation and no planted tree plantation shall be cleared for mining activities (MinCom, 2015).

Small-scale mining activities are often not regulated or partially regulated in many developing countries that host the mines (Mason, 2014). This results in major soil degradation and loss of important soil nutrients that are essential for the proper growth and development of plants (Eludoyin *et al.*, 2017). A study conducted on mined soils showed that there was a greater percentage of sandy soil at mined sites as compared to soils of farmlands and undisturbed areas (Eludoyin *et al.*, 2017). The removal and sieving of soil and the separation of soil during exploitation of soil for gold resources reduce the compaction of the soil and often lead to the destruction of the molecular bonds of silicate minerals in the soil (Edwards et al., 2014). The processes used in small-scale mining promote the removal of top soil of about 20cm deep. This removal of plant available nutrients causes low fertility and productivity of mined soils (Mensah, 2015). As part of the activities to help the rehabilitation of small-scaled mined sites, small-scale miners in Ghana are encouraged to stock pile the top soil in mounds to be used later as surface lining of the land. However, soils that are stock-pilled are often poor in quality and also lose useful micro-organisms and plant propagules (Eludoyin *et al.*, 2017; Mensah, 2015). Gold mining removes large volumes of soil from the mining area and soils of mined sites have relatively higher concentrations of heavy metals as compared to soils of undisturbed sites and farmlands (Eludoyin *et al.*, 2017; Meaza *et al.*, 2017). The activities employed by small-scale miners in the extraction and processing of gold from ores include blasting, digging of pits and the excavation of gold-rich ore deposits. These activities often lead to disruption of soil aggregates, loss of soil organisms and organic matter creating an imbalance in the soil properties and adversely affecting the growth and development of vegetation (Mensah, 2015). Mine substrates usually lack macro-nutrients such as nitrogen, phosphorus and potassium and as reported by Sheoran, Sheoran, & Poonia (2010), plant available nitrogen and phosphorus tend be low in mined soils leading to poor growth and development of trees. Stripping and stock-pilling of soil by miners result in large nitrogen transformation and movements leading to loss of soil fertility and the soil substrates left by miners often tend to be acidic. The weathering of iron pyrites in stock-pilling of mine waste often generates the production of sulphuric acid with low pH levels (Mensah, 2015; Sheoran *et al.*, 2010). The soils of disturbed areas exposed to removal of vegetation and loss of litter layer usually have relatively lower amounts of soil nitrogen and phosphorus as compared to soils of the forest. Work done on soil organic content of mined soils in Prestea, a mining town in Ghana, showed that the organic content was 0.14%. This value is lower than the standard level of soil organic content in soil fertility studies. Soil organic matter content is projected to be high if the value is above 8%, medium if the values fall within 4% to 8% and low if the value falls below 4% (Hazelton & Murphy, 2007; Hazelton & Murphy, 2016). The processes used by small-scale miners are usually associated with loss of important soil nutrients. Eludoyin *et al.* (2017) reported a significant loss of soil elements such as total Nitrogen, available Phosphorus and Organic Carbon in soils of mined sites. This loss of critical soil nutrients poses a threat to food security and sustainability, and the livelihoods of people living in especially local mining communities. The loss of arable lands in mostly mined communities adversely affects the job opportunities of most of the inhabitants as they engage in farming for living (Eludoyin *et al.*, 2017). In a study on the impacts of artisanal gold mining on soil, it was observed that small-scale mining pits were dug to appreciable depths with an average of 3.980m. These activities contributed to severe soil loss especially in the rainy season (Meaza *et al.*, 2017). The methods adopted for separating gold from silt, sand and gravel of alluvial deposits often result in stock-pilling of soil with small particle sizes along rivers and streams. Thus the soils become relatively sandy after the mining processes (Meaza *et al.*, 2017). The significant difference in the soil loss between the mined and un-mined areas observed in the research by Meaza *et al*. (2017) was attributed to the differences in the dimensions of the gold pits, the depths of tree rooting systems and the nature of the vegetation cover of the study sites. Even where the pits were exempted, soil loss was higher in the mined areas as compared to the un-mined areas. The hydro-geomorphic processes that occurred in alluvial gold mining sites led to the conversion of the gold deposits pits into a source of sheet, later rill and eventually to gully erosion. Most of the gullies were found at the bottom of the mined sites developing towards the farmlands (Meaza *et al.*, 2017).

The operations of small-scale gold mining continue to have adverse effect on the already poor status of vegetation resources in most developing countries as the activities used for the extraction and processing of mineral ores during gold production lead to the suppression of growth of vegetation or prevention of its regeneration (Alvarez-Berrios & Aide, 2015). This wanton and uncontrolled destruction of vegetation by the activities of small-scale mining operators lead to loss of biodiversity and genetic resources. Small-scale mining disrupts the spatial arrangement of vegetation through loss of cover. This is usually associated with loss of species richness of keystone tree species and shrubs species, alteration of microbial community leading to low fertility and productivity (Sheoran *et al.*, 2010). Between 1990 and 2005, studies conducted on the effect of mining on vegetation resources in Ghana showed massive loss of forest cover of about 26% in mining towns including Dunkwa, Tarkwa, Ayanfuri and Bogoso. Surface mining accounted for about 58% loss of vegetation in some mining towns in the Western Region of Ghana (Aryee *et al.*, 2003; Schueler *et al.*, 2011). In the work done by Mensah *et al.* (2015) in Prestea, they found out that large areas of the concessions have lost their vegetation cover due to mining activities. This led to severe gully erosion, reduction in soil infiltration and ground water discharge (Mensah *et al.*, 2015). The mined areas of the study sites were relatively more susceptible to erosion due to the presence of fine and dispersed soil particles, slopes and gullies and the lack of vegetation. Small-scale mining operations adversely affect soil and vegetation resources resulting in massive erosion and deforestation (Meaza *et al.*, 2017). From the study of the impacts of artisanal gold mining on soil and woody vegetation, gold mining operations destroyed large areas of vegetation resulting in the variation in the number of tree species between the mined and un-mined sites. Woody species were relatively more in the un-mined sites as compared with the mined areas (Meaza *et al.*, 2017). Other results from the study also revealed that dead trees and exposed tree roots were encountered more in the mined sites as compared to that of the un-mined sites. This negatively affected regeneration and recruitment of woody species in the mined areas. Seedlings and saplings of woody species thrived well in the un-mined areas than the mined areas (Meaza *et al.*, 2017). Soil and rock pitting for gold has been identified as a major contributor to loss of soil fertility whiles deforestation adversely affect regeneration and recruitment of woody species due to the removal of soil that serves as source for dormant seeds (Chalise, Kumar, & Kristiansen, 2019; Doroski *et al.*, 2018). The increasing numbers of small-scale operators in the local communities of developing countries pose a serious threat to land degradation, soil erosion and deforestation. Small-scale mining operations modified the composition and structure of vegetation leading to loss of abundance, richness and diversity of species (Meaza *et al.*, 2017). Moreover, many of the small-scale mined sites are abandoned and become unproductive to support the livelihoods of most of the inhabitants who are farmers. This is a challenge to attaining sustainable development in most rural communities who host the small-scale mines (Hilson, 2016; Schueler *et al.*, 2011).

The decision by the government of Ghana to allow mining companies to prospect for gold in the forest reserves of Ghana, has over the years created tension among the local community members, the mining operators and the Mineral Commission. The permit to prospect for gold in the forest is granted to miners only after Scoping and Environmental Impact Assessment reports on the site has been submitted to the government for critical evaluation. The reports on the prospective forest site are thoroughly assessed before accepting or rejecting mining companies from entering the forest reserves. However, local community inhabitants who argue that the idea of even allowing gold prospecting in the forest reserves if approved, will lead to the destruction of the livelihoods of the local people since most of them engage in subsistence farming for survival (Hilson & Nyame, 2006). The government of Ghana has over the years granted limited access to mining companies to do prospecting for gold in some forest reserves. These events have occurred under strict conditions and control by the Ministry of Mines and Natural Resources and the Mineral Commission of Ghana. Though the forestry sector worldwide employs about 10 million people and is the main source of livelihood for about 2 billion people, forest degradation and deforestation continue to be a major problem in most developing countries (Duguna *et al.*, 2019). Presently in Ghana, the forestry sector provides direct employment to about 100,000 Ghanaians and indirectly to over 2.5 million people (Ghana Statistical Service [GSS], 2014), however, the sector contributes only about 2-3% of the total Gross Domestic Product, down from 10% a decade ago (Ministry of Lands and Natural Resources [MLNR], 2016) . The world`s forest area has declined from 4.1 billion ha to about 4 billion ha, which is a decrease of 3.1% in the last few years. The current deforestation rate in Ghana is about 2.5% of the total land area leading to annual loss of about135, 000 ha of forest. These events have contributed to the continual decline of Ghana`s forest from 8.2 million ha to about 1.6 million ha (FAO, 2010).

Impacts of mining on heavy metals

Heavy metals occur naturally and can be found in waste deposits, fertilizer, pesticides, nuclear waste, atmosphere, water etc. (Eludoyin *et al.*, 2017). Some heavy metals which occur in their right concentrations and quantities are useful for the normal physiological functioning of humans. However, pollution from heavy metals poses a threat to life in the environment due to the toxic effects and non-degradable nature of heavy metal ions in the environment (Ayangbenro & Babalola, 2017). Heavy metals that are important in the environment include Cadmium (Cd), Lead (Pb), Arsenic (As) and Mercury (Hg) (Eludoyin *et al.*, 2017). Cadmium occurs naturally in ores together with zinc, lead and copper. Cadmium can cause damages and cancer of the kidney, acute pulmonary effects and can adversely affect the liver and gastrointestinal tract. Arsenic can be obtained from mining and industrial sources, herbicides and wood preservative. Arsenic pollution causes damage to the skin, eyes and liver, and can also affect the kidney and central nervous system. Lead contamination from sources such as mining and automobile exhaust fumes can cause damage to the kidney and affect the central nervous system. Mercury which occurs as a liquid metal at standard temperature and pressure can be obtained from industrial sources, mining, burning of coal and leaching of soil due to acid rain. Exposure to mercury can cause damage to the lungs and kidneys and adversely affect the nervous system (Eludoyin *et al.*, 2017). Major activities such as mining, mineral processing and metallurgical extraction of mineral from ore deposit, used in the gold mining industry produce waste (Fashola, Ngole-Jeme, & Babalola, 2016). During processing of the ores, the minerals are physically separated and concentrated and in the metallurgical extraction, crystallographic bonds in the ore mineral are broken down so as to retrieve the needed element or compound. These processes lead to the production of large quantities of waste in the gold mining industry (Fashola *et al.*, 2016).

Most heavy metals are toxic and can contaminate different sources even at low concentrations. Heavy metals that occur naturally are mostly in the insoluble forms or in complex forms not easily available to roots of plants. This is mainly due to the high bonding energy between naturally occurring heavy metals and the soil as well as the high absorption capacity of naturally occurring heavy metals (Ayangbenro & Babalola, 2017). However, heavy metals from anthropogenic sources tend to have high bioavailability because they occur in soluble and mobile reactive forms (Dixit *et al.*, 2015). The presence of heavy metals in soil can inhibit the processes for biodegradation of organic compounds thus affecting the availability of these compounds to plants (Eludoyin *et al.*, 2017) and also influence soil matrices and eventually how metal transport proceeds in the soil (Magdi, 2013; Violante, Cozzolino, Perelomov, & Caporale, 2010). High levels of heavy metal can contaminate agricultural soils and eventually the products whiles low concentration of heavy metals can interact with the soil to cause nutrient deficiency in the soil (Eludoyin *et al.*, 2017). The contamination of soils with heavy metals such as copper, lead, mercury, zinc and chromium can occur through irrigation. Soils may also be contaminated by Arsenic and Chromium from the parent materials (Wuana & Okieimen, 2011). The occurrence, distribution and bioavailability of heavy metals in the soil are influenced by several factors. The distribution of heavy metals in the soil can be affected by activities such as erosion, bush burning and oil spillage (Eludoyin *et al.*, 2017; Onojake & Frank, 2012). Soil factors including cation exchange capacity, organic matter content, pH, texture and the level of interactions that exist among the various targets elements in the soil have influence on the occurrence and bioavailability of heavy metals in the soil (Jung, 2008; Violante *et al.*, 2010). Some heavy metals function as co-factors for enzymes and micronutrients and in some cases cause stabilization of molecules. These functions undertaking by heavy metals play critical roles in the physiological, metabolic and biochemical processes of organisms (Fashola *et al.*, 2016). The solubility and availability of heavy metals to plants can be influenced by small changes in the pH levels of the soil. In mining areas, the soils in which heavy metals are found tend to be acidic and nutrient-deficient. This eventually increases the toxicity of such soils (Ayangbenro & Babalola, 2017; Mukhopadhyay & Maiti, 2010; Olaniran, Balgobind, & Pillay, 2013). In acidic soil medium, the heavy metal forms a free ionic species with more protons available to cause saturation of the metal bonding sites. The absorbent surface of the heavy metal then becomes very positively charged causing a reduction in the attraction between absorbent and metal ions. Thus, heavy metals become readily available to cause higher toxicity to plants and microorganisms (Ayangbenro & Babalola, 2017). When the heavy metal is found in a basic soil medium, the metal ions replace protons to form species including hydroxo-metal complexes etc. The solubility of these complexes is influenced by the heavy metals forming the complexes. Some of the soluble complexes are formed from metals such as Cd, Ni and Zn whiles complexes formed from Cr and Fe are insoluble (Ayangbenro & Babalola, 2017; Olaniran *et al.*, 2013). The organic matter content of soil has strong influence on the ability of the soil to retain heavy metals and on the Cation Exchange Capacity of the soil. In organic soils which are contaminated with heavy metals, the plants and microorganisms do not readily get the heavy metals as compared with soils of low organic matter which tend to be contaminated by heavy metals (Ayangbenro & Babalola, 2017; Olaniran *et al.*, 2013).

Heavy metal contaminated soils from eight different land-use forms were assessed in the Patuakhali district of Bangladesh and the result revealed that soils with relatively high levels of heavy metals had high ecological risk (Saiful, Kawser, Habibullah, & Asraful, 2017). Again, on the examination of soil and water samples obtained from the vicinity of abandoned Pb-Zn mines in Yelu in Nigeria, it was ascertained that the levels of Cu, Pb, and Zn in the soil were high and above the background levels and exceeded the permissible limits adopted by the Netherlands. However, the levels of Cd and Fe in the soil were found to be low (Sanusi, Hassan, Abass, & Kura, 2017). The study also showed that the concentrations of Pb, Zn, and Cu in the water samples exceeded the World Health Organization standards but the levels of Cd and Fe were lower than the background levels.

Mercury is mostly used in the small-scale mining industry to extract gold from the ore by forming an amalgam. The amalgam is then heated and the mercury evaporates from the mixture separating the gold. Mercury is often employed in the small-scale mining sector in obtaining gold from the ore deposit because it is cheap, quick and can be used by one or few people (UNEP, 2013). The use of mercury for industrial activities has been going down in recent years principally due to the deleterious side effects of mercury. However, it is forecasted that the demand for mercury use is expected to go up in most developing countries. These countries have significant gold-belts and the small-scale mining industry is poverty-driven (UNEP, 2013).

The use of amalgamation in the small-scale mining sector has been documented severally by many authors (Armah, Luginaah, Yengoh, Taabazuing, & Yawson, 2014). It is reported that about 77.91t of mercury has been released into the atmosphere out of which small-scale mining caused the release of about 3-41t of mercury (Van Straaten, 2000). Studies from Suriname, Phillipines, Bolivia, China and Ghana have all indicated that mercury exposure from small-scale gold mining activities have caused severe environmental and health problems (Armah *et al.*, 2014). Mercury changes from the inorganic state to the methylated state (MeHg) when it is exposed into the natural environment. If mercury is ingested in the methylated state, it primarily affects the nervous system but acute exposure can cause organisms to be anorexic and lethargic. These may be followed by motor control deficits, visual impairment and convulsion and finally death of the organism (Mensah *et al*., 2016). The use of mercury in small-scale mining in Ghana has been a concern to many stakeholders prompting the government to control the trading of mercury especially to miners. Through the activities of small-scale miners, about 4 to 5t of mercury are released into the environment since almost all small-scale miners burn the gold-amalgam over fire to separate the gold (Armah & Gyeabour, 2013). On examination of hair, blood and urine samples of residents in a small-scale mining community, it was discovered that some of the residents had slight neurological disorders and others also complained of muscle weakness (Kwaansa-Ansah, Armah, & Opoku, 2019). A study conducted by Von der Goltz & Barnwal (2014) in 44 developing countries showed that the activities employed by about 800 mines in obtaining gold from the ore deposits, led to heavy metal contamination. This resulted in higher incidence of stunted growth among children and the increase in anemia among women who lived in the miming communities. Environmental pollution arising from gold mining can directly and adversely affect the growth and development of plants and also degrade the quality of soil and water in a mined site. These activities may result in loss of agricultural productivity (Aragón & Rud, 2013). The expansion of small-scale mining activities is usually associated with increase in contamination by mercury. Studies conducted in many countries endowed with small-scale mining shows that the use of mercury tends to exceed the World Health Organization recommended limit for public exposure which is I millionth of a gram per square meter (Chuhan-Pole *et al*., 2017). On assessing releases of mercury from small-scale gold mining areas in Ghana, the researcher indicated that there was widespread pollution which in most cases the values obtained were several orders higher than the standard levels (Clifford, 2017). As reported by Kwaansa-Ansah *et al.* (2010), small-scale miners in Ghana are relatively more exposed to mercury than the local community members who reside in and around the mines. The examination of breast milk intake of 46 babies whose mother were residents of small-scale mining communities showed that, 22 of the 46 children had a higher total mercury intake (Chuhan-Pole *et al*., 2017). Artisanal and small-scale mining activities are the largest source of global air emissions of mercury (UNEP, 2013) which tend to contaminate various surfaces in the mining communities. Fish obtained from surrounding and downstream mining communities were contaminated with methyl mercury (Gibb & O`Leary, 2014). In water, methyl mercury can be ingested by zooplankton and fish, and can also be absorbed by phytoplankton; and the methyl mercury can eventually enter the food chain (Gibb & O`Leary, 2014).

Cyanide is still used in the gold mining industry (Jaszczak, Polkowska, Narkowicz, & Namieśnik, 2017) because it has a good recovery rate and a lower price and it is increasingly being used in the small-scale mining sector mostly after mercury use. The mercury-cyanide compounds from these sources tend to be dispersed in water and promote the mobility and/or bio-availability of mercury (Esdaile & Chalker, 2018; Guimaraes *et al.*, 2011). The use of cyanide in Ghana is mostly found in the large scale mining industry. The effective regulations put in place by the Mineral Commission and the stringent protocols followed by the mining companies in the use of cyanide have resulted in a situation where high concentrations of cyanide are infrequent in Ghana (Chuhan-Pole *et al.*, 2017)

Rehabilitation/reclamation of small-scale mined sites

Mining activities often produce adverse effects on the environment. For sustainability of the livelihoods of mining communities, the government of Ghana through law and regulation has set up many rules and activities to help rehabilitate mined environments. The Minerals and Mining Act of 2006 (Act 703) which was amended by the Minerals and Mining (Amendment) Act (900) in 2015, has a section on rehabilitation of mined sites. Among other things, the concession holder in the case of small-scale mining, is to provide a reclamation plan which specifies how the top soil will be preserved and slopes will be stabilized and restored (Tettey, 2010). According to Macdonald *et al.* (2015), there is the need to have post-mining land use objective in the development of any rehabilitation programme. The rehabilitated mined land should meet the expectations of the local community in terms of using the land for other purposes. The National Academy of Sciences in America has defined rehabilitation of land as "returning land to a form and productivity in conformity with a prior land use plan with a stable ecological state that does contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values". Mined site rehabilitation should ensure the long-term stability and sustainability of the landforms, soils and hydrology of the site and also prevent the pollution of surrounding environment. It should lead to the repair of the ecosystem to allow for habitats that can host biota and also provide other services (Grant, Loch, McCaffrey, Antsee, & Doley, 2016). From the mining industry perspective, an effective rehabilitation of a mined area is ensuring that a land previously impacted by mining is brought back to a state that allows for sustainable usable condition to prevail.

. In line with this, many activities of the different sections of mining have been revisited to examine the procedures and also look at various threats posed to the environment (Carvalho, 2017). The events from mining can destroy cultural and spiritual places of the community and in some cases the impacts are so severe that farming activities cannot be sustained on previously mined land. In Ghana, rehabilitation is an integral part of a mining company`s sustainability through the enforcement of the laws and regulation. However, not the same attention is given to rehabilitation of small-scale mined sites. These mined sites are poorly rehabilitated or in some cases not rehabilitated leading to many legacy problems for the communities. A study conducted on the reclamation of artisanal and small-scale mined areas in Ghana showed a lot of the sites were not reclaimed (Bansah *et al.*, 2016) and reclamation of artisanal and small-scale mined sites have not received much attention from the regulatory institutions. This lack of supervision from the regulatory institutions has been attributed to lack of logistics and personnel to manage the processes (Bansah *et al.*, 2016) If a small-scale mined site is rehabilitated, it results in a post-mining land-use that ensures the sustainability of livelihoods of the community. Presently, re-vegetation is a major component of rehabilitation of small-scaled mined sites in Ghana. As reported by Tetteh (2010a), re-vegetation is effective when native multiple species such as ground covers and trees are employed since these species accommodate higher biodiversity and are better adapted to that habitat. The Ghana Environmental Agency tasked with the duty to ensure a sustainable mined environment has opted for the use of native plant species instead of exotic species and there is the need to identify native species that can effectively promote re-vegetation of mined sites (Tetteh, Ampofo, & Logah, 2015). The sites to be rehabilitated should be upgraded to have good nitrogen status to facilitate plant growth. It has been recommended that there should be chemical analysis of the soils of mined areas to help achieve an effective rehabilitation (Bansah *et al.*, 2016). Soil properties including phosphorous, potassium and nitrogen should be in suitable levels to ensure an effective regeneration of plant species in a rehabilitated site. If need be, there should be targeted interventions to improve the quality of the soil (Tetteh, 2010b).

The processes employed in rehabilitation of mined areas include natural recovery, assisted recovery or through a combination of both processes. The use of any one of these processes in rehabilitation mined sites can take many years to complete. This waiting period affects the economic activities of most of the community members who are mostly farmers. The re-entry of the mined land is critical for sustaining the livelihoods of the community members thus there is the need for targeted assistance in the rehabilitation of mined sites (Tetteh *et al.*, 2015). Again, it has been recommended that both natural and artificial re-vegetation recovery methods are needed in proper rehabilitation of mined sites (Tetteh, 2010b). Due to the overall effect of mined lands on the livelihoods of most mining communities, mined land rehabilitation has been included in the sustainable development strategy in most mineral-rich countries (Tetteh *et al.*, 2015).

Small-scale mining is fast replacing small-holder farming as the main source of income for the local inhabitants in mostly gold mining localities in Ghana. The support provided by the government of Ghana and its agencies to encourage small-holder farmers to produce more to sustain their livelihoods, continue to dwindle over the years. Research done by some authors on the co-existence of farming and the small-scale mining sector indicate that, contrary to the other views especially held by policy makers and those in academia, the small-scale mining sector and farming are complementary (Hilson & Garforth, 2013). Ghana basically has a lot of citizens who fall below the poverty line and they need help to produce enough income to have meaningful livelihoods. Since small-scale mining is principally a poverty-driven activity and is currently competing with small-holder famers for land-use. It is therefore essential to help small-scale-scale miners to obtain the most benefits from mining and also provide assistance for effective rehabilitation of small-scaled mined sites for other uses.

CHAPTER THREE

METHODOLOGY

Introduction

This chapter describes how the research was designed and conducted. The study area and the population of interest were then presented. This chapter also presents the sampling procedures and techniques employed, the data collection instruments, as well as how the data were collected, analyzed and presented.

Research design

The mixed-method approach was considered most appropriate method for the study. Quantitative research design was used because each of the objectives of the study involves measurement and counting, as well as an attempt to categorize and summarize using numbers. The statistically sound hypotheses formulated allow for probabilistic inference and prediction to be made from the data collected and evaluation of the quantitative hypotheses (Choy, 2014; Saunders, Lewis, & Thornhill, 2009). This design related factors about individuals or groups in experiments, correlational studies or surveys and ensured comparisons across groups (Choy, 2014; Younus, 2014).

The descriptive survey design provides systematic information about a phenomenon and also describes the current status of an identified variable (Creswell, 2013). The numerical values obtained from data collected from descriptive survey allow for determination of frequencies, percentages and averages from which conclusions can be drawn (Creswell, 2013). The miner`s survey in this study involved the use of questionnaire and the researcher as much as possible controlled biases and ensured that adequate usable returns of data were obtained to control weaknesses associated with the use of the descriptive survey design. According to Creswell (2013), the survey method offers little or no observer subjectivity and can achieve high representativeness.

The quasi-experimental/causal-comparative research design establishes cause-effect relationships among the variables and determines the causes or consequences of differences that already exist between or among groups (Choy, 2014; Rahman, 2017). In the quasi-experimental/causal-comparative design, an independent variable is identified but not manipulated by the researcher (Saunders *et al.*, 2009; Younus, 2014).

Ethical Considerations

This study partly focused on artisanal gold miners, who are human subjects. In view of this, it is ethically prudent to protect the rights and welfare of the subjects who participate in the study (Akaranga & Makau, 2016; Breault, 2006). Initially, an application for ethical clearance was submitted to and approved by the University of Cape Coast Institutional Review Board (IRB) before data collection commenced. Due to the sensitive nature of artisanal gold mining, permission to conduct research was obtained from the District Assembly. Lastly, the artisanal gold miners were approached and permission to conduct the study at the operations site was requested and approval was given. In addition, there were ethical guidelines for informed consent, confidentiality and anonymity to which I adhered.

The participants in the survey were informed of the purpose of the study when they were invited to participate in the research. The participants were assured of confidentiality and anonymity, as well as the opportunity to withdraw from the research at any given time. After explaining the contents of the questionnaire to the participants, dates and times for answering copies of the questionnaire were negotiated with the participants. This was the first stage of building a trustworthy relationship with the participants. On agreeing to participate, consent forms were purposively given to participants (members of small-scale miners association who owned concessions), thus obtaining informed consent from the participants. Confidentiality and anonymity were also discussed with the participants. They were assured that the operations and their names would not be identified in print. To ensure anonymity, the study sites and all participants were given code names.

Study location

This study was carried out in the Dunkwa East Municipality located in the Central Region of Ghana. The area lies within latitudes 5^0 30^1 and 6^0 02^1 north of the equator and longitudes 1^0 W and 2^0 W of the Greenwich Meridian. The Municipality shares boundaries with Adansi South District to the north, Assin North Municipality to the east, Atti-Morkwa District to the west and Upper Denkyira West District to the north-west (Dunkwa East Municipal Assembly (Ghana Statistical Service [GSS], 2014). The study site was selected because it is one of the oldest mining areas in Ghana. The geology of the area makes it attractive for mining and over the years, several concessions have been granted to companies and individuals for both large-scale and small-scale mining. Presently, the area is noted for extensive small-scale mining operations (Kpan *et al.*, 2014; Kwaansa-Ansah *et al.*, 2010). This has resulted in the setting up of one of the District Mining Commission offices in Dunkwa-on-Offin. The study site offers unique opportunity to understand how the activities of small-scale mining affect land availability for agricultural activities especially farming in the local communities.

Climate

The Municipality falls within the semi-equatorial zone. There are two main rainfall seasons in the Municipality. The total annual mean rainfall is between 1200 mm and 2000 mm. The first rainy season is from May to June and the second rainy season covers September to Mid-November. The mean temperature ranges from 29^oC in the hottest months and about 24^oC in the coolest months. The main dry season is experienced from late November to February (GSS, 2014).

Topography and drainage

The Dunkwa East Municipality falls under a forest-dissected plateau which can rise to about 250m above sea level. There are few steep sided hills which alternate with flat bottomed valleys. The major river in the area is River Offin. The tributaries of rivers Offin and Pra flow through the district. Some of the tributaries are Aponapon and Tuatian in the south and Afieti and Subin in the north of the Municipality (GSS, 2014; Dunkwa East Municipal Assembly [DEMA], 2014).

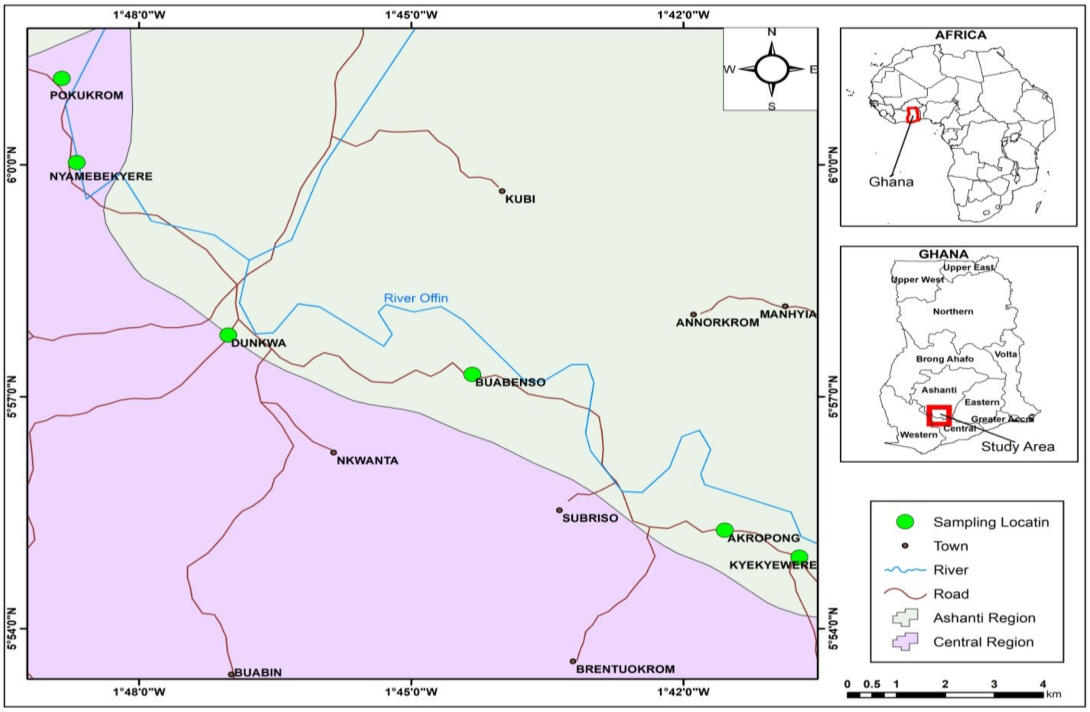


Figure 1: Map of study area showing the sampling locations (Field study, 2016).

Soil

The major soils found in the Dunkwa East Municipality are the Forest Ochrosols (Brammer, 1962; FAO (1988). The soils are deeply weathered and the parent material is of the Upper Birimian type. The top soil depth is between 0-14 cm and that for the sub-soil ranges from 14 cm to > 180 cm. The top soils are usually moderate fine granular in structure and friable in consistency. The colour of soils in the study area ranges between dark brown and strongly brown and the texture of the top soil is of the silty clay loam type. The pH of the soils is between 4.6 and 5.0. The soils are of the Asikuma Series belonging to the suborder Hygropeds in the Latosol soil family group. Forest ochrosols in the study area belong to the Great soil subgroup, the Red/Brown Ochrosols (Brammer, 1962; FAO, 1988). The soils are generally low in nutrients especially nitrogen, phosphorous and potassium.Soils in the study area are suitable for cultivation of food crops maize, plantain, yam and cassava; and for tree crops cocoa, oil palm and citrus (DEMA, 2014).

Geology

The rocks in the Municipality are mostly of the Birimian and Tarkwian formation. The Birimian form Phyllites, Schist and Lava accounting for the rich mineral deposits particularly alluvial gold deposits along the valleys of River Offin and its tributaries and gold deposits found inland (GSS, 2014).

Vegetaion/ Flora

The study area falls within the semi-deciduous forest zone (Hall & Swaine, 1981b) and is characterized by a three-tree strata. Trees of the lower layer and some of the topmost layers stay evergreen throughout the year. The establishment of cocoa farms and the operations of mining groups have degraded the forest especially in the northern section of the area. This has resulted in massive reduction of the original forest and most of what is left is secondary forests. Various timber species including *Terminalia ivoriensis*, *Terminalia superba*, *Triplochiton scleroxylon*, *Allanblackia floribunda*, *Anthcleista nobilis* and *Bombax buonopozense* are found in the forest (DEMA, 2014; GSS, 2014). The three forest reserves in the study area are Benso-Benn, Oppong Manse and Minta forest reserves. Lumbering which has been an essential economic activity in the area has been associated with degradation of the environment. The forest reserves have been encroached upon largely by chainsaw operators. The outbreak of bushfires has resulted in loss of habitats, reduction in species numbers and in some cases extinction of species such as deer and monkey (DEMA, 2014).

Demography

The total population recorded in the 2010 census showed that the Dunkwa East Municipality had a population of 72,810 (GSS, 2014). Males form 49.2 percent and female constitute 50.8 percent. Majority of the population reside in rural communities (50.8%) and this may be due to the predominance of mining and farming activities in the rural areas. The Municipality has a very youthful population with persons under 15 years forming the highest proportion (27,580 people) representing 38.87 percent of the population. This is followed by persons within the age group of 30-59 years who formed 27.43 percent of the population and persons of 60 years and older who constitute 6.66 percent of the population (GSS, 2014).

Economic activities

The economy of the study area can generally be said to be agrarian. About 59.7 percent of the households in the Municipality engage in agriculture. Most of these agricultural activities occur in the rural communities as 83 percent of the households in the rural areas are involved in agriculture (GSS, 2014). The soils and vegetation support agricultural activities especially farming. About 60-65 percent of the working population is into farming, 15 percent engage in small-scale mining and 10 percent do trading. Small-scale mining, both legal and illegal, goes on in almost all the towns within the Municipality. Other migrants such as the Chinese are engaged in the surface mining activities (DEMA, 2014; GSS, 2014).

Data Collection

Vegetation/ floral studies were conducted to assess the distribution of vegetation and tree species in the study area (objective 1). The quality of soils in mined and unmined areas were assessed based on nutrients, physicochemical characteristics and heavy metals (objectives 2 and 3). A survey questionnaire was administered to ascertain the perceptions of small-scale gold miners regarding the environmental effects of gold mining (objective 4).

Vegetational/ Floral studies

This section makes an inventory of plant species in the mined and unmined sampling plots, categorises the species into families, life-form, star rating and ecological guild. Ecological parameters including density, frequency, diversity of species and evenness were determined. Other indices determined for the plant species in the mined and unmined areas were genetic heat indices, pioneer indices, Sorenson`s index and the similarity ratio.

Inventory of plant species

Ten belt transects each measuring 200 m × 200 m were constructed for the vegetational/floral studies. Five of the belt transects (200 m × 200 m) were constructed in the mined areas and another five belt transects (200 m × 200 m) in the unmined areas. Each belt transect (200 m × 200 m) was divided into 100 quadrats (20 m × 20 m) and plant species in each of the quadrats (20 m × 20 m) were identified in the field or the herbarium. Four herbalist and herbarium staff at the School of Biological Sciences helped with the identification processes.

The trees and shrubs in the study area were identified by the leaves, crown, bole, buttresses and slash exudates, texture, colour and smell. For plant species that were not readily identified in the field, voucher specimens (leaves, seeds, fruits, bark slashes etc.) and photographs of the specimens were sent to the herbarium at the School of Biological Sciences, University of Cape Coast for identification. The herbarium identification was done by comparison with already identified herbarium material and the use of published flora (Dokosi, 1998; Hall & Swaine, 1981a; Hawthorne, 1993; Hawthorne & Jongkind, 2006; Hutchinson & Daizel, 1958; Hutchinson & Daizel, 1963; Innes, 1977; Irvine, 1961).

Categorization of plant species

A comprehensive list of plants species obtained was used in the determination of the proportion of taxa, life-form, star rating and ecological guild of species in the study area. Star rating and ecological guild of species were determined with the help of the Forest of Ghana Graphical Information Exhibitor (FROGGIE) by Hawthorne (1993).

The guild refers to a group of species associated with a common way of life. Thus, how the species respond to the most significant influences on the flora community.

The guild generally expresses the ecology of each species with respect to gaps /canopy disruption. The flora was classified into ecological guild as follows:

Pioneer (P) - species which regenerate only under gaps in canopy.

Non – Pioneer - species whose seedlings are common in shade relative to gaps

Non- Pioneer Light Demanding (NPLD) - need gaps to grow

Shade Bearers – often found in understorey

Swamps - species only or almost entirely found in swamps, river banks or other wet places

Non – Forest – species which are exotic, invaded or savanna plants

(Hawthorne, 1993)

The plant species were grouped into star ratings to reflect genetic conservation value. The star classification provides a priority list for species. It also highlights the "genetic hot-spots" of the plant community. In this study, the plant species were star-rated according to the specific circumstances of Ghana as follows:

Black star - species are rare internationally and at least uncommon in Ghana; urgent attention to conservation of population needed.

Gold star - species are fairly rare internationally and / or locally.

Blue star - species are widespread internationally but rare in Ghana or vice- versa

Pink star – species are common and moderately exploited. Also non- abundant species of potential value.

Red star – species are common but under serious pressure from exploitation. Current rate of exploitation if not controlled can lead to economic damage in the next few years.

Scarlet star – species are common but under extreme pressure from heavy exploitation. Presently, economic damage from heavy exploitation being experienced.

Green star – species of no particular conservation concern and are common in Ghana.

(Hawthorne, 1993)

Life form of plant species

The plant species in the study area were grouped into life forms on the basis of their similarities in structure and function. In this study, the plant species were grouped as Trees, Shrubs, Herbs, Lianes, Ferns and Climbers.

Ecological parameters of plant species

Each of the belt transect (200 m × 200 m) was sampled to determine ecological parameters of species in the mined and unmined study areas. In the determination of the density and frequency on plant species, only plants rooted in the quadrats (20 m × 20 m) were counted. Shoots arising from a common tussock and those with rooted stolons were considered as single / individual plants.

Density of plant species

Plant species in each quadrat (20 m× 20 m) were counted and the total number for each species recorded. This was done for the 500 quadrats (20 m × 20 m) in the mined site and another 500 quadrats (20 m× 20 m) in the unmined site.

Density of plant species in each study site was then calculated as:

$$\text{Density} = \frac{Number\ of\ individuals\ of\ a\ particular\ plant\ species}{Total\ area\ of\ belt\ transect\ (1000m^2)}$$

Frequency of plant species

100 quadrats (20m × 20m) were constructed in each transect belt (200m × 200m). The presence or absence of a particular plant species in each quadrat was recorded for the determination of frequency.

The frequency of each plant species was obtained from the relation:

$$\text{Frequency} = \frac{\textit{Number of quadrats}\ (20m \times 20m)\ \textit{in which a particular species occurred}}{\textit{Total number of quadrats}\ (500\ \textit{quadrats})} \times 100$$

Diversity of plant species

The diversity of the plant species was determined using Shannon-Weiner (1949) and Simpson`s (1949) indices.

Shannon-Weiner Index, H:

$$H = -\sum \text{Pi} \ln \text{Pi}$$

Where, $\text{Pi} = \text{ni} / \text{N}$

and ni = number of individuals of the i^{th} species

N = total number of individuals

Simpson`s Index, D:

$$D = 1 - C$$

Where, C = Concentration of Dominance

$$C = \frac{\sum \text{ni}\,(\text{ni} - 1)}{\text{N}\,(\text{N} - 1)}$$

Where ni and N are defined as above.

Species evenness (E):

$$E = \frac{\text{H1}}{\ln S} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Pielou, 1969)}$$

Where, H^1 = Shannon – Weiner diversity index

S = number of species

Similarity of species

The similarity of species between the mined and unmined areas was obtained using Sorenson`s Index and Similarity Ratio.

Sorenson`s index for this study was obtained from the relation:

$$Ss = \frac{2a}{(2a+b+c)}$$

Where;

a = number of species common to both mined and unmined study sites
b = number of species unique to mined site
c = number of species unique to unmined site

Similarity Ratio (SR)

The similarity between species in mined site (a) and unmined site (b) was obtained from the relation:

$$SRij = \frac{\sum KYKaYKb}{(\sum KYKa^2 + \sum KYKb^2 - \sum KYKaYKb)}$$

Where KYKa = abundance of K^{th} species in mined site

KYKb = abundance of K^{th} species in unmined site

Pioneer Index (PI)

The Pioneer Index of plant species for each of the study sites (mined and unmined) was obtained from the relation:

$$PI = \frac{(\text{Pioneers} \times \text{Pioneer Weight}) + (\text{NPLD} \times \text{NPLD Weight}) \times 100}{\text{Total Number (of individuals of species sampled)}}$$

Where; Pioneer weight = 2; NPLD weight = 1 (Hawthorne, 1993).

Pioneers – Number of Pioneer species

NPLD - Number of NPLD species

Genetic Heat Index (GHI)

The Genetic Heat Index for species in each of the study sites (mined and unmined) was obtained from the relation:

$$\mathrm{GHI} = \frac{(BK \times BKweight) + (GD \times GDweight) + (BU \times BUweight) + (RD \times RDweight) \times 100}{BK + GD + BU + GN + RD}$$

Where; BK, BU, GD, GN and RD represent black, blue, gold, green and red species respectively. BKweight is the weight of black species etc.

Weights of black, gold, blue, red and green species are 27, 9, 3, 1 and 0 respectively (Hawthorne, 1993).

Economic Index (EI)

The economic index for species in each of the study areas (mined and unmined) was obtained from the relation:

$$\mathrm{EI} = \frac{(SC \times SCweight) + (RD \times RDweight) + (PK \times PKweight) \times 100}{Total\ all\ stars}$$

Where; SC is scarlet; RD is red and PK is pink.

Weight of scarlet = 3; red = 2; pink = 1 (Hawthorne, 1993)

Miner`s survey

All small-scale miners used for the survey were 18 years and older, owned concessions and were members of the Association for Small-Scale Miners in the study area at the time of the survey and had lived in the study area continuously for at least one year were approached to take part. Participants who had not engaged in small-scale mining for the past five years were excluded from the study to reduce recall bias. Some individual miners declined participation because of perceived possible reduction in gold deposits in their concession through spiritual activities of the researcher, time constraints due to work schedule and personal disinterest and apathy because of previous un-met expectation from other researchers.

Participants of this study were resident in Dunkwa, Kyekyewere, Akropong, Nyamebekyere, Pokukrom, Buabenso, Mfuom, Abesewa, Opponso, Asikuma, Babianiha, Kadadwene, Meretweso, Esaase and Acquakrom, all in the Denkyira enclave.

Data Collection Instrument

For the survey, structured questionnaire were used. Structured questionnaire allowed for the exploration of patterns and trends and also provided a measure of the participant attitudes, feelings and perceptions (Bolarinwa, 2015). The close-ended questions used in this study provided a variety of multiple choice answers from which the participants were given the opportunity to tick as applicable. The questionnaire was structured into two parts; knowledge of miners on the impacts of small-scale mining on the environment and the socio-demographic profile of the participants. The demographic aspects included gender, age, marital status, ethnic origin, education, religion, income and experience in mining. The part of small-scale mining and its impacts on the environment focused on ownership of small-scale concession and how it was acquired, number of workers employed, and the rehabilitation of mined sites and reduction of the adverse effects of small-scale mining.

Pretesting and reliability of the questionnaire

Pre-testing was done to test the questionnaire and instructions for filling out the questionnaire. The questionnaire was tested among 20 participants from Dunkwa and Kyekyewere towns with different levels of educational attainment to ensure its feasibility. The pilot group was first asked to complete the questionnaire and comment on how comprehensible the questions were. This gave indications on suitability of the questions and also tested the adequacy and completeness of the responses. This led to minor modifications of the questionnaire to improve understanding. The reliability test (Cronbach α) was higher than 0.7, the threshold for accepting the internal consistency of the items in the questionnaire indicating that the items actually measure the constructs they were designed to measure.

Survey data collection and analysis

The study was undertaken between April 2016 and January 2017. The questionnaire was administered and collected from each respondent within the stated period. The survey data were analysed using the IBM Statistical Product and Software Solutions (SPSS) version 22 (IBM, Chicago, IL, USA) and STATA version 13 (StataCorp, 2013). Non-parametric tests (Pearson chi-square and Cramer's V statistic) were jointly used to determine whether the observed differences in knowledge of environmental effects of small-scale gold mining on the one hand, and compositional factors on the other hand, were independent (statistical significance was set to $\alpha \leq 0.05$). The outputs were presented as contingency tables in the results. Cramer's V was used to measure the strength of the association between the variables consisting of two or more categories. Cramer's V greater than 0.3 reflects strong association between any pair of variables.

For the analysis of the relationship between knowledge of multiple environmental effects of gold mining and compositional attributes of respondents, inferential and multivariate statistical techniques were applied to examine associations between number of environmental effects reported by gold miners and contextual factors while controlling for theoretically relevant socio-cultural (income, education, experience, religion, occupation) factors and biosocial variables (age, gender, ethnicity) using STATA 13SE software. The environmental effects considered included air pollution (mostly suspended particulate matter), degradation of land and vegetation, water pollution, and noise pollution. Responses on each of the environmental effects of gold mining were dichotomized (coded 0 if not reported, coded 1 if reported by the gold miner). These codes were then aggregated to obtain a cumulative environmental effect ranging from 0 (none of the environmental effects were reported by respondents) to 4 (each of the four environmental effects was reported by respondents). Analyses were preceded by diagnostic tests to establish whether variables met the assumptions of the statistical model. Univariate analyses of the predictors of each of the four questions that measure environmental effects were operationalised via Pearson's chi-square statistics.

Soil studies

Soil sampling locations

The soils for the study were obtained from 13 locations from 5 towns, Akropong, Kyekyewere, Dunkwa, Nyamebekyere and Pokukrom in the Dunkwa East Municipality. Nine sampling locations were in the mined areas (Table 2) and 4 sampling locations in the unmined sites (Table 3). For the mined areas, the sampling locations were selected based on the years of fallow of the sampling site after mining and the pit status (filled or unfilled). For the mined areas, the sampling locations were selected based on the years of fallow of the sampling site after mining and the pit status (filled or unfilled). Sixteen soil samples each from two sampling sites were obtained from Akropong, Nyamebekyere and Dunkwa respectively. The rest of the soil samples in the mined areas were 26 samples from 3 sampling sites in Kyekyewere and 8 samples from one sampling site in Pokukrom. Thus a total of 82 soil samples from the mined areas was used for this study (Table 2). For the unmined study areas, 38 soil samples were obtained and used. Eight soil samples each from Akropong and Pokukrom. Buabenso and Dunkwa had 15 and 7 soil samples respectively (Table 3). In all, a total of 120 soil samples were used in the study. The large number of soil samples taken from each sampling site (8 samples) was to reduce distribution heterogeneity of the soil (Klesta & Bartz, 1996) (National Institute of Standards and Technology,[NIST] 1995).

The sampling locations, years of fallow after mining and the status of pits in the mined study areas have been presented in Table 2 below.

Table 2: *Sampling location, pit status of sampling site and years of fallow of mined area*

Sample location	Year(s) of fallow	Pit status of Sampling site	Number of soil samples
Akropong (1)	1	Filled	8
Akropong (2)	1	Not filled	8
Kyekyewere (1)	2	Filled	8
Kyekyewere (2)	2	Not filled	8
Kyekyewere (3)	3	Filled	10
Dunkwa (1)	4	Not filled	8
Dunkwa (2)	4	Filled	8
Nyamebekyere	5	Filled	16
Pokukrom	Freshly mined	Not filled	8
Total			82

Source: Field study (2016)

The sampling locations and number of soil samples taken from the unmined study areas have been presented in Table 3.

Table 3: *Sampling locations and number of soil samples from the unmined study area*

Sampling location	Number of soil sample
Akropong	8
Buabenso	15
Dunkwa	7
Pokukrom	8
Total	38

Source: Field study (2016).

Soil sampling

A 200 m × 200 m belt transect was constructed across each of the mined and unmined study sites. Each belt transect was divided into 16 quadrats with each quadrat measuring 50 m × 50 m. In all, 11 belt transects (200 m × 200 m) were constructed in the mined areas and 5 belt transects (200 m × 200 m) in the unmined study sites for the soil sampling. At each sampling location, 8 out of the 16 constructed quadrats (50 m × 50 m) were randomly selected for sampling. Soil samples were taken from the mid – point of each randomly selected quadrat. The soils were collected with hand auger to the depth of 0 – 30cm at each sampling point. Soil replicates (three replicates for each sample) were taken to help monitor the precision of the overall procedure and field variability (National Institute of Standard Technology, 1995). The soils were sealed in plastic bags and returned promptly to the laboratory. The geographical position of each of the sampling point was recorded with a hand held Geographical Positioning Unit (Garmin eTrex 10).

Sample preparation, handling and storage

The soil samples were left to air dry in a room free of dust, fumes and other contaminants for two weeks. The soils were rolled gently with a roller and clods were broken to facilitate drying. Soil debris and larger coarse fragments were hand-picked. Mortar and pestle were used to grind the soil to break down the soil aggregates and reduce soil particle size so as to pass through 2mm sieve. The soils were then screened through a 2 mm sieve (Klesta & Bartz, 1996). The sieved soil samples were put into plastic pots and sent for analysis in the laboratory of School of Agriculture, University of Cape Coast for determination of pH, electrical conductivity, texture, extractable acidity and available phosphorus; and in the laboratory of Soil Research Institute, Kumasi for determination of Total nitrogen, magnessium, calcium, sodium, organic carbon, potassium, cadmium, mercury, copper, lead and arsenic. For each soil property, three replicates were analysed. The soils were stored and preserved according to protocols for preservation of soil samples as found in the Guideline on LaboratoryAnalysis of Potentially

Contaminated Soil (NEPM, 2013). In this study, the protocols on holding times for the elements of interest in soil samples as found in the Guideline on Laboratory Analysis of Potentially Contaminated Soils (NEPM, 2013) were followed. An appropriate programme of quality control as described by Canadian Society of Soil Science (2008) and American Society for Testing and Materials (ASTM) (1985) were employed during all stages of sample collection, preparation and handling to reduce potential errors.

Methods for the determination of various elements in soil

Determination of soil pH

The soil pH was determined by the use of a pH meter (Orion star, A211 by Thermofisher Scientific Inc., NY) in the School of Agriculture Laboratory, University of Cape Coast. Tweny five millilitres distilled water was added to 10 g of the prepared air-dried soil sample in a 50 ml beaker. The suspension was stirred at regular intervals for about 10 minutes and allowed to settle for 15 minutes. The pH meter was calibrated with 7.0 distilled water and pH buffer solution before use. The probe of the pH meter was inserted into the soil solution making sure the end of the probe made contact with the soil. The reading displayed on the pH meter was allowed to stabilize to a constant value before the reading was recorded. After every reading, the probe was removed and washed with distilled water, then rinsed with soil suspension (Sumner, 1994).

Soil texture determination

The hydrometer method (Day, 1965) was used for the soil particle size analysis. This method quantitatively determines the physical proportions of three primary soil particles as determined by their settling rates in aqueous solution (ASTM, 1985). A 100 g of a 2.0 mm sieved soil was weighed into a baffled stirring cup. The cup was filled to its half with distilled water and 10 ml of sodium hexametaphosphate ($Na_6O_{18}P_6$) solution was added. The cup was placed on a stirrer and the content stirred until soil aggregates were broken down. The suspension was transferred quantitatively to the sedimentation cylinder. The cylinder was filled to the 100 mL mark with distilled water after placing the hydrometer in the liquid. The hydrometer was removed, cylinder was stoppered and the suspension was shaken vigorously end over end for one minute. Circular currents in the liquid were avoided as they can influence the settling rate. The cylinder was placed on a table and after 20 seconds, the hydrometer was inserted and readings on the hydrometer were taken at the end of 40 seconds. The above steps were repeated to obtain hydrometer readings within 0.5 g differences from each other. The hydrometer was calibrated to read grams of soil material in suspension and the readings were recorded on the Data sheet. The suspension was re-shaken and the cylinder placed on a table where it was not disturbed. Hydrometer reading was then taken exactly two hours later (ASTM, 1985). The temperature (^{o}c) readings were recorded during the 40 second and 2 hour hydrometer readings. A blank hydrometer reading was recorded from a sedimentation cylinder filled with distilled water and 10 ml of sodium hexametaphosphate to the 1000 mL mark .

Calculations:

Temperature Correction Factor (T) = (observed temperature – 20^{o}c) × 0.3

Corrected 40 -seconds reading = 40 sec – Blank + T

Corrected 2- hour reading = 2 hour – Blank + T

$$\%\,Sand = \frac{\text{(OD soil wt) – (Corrected 40 sec reading)}}{OD\ Soil\ wt}\ x\ 100$$

$$\%\,Clay = \frac{\text{Corrected 2hour reading}}{OD\ Soil\ wt}\ x\ 100$$

$\%\,Silt$ = 100% - (% Sand + % Clay)

The USDA textural guide was used to determine the textural class of the soil (Anderson & Ingram, 1993). The percentages of sand, silt and clay were traced along the texture triangle and the point where the percentages converged was used as the description of the texture of the soil.

Determination of soil electrical conductivity

A 1:5 (soil – water) suspension was prepared by weighing 10 g air-dry soil (<2 mm) into a bottle. Fifty millilitre distilled water was added and mechanically shaken at 15 rpm for 1 hour to dissolve soluble salts. The conductivity meter (AD 8000 by Adwa Instruments, Hungary) was calibrated according to the manufacturer's instructions using the KCl reference solution to obtain the cell constant. The probe was rinsed thoroughly before and after calibration using distilled water and wiped dry with clean filter paper. The electrical conductivity meter was calibrated before each use (before each series of 10 samples)). The probe was rinsed with distilled water and the electrical conductivity of the 0.01M KCl standard solution was measured at the same temperature as the soil suspensions. The conductivity probe was rinsed with soil suspension and inserted into the soil suspension. The value indicated on the conductivity meter was recorded when the probe was submerged into the suspension and the electrical conductivity reading on the meter was stabilized. The probe was rinsed with distilled water and soil extract between samples. Sample extracts and calibration standards were allowed to equilibrate to ambient temperature prior to analysis (Korsaeth, 2005: ASTM, 1985).

Determination of soil organic carbon

The Walkley-Black chromic acid wet oxidation method (Walkley & Black, 1934) was used in determining the organic carbon content of soil samples. A 0.5 g of soil sample was weighed into a dry tarred 250 mL conical flask and 5 mL of 0.4 N potassium dichromate solution ($K_2Cr_2O_7$) was added and the flask gently swirled to disperse the soil in the solution. A 10 mL concentrated H_2SO_4 was added directing the stream into the suspension. The mixture was gently swirled and left at room temperature in a fume hood for 8-10 hours and then, 20 mL of distilled water was added to the mixture. The excess dichromate solution was back-titrated potentiometrically with standard 0.2 N ferrous ammonium sulphate solution. At the beginning of the batch analysis, blank titration (without soil) of the acidic dichromate with ferrous ammonium sulphate was perfomed. One mL of 0.2 N ferrous ammonium sulphate is eguivalent to 0.009807 g of $K_2Cr_2O_7$ or 0.0006 g of carbon. The organic carbon content in the soil sample was calculated as:

$$\text{Organic carbon (\%)} = (B - S) \times (0.0006) / M \times 100$$

Where;

S = Volume of ferrous solution required to titrate the sample.

B = Volume of ferrous solution required to titrate the blank.

M = Mass of the sample (g) used in the analysis.

(Sato *et al*., 2014; Walkley & Black, 1934)

Determination of total nitrogen

The two-step digestion-UV Spectrophotometry method was employed in the determination of soil sample nitrogen (Liu, Zeng, & Jiang, 2013).

First digestion

A 0.1 g sample was transferred to the digestion tube and 0.1 mL distilled water was added to it. The tube was heated in an oil bath at 150 ^{0}C for 5 minutes. Sulfuric acid and hydrogen peroxide (30%) were added to the contents in the tube. The digestion temperature was increased to 360 ^{0}C and maintained for 40 min. The digestion temperature was later decreased to 150 ^{0}C and maintained for 15 min.

Second Digestion

The digested solution was cooled and transferred into a 50-mL volumetric flask made to the mark with distilled water. A 5 mL of the solution from the volumetric flask was transferred into a colorimetric tube and 5 mL alkali–potassium per sulfate ($K_2S_2O_8$) solution was added to the colorimetric tube. The colorimetric tube was digested in an autoclave at 120–125 ^{0}C for 30 minutes.

Spectrophotometry

The colorimetric tube was cooled to room temperature, and 1 mL hydrochloric acid was added to the colorimetric tube. Distilled water was added to bring the colorimetric tube up to its calibration. The N in the sample was determined by spectrophotometry, measuring absorbance at 275 nm and 220 nm (Liu *et al.*, 2013).

Determination of available Phosphorus

The Dickman and Bray`s method (1940) was used to determine the concentration of phosphorus in the soil. A 5.0 g of soil was transferred into a 250 mL conical flask and 50 mL of Bray`s extractant was added. The content of the flask was mixed and shaken for 5 minutes and filtered (Whatman No. 1 filter paper) into a new conical flask. 5 mL of the filtrate was transferred into a 25 mL volumetric flask and 5 mL of ammonium molybate solution was added, mixed until the evolution of CO_2 ceased. 10 mL of distilled water was used to wash the neck of the flask to remove the adhering molybate. 1 mL of working stannous chloride solution was added and the content of the flask made up to the mark with distilled water. The wavelength of the Colorimeter was adjusted to 660 nm and allowed to warm up for about 10- 15 minutes. The test solution was poured into a colorimeter tube and the percentage transmission or the absorbance was read. The intensity, measure of concentration of phosphorus in the soil sample was read on the colorimeter. A graph of absorbance against concentration in ppm was plotted and used to determine the concentration of phosphorus in the soil sample from the standard curve.

Calculations:

$$\text{P (ppm) in soil} = \frac{P\ (ppm) in\ solution \times Total\ mL\ extracting\ solution\ used}{Weight\ of\ soil}$$

Determination of concentrations of various soil elements (Mg, Ca, Na, K, Cd, Hg, Cu, Pb and As) using Atomic Absorption Spectrometry

Sample digestion

A 1.0 g of sieved soil sample was placed in a 16- by 150-mm test tube. One small Teflon-covered magnet and 5 ml concentrated nitric acid were added. The tube and contents were placed in one hole of an aluminum heating block fitted on top of hotplate equipped with magnetic stirrer. The sample-acid mixture was agitated and heated to boil whiles continuously stirring for 30 minutes. The tube from the block was removed and the solution allowed to cool slightly before adding 5 m off distilled water,. The mixture was heated to boil and then allowed to cool. The mixture was made up to 10-ml mark with concentrated nitric acid. The solution was then thoroughly mixed and centrifuged. The above procedure was repeated for all the samples.

Instrumental Analyses

The Atomic Absorption Spectrometry method (Agilent Technologies [AT], 2017) was used in analyzing the concentrations of the above soil elements at Soil Research Institute, Kumasi. The AAS method has several benefits over other methods. This technique measures the total concentration of an element, regardless of its form. In addition, the wavelength used is specific to the element being tested, so there is no interference from other elements in the sample, making it a fast and easy technique. Moreover, there is good precision and automation of the measurements (AT, 2017).

The supernatant liquid sample was aspirated into a nebulizer and the formed aerosol was introduced into flame, where aerosol desolvation, evaporation and analyte atomization occurred. A Hitachi Model Z-8000, flame and graphite furnace atomic absorption spectrophotometer (Hitachi, Ltd., Tokyo, Japan) was calibrated and tested by atomizing five working standard solutions, and manually measured the percent absorption as per manufacturer recommended operating conditions. Calibration solutions were freshly prepared by successive dilution of the stock standard solutions immediately before analysis. All the measurements were based on an integrated absorbance and were performed using a Zeeman-effect background correction system with respective element hollow-cathode lamps as the light sources. The concentrations of the various elements were determined by flame atomic absorption spectrometry (FAAS) technique in air–acetylene flame (2000-2300 ^{0}C) (AT, 2017). The absorbance of each element was measured at the following wavelength; Arsenic – 193.7 nm, Cadmium – 326.1 nm, Copper – 324.7 nm, Potassium – 766.5 nm, Magnesium – 285.2 nm, Calcium – 422.7 nm, Sodium – 589.0 nm, Lead – 405.8 nm and Mercury – 253.7 nm (AT, 2017).

Determination of extractable acidity

The KCl extractable acidity method was used for this analysis (Ahern, Blunden, & Stone, 1998; Dai & Richter, 2000).

A 2.5 mL of soil was scooped into a sample cup and 25 mL of 1 M KCl solution was added. The suspension was stirred at 400 rpm for ten minutes using a multiple stirrer and left to stand for 10 hours. The extract was filtered using Whatman No.1 paper. 5 mL of the filtrate was diluted with 20 mL of 0.0356 M $SrCl_2$. 10 mL of this filtrate was diluted with 10 mL of distilled water containing 2-4 drops of phenolphthalein, and titrated with 0.005 M NaOH (Dai & Richter, 2000)

Analysis of soil data

The data obtained from both field and laboratory studies were subjected to both basic descriptive and detailed statistics of standard deviation, correlation and LSD; which were achieved using Microsoft excel for data entry, SAS for mean, range, ANOVAs and mean separation (LSD). The data for the soil samples were subjected to Principal Component Analysis (PCA) and correlation analysis using SYSTAT version 8.0 software. Both correlation and principal component analysis used in this study provided a multivariate view, a good representation of the overall level of interactions and also reflected the possible sources of the variations found in the soils (Anazawa & Ohmori, 2005; Yidana, Ophori, & Banoeng-Yakubo, 2008). The procedures outlined in Field and Laboratory Procedure and Protocols (Ayers, 2016) and that of the Guideline on Laboratory Analysis of Potentially Contaminated Soil (NEPM, 2013) were used for data transfer, verification and reporting.

Determination of soil quality index (SQI)

As soil quality is a complex functional concept and cannot be measured directly in the field or laboratory (Stocking, 2003) but can only be inferred from soil characteristics (Diack & Stott, 2001), it was apt to construct a soil quality index (SQI) that integrated the measured soil physical and chemical properties into a single parameter that could be used as an indicator of overall soil quality. The study focused on the development of the Soil Quality Index (SQI) that integrated 16 soil physical and chemical properties measured in the study area into a single number to monitor changes in soil properties of the mined and unmined areas with time. The chemical properties used included soil pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (N), available phosphorus (P) and potassium (K), sodium (Na), magnesium (Mg)), calcium (C), trace elements such as copper (Cu), cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As). The physical properties included soil bulk density and coarse fragments of the soil. The mineral soil property threshold levels, interpretations, and associated soil index values have been presented in table 4. The individual index values for all the mineral soil properties measured were summed to give a total Soil Quality Index. The maximum value for the total Soil Quality Index for this study was 18 provided all the 16 soil properties were measured.

Total SQI = Σ individual soil property index values. The total SQI was then expressed as a percentage of the maximum possible value of the total SQI for the soil properties that were measured:

SQI (%) = (total SQI / maximum possible total SQI for properties measured) x 100

Table 4: *Soil quality index values and associated soil property threshold values and interpretation*

Parameter	Level	Interpretation	Index
Bulk density (g cm^{-3})	> 1.5	Possible adverse effects	0
	≤ 1.5	Adverse effects unlikely	1
Coarse fragments (%)	> 50	Possible adverse effects	0
	≤ 50	Adverse effects unlikely	1
Soil pH	< 3.0	Severely acid – almost no plants can grow in this environment	-1
	3.01 to 4.0	Strongly acid – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals	0
	4.01 to 5.5	Moderately acid – growth of acid intolerant plants is affected depending on levels of extractable Al, Mn, and other metals	1
	5.51 to 6.8	Slightly acid – optimum for many plant species, particularly more acid tolerant species	2
	6.81 to 7.2	Near neutral – optimum for many plant species except those that prefer acid soils	2
	7.21 to 7.5	Slightly alkaline – optimum for many plant species except those that prefer acid soils, possible deficiencies of available P and some metals (for example, Zn)	1
	7.51 to 8.5	Moderately alkaline – preferred by plants adapted to this pH range, possible P and metal deficiencies	1
	> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities	0
Total organic carbon in mineral soils (%)	> 5	High – excellent buildup of organic C with all associated benefits	2
	1 to 5	Moderate – adequate levels	1
	< 1	Low – could indicate possible loss of organic C from erosion or other processes, particularly in temperate or colder areas	0
Total nitrogen in mineral	> 0.5	High – excellent reserve of nitrogen	2
	0.1 to 0.5	Moderate – adequate levels 1	1

soils (%)	< 0.1	Low – could indicate loss of organic N	0
Exchangeable Na (%) **(exchangeable Na/ECEC x 100)**	> 15	High – sodic soil with associated problems	0
	≤15	Adverse effects unlikely	1
K (mg kg^{-1})	> 500	High – excellent reserve	2
	100 to 500	Moderate – adequate levels for most plants	1
	< 100	Low – possible deficiencies	0
Mg (mg kg^{-1})	> 500	High – excellent reserve	2
	50 to 500	Moderate – adequate levels for most plants	1
	< 50	Low – possible deficiencies	0
Ca (mg kg^{-1})	> 1000	High – excellent reserve, probably calcareous soil	2
	101 to 1000	Moderate – adequate levels for most plants	1
	10 to 100	Low – possible deficiencies	0
	< 10	Very low – severe Ca depletion, adverse effects more likely	-1
Al (mg kg^{-1})	> 100	High – adverse effects more likely	0
	11 to 100	Moderate – only Al sensitive plants likely to be affected	1
	1 to 10	Low – adverse effects unlikely	2
	< 1	Very low – probably an alkaline soil	2
Mn (mg kg^{-1})	> 100	High – possible adverse effects to Mn sensitive plants	0
	11 to 100	Moderate – adverse effects or deficiencies less likely	1
	1 to 10 Low	Low - adverse effects unlikely, possible deficiencies	1
	< 1	Very low – deficiencies more likely	0
Fe (mg kg^{-1})	> 10	High – effects unknown	1
	0.1 to 10	Moderate – effects unknown	1
	< 0.1	Low – possible deficiencies, possibly calcareous soil	0
Ni (mg kg^{-1})	> 5	High – possible toxicity to Ni sensitive plants, may indicate serpentine soils, mining areas, or industrial sources of Ni	0
	0.1 to 5	Moderate – effects unknown	1
	< 0.1	Low – adverse effects highly unlikely	1
Cu (mg kg^{-1})	> 1	High – possible toxicity to Cu sensitive plants, may indicate mining areas or	0

		industrial sources of Cu	
	0.1 to 1	Moderate – effects unknown, but adverse effects unlikely	1
	< 0.1	Low – possible deficiencies in organic, calcareous, or sandy soils	0
Zn (mg kg^{-1})	> 10	High – possible toxicity to Zn sensitive plants, may indicate mining areas or industrial sources of Zn	0
	1 to 10	Moderate – effects unknown, but adverse effects unlikely	1
	< 1	Low – possible deficiencies in calcareous or sandy soils	0
Cd (mg kg^{-1})	> 0.5	High – possible adverse effects	0
	0.1 to 0.5	Moderate – effects unknown, but adverse effects less likely	1
	< 0.1	Low – adverse effects unlikely	1
Pb (mg kg^{-1})	> 1	High – adverse effects more likely, may indicate mining areas or industrial sources of Pb	0
	0.1 to 1	Moderate – effects unknown, but adverse effects less likely	1
	< 0.1	Low –adverse effects unlikely	1
S (mg kg^{-1})	> 100	High – may indicate gypsum soils, atmospheric deposition, mining areas, or industrial sources	0
	1 to 100	Moderate – adverse effects unlikely	1
	< 1	Low – possible deficiencies in some soils	0
0.03 M NF_4 + 0.025 M HCl (Bray 1) P (mg kg^{-1})	> 30	High – excellent reserve of available P for plants in acid soils, possible adverse effects to water quality from erosion of high P soils	1
	15 to 30	Moderate – adequate levels for plant growth	1
	< 15	Low – P deficiencies likely	0
pH 8.5, 0.5 M $NaHCO_3$ (Olsen) P (mg kg^{-1})	> 30	High – excellent reserve of available P in slightly acidic to alkaline soils, possible adverse effects to water quality from erosion of high P soils	1
	10 to 30	Moderate – adequate levels for plant growth	1
	< 10	Low – P deficiencies likely 0	0

Modified from Amacher, O`Neil, Katherine, & Perry (2007). The value of Mercury (Hg) is not included in the table given that it is not a natural constituent of soil.

CHAPTER FOUR

RESULTS

Introduction

This chapter presents the results from analysis of flora data regarding distribution, abundance, diversity, ecological and conservational status of plant species; and the similarity of the flora between unmined and mined study areas. The data on the effect of small-scale mining activities on the levels and spatial distribution of nutrients and heavy (trace) metals in soils of the study area have also been presented. This section also reports on soil data for the spatial distribution of the soil quality index values across sampling locations and the analysis of the knowledge of small-scale miners on environmental effects of gold mining.

Flora of the study area

Two hundred and seventy eight plant species belonging to 238 genera and 84 families were identified in the study area (Table 5). The Magnoliopsida (Dicots) which emerged with 80.21% of the species distributed among six subclasses, was the most dominant group in terms of number of species. The Liliopsida (Monocots) followed with a dominance of 15.83% of the species distributed among four subclasses. The plant group with the least number of species was the Pteridophyta which accounted for 3.96% of the total number of species in the study area.

Table 5: *Plant groups of the flora in the study area*

Plant group	**Number of families**	**Number of genera**	**Number of species**
Magnoliopsida	63	188	223
Liliopsida	13	42	44
Pteridophyta	8	8	11
Totals	**84**	**238**	**278**

.Source: Field study (2017)

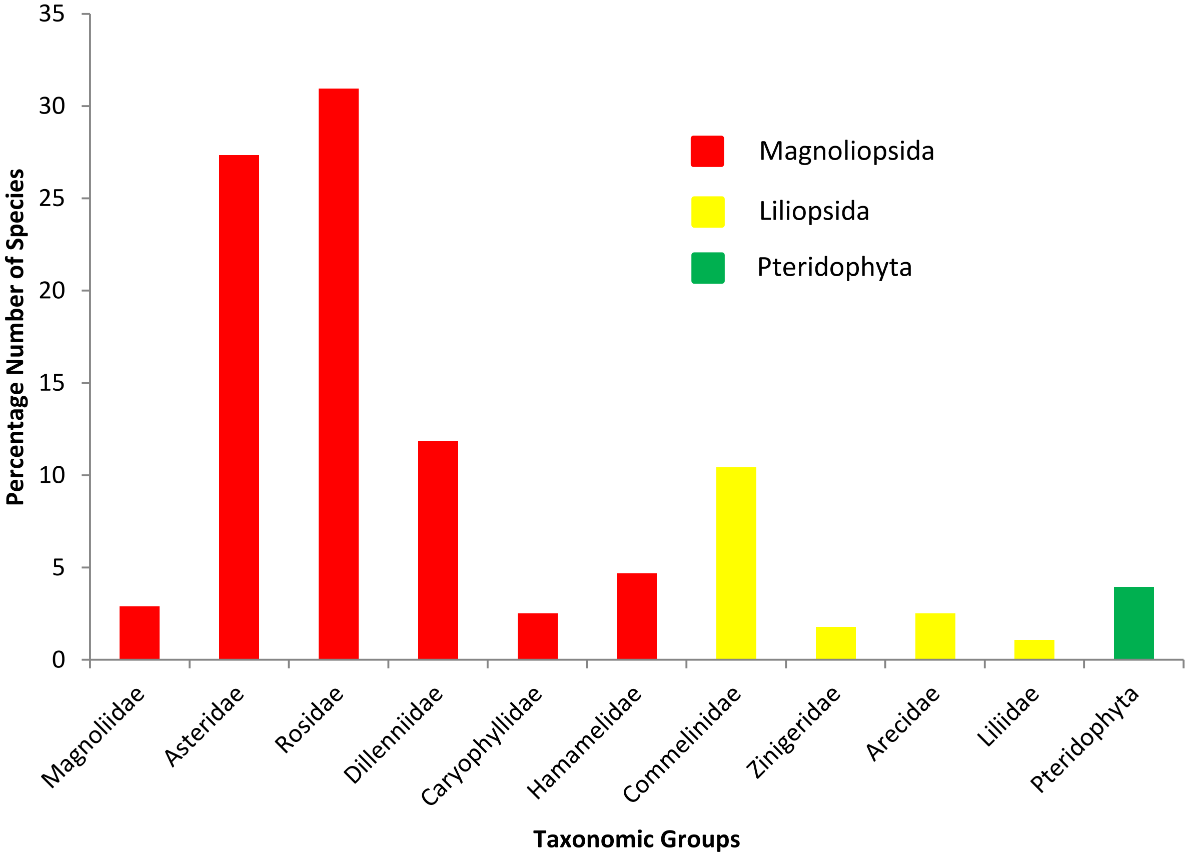


Figure 2: Distributrion of plant species among taxonomic groups

The Magnoliopsida (Dicots) consisted of plant species from six subclasses which were the Magnoliidae, Asteridae, Rosidae, Dillenidae, Caryophyllidae and Hamamelidae. The dicot with the most number of species was the Rosidae which accounted for 30.93% of all the species encountered (Figure 2). This was followed by the Asteridae (27.33%) and the Dillenidae (11.87%). In order of decreasing number of species, the contributions of the remaining subclasses of the dicots were Hamamalidae (4.68%), Magnoliidae (2.88%) and Caryophyllidae (2.52%). The monocots were distributed in four subclasses; namely, Commelinidae, Arecidae, Zingiberidae and Liliidae and their contribution to the total number of species encountered in the study were 10.43%, 2.52%, 1.80% and 1.08% respectively. The Pteridophyta group formed 3.96% of the total number of plant species obtained in the study (Figure 2).

Plant species of the flora of the unmined area

Two hundred and nine species found in the unmined study area were distributed in 185 genera and 73 families (Table 6).

Table 6: *Plant species of the unmined study area*

Species Name	Family	Life form	Star rating	Ecological guild
Justicia flava (**Forsk) Vahl.**	Acanthaceae	Herb	NA	Pioneer
Cyathula achyranthoides **(H.B.&K.) Miq.**	Amaranthaceae	Herb	NA	Pioneer
Cyathula prostrata **(L.) Blume**	Amaranthaceae	Herb	NA	Pioneer
Antrocaryon micraster **A. Chev. & Guillaum.**	Anacardiaceae	Tree	Red	NPLD
Xylopia aethropica **(Dunal) A. Rich**	Annonaceae	Climber	Blue	Swamp
Hexalobus crispiflorus **A. Rich**	Annonaceae	Tree	Green	SB
Pachypodanthium standtii **Engl. & Diels.**	Annonaceae	Tree	Green	NPLD
Cleistopholis patens **(Benth.) Engl. & Diels.**	Anonaceae	Tree	Green	Pioneer
Funtumia elastica **(Preuss) Stapf.**	Apocynaceae	Tree	Pink	NA
Holarrhena floribunda **(G.Don) Dur. & Schinz.**	Apocynaceae	Tree	Green	Pioneer
Rauvolfia vomitoria **Afzel.**	Apocynaceae	Tree	Green	Pioneer
Tabernaemontana africana **DC.**	Apocynaceae	Tree	Green	SB
Voacanga africana **Stapf.**	Apocynaceae	Tree	Green	Pioneer
Voacanga thouarsii **Roem & Schult.**	Apocynaceae	Tree	Green	Swamp
Colacassia esculenta **(Linn.)**	Araceae	Herb	NA	NA
Cussonia bancoensis **Aubrev. & Pellegr.**	Araliaceae	Tree	Gold	Pioneer
Secamone afzelii **(Shult) K. Schum**	Asclepiadaceae	Cimber	Green	SB
Tylophora sylvatica **Decne.**	Asclepiadaceae	Climber	NA	Pioneer
Gynura sarmentosa **(Blume.) DC.**	Asteraceae	Climber	NA	Pioneer
Bidens pilosa **Linn.**	Asteraceae	Herb	NA	Pioneer
Eclipta prostrata **(Linn.) Linn.**	Asteraceae	Herb	NA	Pioneer
Emilia coccinea **(Sims.) G. Don**	Asteraceae	Herb	NA	Pioneer
Mikania scandens **(Burm.f.) Robinson**	Asteraceae	Herb	NA	NA
Spilanthes filicaulis **(Schum. And Thunn.) C.D.Adams**	Asteraceae	Herb	NA	Pioneer
Synedrella nodiflora **Gaertn.**	Asteraceae	Herb	Green	Pioneer
Tridax procumbens **L.**	Asteraceae	Herb	NA	Pioneer

Table 6, continued

***Chromolaena odorata* (L.) King & Robinson**	Asteraceae	Shrub	Green	Pioneer
***Vernonia conferta* Benth.**	Asteraceae	Tree	Green	Pioneer
***Diplazium sammatii* (Kuhn.) C. Chr.**	Athyriaceae	Fern	Green	NA
***Diplazium welwitschii* (Hook.) Diels**	Athyriaceae	Fern	Gold	NA
***Kigelia africana* (Lam.) Benth.**	Bignoniaceae	Tree	Green	NPLD
***Newbouldia laevis* (P.Beauv.) Seeman ex Bureau**	Bignoniaceae	Tree	Green	Pioneer
***Bombax buonopozense* P. Beauv.**	Bombacaceae	Tree	Pink	Pioneer
***Ceiba pentandra* Gaertn.**	Bombacaceae	Tree	Green	Pioneer
***Ananas sativa* Schult. f.**	Bromeliaceae	Herb	NA	Pioneer
***Dacryodes klaineana* (Pierre). H.J. Lam**	Burseraceae	Tree	Green	SB
***Anthonatha macrophyla* P.Beauv.**	Caesalpinaceae	Tree	Green	SB
***Daniellia ogea* (Harms) Holland**	Caesalpinaceae	Tree	Pink	Pioneer
***Dialium aubrevillei* Pellegr.**	Caesalpinaceae	Tree	Green	SB
***Distemonanthus benthamianus* Baill**	Caesalpinaceae	Tree	Pink	NPLD
***Griffornia simplicifolia* (Vahl. ex DC) Baill**	Caesalpinaceae	Tree	Green	NPLD
***Musanga cecropioides* R. Br.**	Cecropiaceae	Tree	Green	Pioneer
***Dactyladenia dinklagei* (Engler) G.T.Prance & F.White**	Chrysobalanaceae	Tree	Gold	SB
***Parinan excelsa* Sabine**	Chrysobalanaceae	Tree	Green	NPLD
***Mammea africana* Sabine**	Clusiaceae	Tree	Pink	SB
***Combretum racemosum* P. Beauv.**	Combretaceae	Climber	Green	Pioneer
***Combretum hispidium* Laws**	Combretaceae	Liane	Green	NA
***Terminalia ivorensis* A. Chev.**	Combretaceae	Tree	Scarlet	Pioneer
***Terminalia superba* A. Chev.**	Combretaceae	Tree	Green	Pioneer
***Commelina benghalensis* Linn**	Commelinaceae	Herb	Green	Pioneer
***Palisota hirsuta* (Thunb.) K.**	Commelinaceae	Herb	Green	Pioneer
***Castanola paradoxa* (Gilg) Schellenb**	Connaraceae	Liane	Green	NPLD
***Ipomoea involucrata* P. Beauv.**	Convolvulaceae	Climber	NA	Pioneer
***Calycobolus africanus* (G.Don) Heine**	Convolvulaceae	Liane	Green	NA
***Ipomoea mauritania* Jacq.**	Convulvulaceae	Climber	NA	Pioneer
***Ipomoea aquatica* Forsk.**	Convulvulaceae	Herb	NA	NA
***Ipomoea herderifolia* Linn**	Convulvulaceae	Herb	NA	Pioneer
***Sclerea verrucosa* Wild**	Cyperaceae	Herb	Green	Pioneer
***Pteridium aquilinum* (Linn.) Kuhn.**	Dennstaedtiaceae	Fern	NA	Pioneer
***Dichapetalum jonstoni* Engl.**	Dichapetalaceae	Climber	Green	NPLD

Table 6, continued

Tetracera alnifolia **Willd.**	Dilleniaceae	Liane	Green	NA
Dioscorea alata **Linn.**	Dioscoreaceae	Climber	Green	NA
Diospyros viridicans **Hiem**	Ebenaceae	Tree	Green	SB
Euphorbia hirta **L.**	Euphorbiaceae	Herb	Green	Pioneer
Phyllantus amarus **Schum. et Thonn.**	Euphorbiaceae	Herb	NA	Pioneer
Tragia benthamii **Bak.**	Euphorbiaceae	Herb	NA	NA
Maniophyton fulvrum **Mull.Arg.**	Euphorbiaceae	Liane	Green	NPLD
Jatropha gossypiifolia **Linn.**	Euphorbiaceae	Shrub	NA	NA
Manihot esculenta **Crantz.**	Euphorbiaceae	Shrub	NA	NA
Alchornea cordifolia **(Schum.&Thonn.) Muell.Arg**	Euphorbiaceae	Tree	Green	Pioneer
Discoglypremna caloneura **(Pax) Prain**	Euphorbiaceae	Tree	Green	Pioneer
Drypetes aubrevillei **Leandri**	Euphorbiaceae	Tree	Blue	SB
Macaranga barteri **Mull. Arg.**	Euphorbiaceae	Tree	Green	Pioneer
Macaranga heterophylla **(Mull. Arg.) Mull. Arg.**	Euphorbiaceae	Tree	Green	Pioneer
Macaranga hurifolia **Beille**	Euphorbiaceae	Tree	Green	Pioneer
Mallotus oppositifolius **(Geisel.) Mull.Arg.**	Euphorbiaceae	Tree	Green	SB
Mareya micrantha **(Benth.) Mull. Arg.**	Euphorbiaceae	Tree	Green	SB
Margaritaria discoidea **(Baill.) Webster**	Euphorbiaceae	Tree	Green	Pioneer
Ricinodendron heudolotii **(Baill) Pierre ex Pax.**	Euphorbiaceae	Tree	Green	Pioneer
Tretrorchidium didymostemom **(Baill.) Pax & Hoffm**	Euphorbiaceae	Tree	Green	NA
Uapaca guineensis **Muell. Arg.**	Euphorbiaceae	Tree	Green	NPLD
Afzelia africana **Sm.**	Fabaceae	Tree	Red	NPLD
Bambusa vulgaris **Schrad. ex Mendel**	Gramineae	Tree	Green	Swamp
Allanblackia floridunda **A.Chev.**	Guttiferae	Tree	Green	SB
Pentadesma butyracea **Sabine**	Guttiferae	Tree	Blue	SB
Pityrogramma calomelanos **(Linn.) Link**	Gymnogrammaceae	Fern	Green	NA
Harungana madagascariensis **Lam. Ex Poir.**	Hypericaceae	Tree	Green	Pioneer
Iodes africana **Welw. ex Oliv.**	Icacinaceae	Climber	Green	NA
Hoslunda opposita **Vahl./**	Lamiaceae	Herb	Green	Pioneer
Platostomi africanum **P. Beauv.**	Lamiaceae	Herb	NA	Pioneer
Cassytha filiformis **Linn.**	Lauraceae	Climber	NA	NA
Petersianthus macrocarpus **(Beauv.) Liben**	Lecythidaceae	Tree	Green	Pioneer
Berlinia occidentalis **Keay**	Leguminosae	Tree	Gold	NA
Gilbertiodendro limba **(Scott Elliot) J. Leonard**	Leguminosae	Tree	NA	NA
Pentaclethra macrophyla **Benth.**	Leguminosae	Tree	Green	NPLD

Table 6, continued

Piptadeniastrum africanum (Hook f.) Brenan	Leguminosae	Tree	Pink	NPLD
Spigelia anthelmia L.	Loganiaceae	Herb	NA	Pioneer
Usteria guineensis Wild.	Loganiaceae	Liane	Green	NPLD
Anthocleista nobilis (G..Don)	Loganiaceae	Tree	Green	Pioneer
Bolbitis gemmifera (Hierm) C.Chr.	Lomariopsidaceae	Fern	Green	NA
Lycopodium cernum Linn.	Lycopodiaceae	Fern	Green	NA
Lygodium macrophylla (Kuntz.) Sw.	Lygodiaceae	Fern	NA	NA
Sida acuta Burm.f.	Malvaceae	Herb	NA	Pioneer
Thespesia _populnea_ (L.) Soland. ex Correa	Malvaceae	Tree	NA	NA
Sarcophrynium brachystachys ıum.	Maranthaceae	Herb	NA	NA
Thalia geniculata L.	Maranthaceae	Shrub	NA	NA
Carapa procera DC.	Meliaceae	Tree	Green	SB
Entandopgragma cylindricum (Sprague) Sprague	Meliaceae	Tree	Scarlet	NPLD
Entandophragma angolense (Welw.) DC.	Meliaceae	Tree	Red	NPLD
Guarea thompsoni Sprague & Hutch	Meliaceae	Tree	Pink	SB
Khaya ivoriensis A.Chev.	Meliaceae	Tree	Scarlet	NPLD
Trichilia monadelpha (Thonn.) De Wild	Meliaceae	Tree	Green	NPLD
Trichilia prieuriana A. Juss.	Meliaceae	Tree	Green	NPLD
Turraenthus africanus (Weiw. ex C. DC.) Pellegr.	Meliaceae	Tree	Pink	SB
Mimosa pudica L.	Mimosaceae	Herb	NA	NA
Schrankia leptocarpus DC.	Mimosaceae	Herb	NA	Pioneer
Albizia ferruginea (Guill & Perr.) Benth.	Mimosaceae	Tree	Scarlet	NPLD
Albizia zygia (DC.) J.F Machr.	Mimosaceae	Tree	Green	NPLD
Cylicodiscus gabuneensis Harms.	Mimosaceae	Tree	Pink	SB
Parkia bicolor A.Chev.	Mimosaceae	Tree	Green	NPLD
Tetrapleura tetraptera (Schum & Thonn.)	Mimosaceae	Tree	Green	Pioneer
Xylia evansii Hutch.	Mimosaceae	Tree	Blue	NPLD
Ficus asperifolia Miq.	Moraceae	Herb	Green	Pioneer
Antiaris toxicaria Leschen.	Moraceae	Tree	Pink	NPLD
Ficus capensis Thunb.	Moraceae	Tree	NA	NA
Ficus craterostoma Mildbr. & Buretti	Moraceae	Tree	Green	NA
Ficus exasperata Vahl.	Moraceae	Tree	Green	Pioneer
Milicia excelsa (Welw.) Berg.	Moraceae	Tree	Green	Pioneer
Treculia africana Decne.	Moraceae	Tree	Green	NPLD
Pycnanthus angolensis (Welw.) Warb.	Myristicaceae	Tree	Pink	NPLD

Table 6, continued

Nephrolepis bisserata **(Swartz.) Schott.**	Nephrolepidaceae	Herb	Green	NPLD
Ochna staudtii **Engl. & Gilg.**	Ochnaceae	Tree	Green	SB
Ludwigia decurren **Walter**	Onagraceae	Herb	NA	NA
Eremospatha marocarpa **(Man. & Wendl) Wendl.**	Palmaceae	Liane	Pink	NA
Elais guineensis **Jacq.**	Palmaceae	Tree	Pink	Pioneer
Raphia hookeri Mann. **& Wendi**	Palmaceae	Tree	Green	Swamp
Centrosema pubescens **Benth.**	Papilionaceae	Climber	Green	Pioneer
Calopogonium mucunoides **Desv.**	Papilionaceae	Herb	NA	Pioneer
Desmodium adscendens **(Sw.) DC.**	Papilionaceae	Herb	Green	NA
Amphimas pterocarpoides **Harms.**	Papilionaceae	Tree	Red	NPLD
Baphia nitida **Lodd.**	Papilionaceae	Tree	Green	SB
Milletia zechiana **Harms**	Papilionaceae	Tree	Green	Pioneer
Piper guineense **Schumach. & Thonn.**	Piperaceae	Climber	NA	NA
Piper umbellatum **L.**	Piperaceae	Shrub	Green	Pioneer
Acroceras zizaniodes **(Kunth.) Dandy.**	Poaceae	Herb	Green	Pioneer
Brachiaria deflexa **(Schumach.) Hubbard ex Robyns**	Poaceae	Herb	NA	Pioneer
Digitaria horizontalis **Willd.**	Poaceae	Herb	NA	Pioneer
Panicum laxum **Sw. Pr.Br.**	Poaceae	Herb	NA	Pioneer
Panicum maximum **Jacq.**	Poaceae	Herb	NA	Pioneer
Paspalum scrobiculatum **L.**	Poaceae	Herb	NA	Pioneer
Setaria barbata **(Linn.) Kunth**	Poaceae	Herb	NA	Pioneer
Sorghum arundinaceum **(Desv.) Stapf.**	Poaceae	Herb	NA	Pioneer
Sporobolus pyramidalis **P.Beauv.**	Poaceae	Herb	NA	Pioneer
Polygonium lanigerum **R.Br.**	Polygonaceae	Herb	NA	NA
Mussaenda elegans **Schumach & Thonn.**	Rubiaceae	Climber	Green	Pioneer
Mussaenda tristigmatica **Cummins**	Rubiaceae	Climber	Blue	Pioneer
Coffea abracteolata **(Hiem) Brenan**	Rubiaceae	Herb	Green	SB
Euclinia longiflora **Salisb.**	Rubiaceae	Herb	Green	NA
Geophila obvallata **(Schum.) F. Didri**	Rubiaceae	Herb	Green	SB
Geophila repens **(Linn.) I.M.Johnston**	Rubiaceae	Herb	Green	NA
Oldenlandia corymbosa **Linn.**	Rubiaceae	Herb	NA	Pioneer
Richardia brasiliensis **Gomez**	Rubiaceae	Herb	NA	NA
Urena lobata **Linn.**	Rubiaceae	Herb	NA	Pioneer
Cremaspora triflora **(Thonn.) Schum.**	Rubiaceae	Liane	Green	SB

Table 6, continued

***Pauridiantha afzelii* (Hiern.) Brem.**	Rubiaceae	Shrub	Blue	Pioneer
***Aulacocalx jasminiflora* Hook. f.**	Rubiaceae	Tree	Green	SB
***Bertiera racemosa* (G.Don) K. Schum.**	Rubiaceae	Tree	Green	Pioneer
***Mitragyna* sp.**	Rubiaceae	Tree	Red	NA
***Morinda lucida* Benth.**	Rubiaceae	Tree	Green	Pioneer
***Nuclea diderrichii* (De Wild) Merr**	Rubiaceae	Tree	Scarlet	NA
***Pavetta corymbosa* (SC.) F.N.Williams**	Rubiaceae	Tree	Green	NA
***Psydrax subcordata* DC.Bridon**	Rubiaceae	Tree	Green	Pioneer
***Citrus sinensis* (l.) Osbeck**	Rutaceae	Tree	NA	NA
***Zanthoxylum gilletii* (De Wild) Waterman**	Rutaceae	Tree	Green	Pioneer
***Zanthoxylum lemairei* (De Willd.) Waterman**	Rutaceae	Tree	Blue	Pioneer
***Grandiflorum Cardiospermum* Sw.**	Sapindaceae	Climber	Green	Pioneer
***Allophylus africanus* P. Beauv.**	Sapindaceae	Tree	Green	Pioneer
***Blighia sapida* Konig.2253**	Sapindaceae	Tree	Green	NPLD
***Dienbollia pinnata* (Poir.) Schum. & Thonn**	Sapindaceae	Tree	Green	NPLD
***Aningeria altissima* (A. Chev) Aubrev. & Pellegr.**	Sapotaceae	Tree	Red	NPLD
***Chrysophyllum giganteum* A. Chev**	Sapotaceae	Tree	Pink	SB
***Pachystela brevipes* Engl.**	Sapotaceae	Tree	Green	NPLD
***Scoparia dulcis* Linn.**	Scrophulariaceae	Herb	Green	Pioneer
***Hannoa klaineana* Pierre & Engl.**	Simaroubaceae	Tree	Green	Pioneer
***Smilax kraussiana* Meisn.**	Smilacaceae	Climber	Green	Pioneer
***Physalis angulata* Linn.**	Solanaceae	Herb	NA	Pioneer
***Schwenkia americana* L.**	Solanaceae	Herb	NA	Pioneer
***Solanum erianthum* D. Don**	Solanaceae	Tree	Green	Pioneer
***Melochia corchorifolia* L.**	Sterculiaceae	Herb	NA	Pioneer
***Waltheria indica* Linn.**	Sterculiaceae	Herb	NA	Pioneer
***Cola chlamydantha* K,Schum.**	Sterculiaceae	Tree	Red	SB
***Cola gigantea* A. Chev.**	Sterculiaceae	Tree	Green	NPLD
***Herittiera utilis* (Sprague) Sprague**	Sterculiaceae	Tree	Red	NPLD
***Nesogordonia papaverifera* (A. Chev.) R. Capuron**	Sterculiaceae	Tree	Pink	SB
***Theobroma cacao* L.**	Sterculiaceae	Tree	NA	NA
***Triplochiton scleroxylon* K.Schum.**	Sterculiaceae	Tree	Scarlet	Pioneer
***Cyclosorus afer* (Christ) Ching**	Thelypteridaceae	Fern	NA	NA
***Cyclosorus striatus* (Schum.) Ching**	Thelypteridaceae	Fern	NA	NA

Table 6, continued

Grewia pubescens **P. Beauv.**	Tiliaceae	Herb	Green	Pioneer
Christiana africana **DC**	Tiliaceae	Tree	Green	NA
Glphaea brevis **(Spreng) Monach.**	Tiliaceae	Tree	Green	NA
Celtis mildbraedii **Engl.**	Ulmaceae	Tree	Green	SB
Trema orientalis **(L.) Blume**	Ulmaceae	Tree	Green	Pioneer
Fleurya aestuans **Miq.**	Urticaceae	Herb	NA	NA
Lantana camara **Linn.**	Verbenaceae	Herb	NA	Pioneer
Rinorea welwitschii **(Oliv.) O.Ktze**	Violaceae	Tree	Green	SB
Cissus aralioides **(Welw. ex Bak.) Planch.**	Vitaceae	Climber	Green	NA
Cissus cymosa **Schum.& Thonn.**	Vitaceae	Climber	Green	NA
Aframomum melegueta **(Hook. f.)**	Zingiberaceae	Herb	Blue	Pioneer

Plant species of the flora of the mined study area

One hundred and fifty seven species identified in the mined area were distributed in 140 genera and 54 families (Table 7). Eighty eight plant species found in this study were common to both the unmined and mined areas (Appendix J).

Table 7: *Plant species of the mined study area*

Species name	**Family**	**Life form**	**Star rating**	**Ecological guild**
Aspilia africana **(Pers.) C.D.Adams**	Asteraceae	Climber	NA	Pioneer
Calopogonium mucunioides **Desv.**	Papilionaceae	Climber	NA	Pioneer
Cardiospermum grandiflorum **Swartz.**	Sapindaceae	Climber	Green	Pioneer
Centrosema pubescens **Benth.**	Papilionaceae	Climber	Green	Pioneer
Cissus aralioides **(Welw. ex Bak.) Planch.**	Vitaceae	Climber	Green	NA
Combretum racemosum **P. Beauv.**	Combretaceae	Climber	Green	Pioneer
Hewittia sublobata **L**	Convolvulaceae	Climber	NA	Pioneer
Indigofera macrophylla **Schum. & Thonn.**	Papilionaceae	Climber	**NA**	Pioneer
Iodes africana **Welw. ex Oliv.**	Icacinaceae	Climber	Green	NA
Ipomoea cairica **(L.) Sweet**	Convolvulaceae	Climber	NA	Pioneer
Ipomoea involucrata **L.**	Convolvulaceae	Climber	NA	Pioneer
Melanthera scandens **(Schum. & Thonn.) Roberty**	Asteraceae	Climber	NA	Pioneer
Momordica charantia **L.**	Cucurbitaceae	Climber	NA	Pioneer
Mussaenda elegans **Schum. &**	Rubiaceae	Climber	Green	Pioneer

Table 7, continued

Thonn.				
Operculina macrocarpa **(Linn.) Urban**	Convolvulaceae	Climber	NA	NA
Secamone afzelli **(Schult) K. Schum.**	Asclepiadaceae	Climber	Green	SB
Smilax kraussiana **Meisn.**	Smilacaceae	Climber	Green	NA
Tylophora sylvatica **Decne.**	Asclepiadaceae	Climber	NA	Pioneer
Xlyopia aethropica **(Dunal.) A. Rich.**	Annonaceae	Climber	Blue	Swamp
Cyclosorus afer **(Christ) Ching.**	Thelypteridaceae	Fern	NA	NA
Lycopodium **sp.**	Lycopodiaceae	Fern	NA	NA
Nephrolepis bisserata **(Swartz) Schott.**	Nephrolepidiaceae	Fern	Green	NPLD
Acroceras zizanoides **(Kunth.)**	Poaceae	Herb	Green	Pioneer
Ageratum conyzoides **L.**	Asteraceae	Herb	NA	Pioneer
Anchomanes difformis **(Blume) Engl.**	Araceae	Herb	Green	NA
Andropogon gayanus **Kunth.**	Poaceae	Herb	NA	NA
Aneilema beniniense **(P. Beauv.) Kunth.**	Commelinaceae	Herb	Green	Pioneer
Asystasia gigantica **(L.) T. Anders.**	Acanthaceae	Herb	Green	Pioneer
Bidens pilosa **L.**	Asteraceae	Herb	NA	Pioneer
Boerhavia diffusa **L.**	Nyctaginaceae	Herb	NA	Pioneer
Bracharia deflexa **(Schumach.) Hubbard ex Robyns.**	Poaceae	Herb	Green	Pioneer
Brillantaisia nitens **Lindau**	Acanthaceae	Herb	Green	Pioneer
Bryophylum pinnatum **(Lam.) Kutz.**	Crassulaceae	Herb	NA	NA
Capsicum frutescens **L.**	Solanaceae	Herb	NA	Pioneer
Coffea abracteolata **(Hiem) Brenan**	Rubiaceae	Herb	Green	SB
Coix lacryma-jobi **L**	Poaceae	Herb	NA	Pioneer
Commelina benghalensis L.	Commelinaceae	Herb	Green	Pioneer
Crotalaria retusa **Linn.**	Papilionaceae	Herb	NA	Pioneer
Cyathula achyranthoides **(H.B.& K.) Moq.**	Amaranthaceae	Herb	NA	Pioneer
Cynodon dactylon **(L.) Pers.**	Poaceae	Herb	NA	NA
Cyperus rotundus **L.**	Cyperaceae	Herb	NA	Pioneer
Dactyloctenium aegyptium **(L.) P.Beauv.**	Poaceae	Herb	NA	NA
Desmodium adscendens **(Sw.) DC.**	Papilionaceae	Herb	NA	Pioneer
Desmodium scopiurus **(SW.) Desv.**	Fabaceae	Herb	NA	NA
Dieffenbachia seguire **Schott.**	Araceae	Herb	NA	NA
Digitaria horizontalis **Willd.**	Poaceae	Herb	NA	Pioneer
Dissotis rotundifolia **(Sm.) Triana**	Melastomataceae	Herb	Green	Pioneer
Echinochloa cruspavonis **(Kunth)**	Poaceae	Herb	NA	Pioneer

Table 7, continued

Schult.				
***Eleusine indica* (L.) Gaertn.**	Poaceae	Herb	NA	Pioneer
***Emilia coccinea* (Sims) G.Don.**	Asteraceae	Herb	NA	Pioneer
***Eregeron floribundus* (H.B &K.) Sch. Bip**	Asteraceae	Herb	NA	NA
***Euphorbia heterophylla* L.**	Euphorbiaceae	Herb	NA	Pioneer
***Euphorbia hirta* L.**	Euphorbiaceae	Herb	Green	Pioneer
***Euphorbia prostrata* L.**	Euphorbiaceae	Herb	NA	Pioneer
***Ficus asperifolia* Miq.**	Euphorbiaceae	Herb	Green	Pioneer
***Fleurya aestuans* Miq.**	Urticaceae	Herb	NA	NA
***Fluerya ovalifolia* (Schum. & Thonn.) Dandy**	Urticaceae	Herb	NA	NA
***Hibiscus esculentus* L.**	Malvaceae	Herb	NA	NA
***Hilleria latifolia* (Lam) H. Walt**	Phytolaccaceae	Herb	NA	NA
***Hydrolea globra* Schum. & Thonn.**	Hydrophyllaceae	Herb	NA	NA
***Hyptis suaveolens* Poir**	Lamiaceae	Herb	NA	NA
***Imperata cylindrica* (L.) Beauv.**	Poaceae	Herb	NA	NA
***Ischaemum rugosum* Salisb.**	Poaceae	Herb	NA	Pioneer
***Leptochloa caerulescens* Steud.**	Poaceae	Herb	NA	Pioneer
***Ludwigia decurren* Walter.**	Onagraceae	Herb	NA	NA
***Lycopersicum esculentum* Mill.**	Solanaceae	Herb	NA	NA
***Mariscus althernifolia* Vahl.**	Cyperaceae	Herb	NA	Pioneer
***Melochia corchorifolia* L.**	Sterculiaceae	Herb	NA	Pioneer
***Microglossa afzelii* O. Hoffm.**	Asteraceae	Herb	NA	NA
***Mimosa nigra* L.**	Mimosaceae	Herb	NA	Pioneer
***Mimosa pudica* L.**	Mimosaceae	Herb	NA	Pioneer
***Mollugo verticillata* L.**	Molluginaceae	Herb	NA	Pioneer
***Momordica foetida* Schum. &Thonn.**	Cucurbitaceae	Herb	NA	Pioneer
***Musa paradisiaca* L.**	Musaceae	Herb	NA	NA
***Oldenlandia corymbosa* L.**	Rubiaceae	Herb	NA	Pioneer
***Palisota hirsuta* (Thunb.) K. Schum.**	Commelinaceae	Herb	Green	Pioneer
***Panicum laxum* Jacq.Sw. PR.Br.**	Poaceae	Herb	NA	Pioneer
***Panicum maximum* Jacq.**	Poaceae	Herb	Green	Pioneer
***Paspalum conjugatum* Berg.**	Poaceae	Herb	NA	Pioneer
***Paspalum scrobiculatum* L.**	Poaceae	Herb	NA	Pioneer
***Pauzolzia guineensis* Benth**	Urticaceae	Herb	NA	NA
***Pennisetum polystachion* (L.) Schult.**	Poaceae	Herb	NA	Pioneer
***Pergularia daemia* (Forsk.) Chiov.**	Asclepiadaceae	Herb	NA	Pioneer
***Phyllantus amarus* Schum. et Thonn.**	Euphorbiaceae	Herb	NA	Pioneer
***Physalis angulata* L.**	Solanaceae	Herb	NA	NA
***Physalis micrantha* Link**	Solanaceae	Herb	NA	NA
***Platostomi africanum* P. Beauv.**	Lamiaceae	Herb	NA	Pioneer

Table 7, continued

Polygonium lanigerum **R.Br.**	Polygonaceae	Herb	NA	NA
Richardia brasiliensis **Gomez**	Rubiaceae	Herb	NA	NA
Rottboellia cochinchinensis **(Lour.) W.Clayton**	Poaceae	Herb	NA	Pioneer
Schrankia leptocarpus **DC.**	Mimosaceae	Herb	NA	Pioneer
Schwenckia americana **L.**	Solanaceae	Herb	NA	Pioneer
Sclerea verrucosa **Wild.**	Cyperaceae	Herb	Green	Pioneer
Scoparia dulcis **Linn.**	Scrophulariaceae	Herb	Green	Pioneer
Selaginella mysorus **(Sw.) Alston**	Selaginellaceae	Herb	Green	NA
Setaria barbata **(Lam) Kunth.**	Poaceae	Herb	NA	Pioneer
Sida acuta **Burn. F.**	Malvaceae	Herb	NA	Pioneer
Solanum nigrum **L.**	Solanaceae	Herb	NA	Pioneer
Solanum torvum **Sw.**	Solanaceae	Herb	NA	Pioneer
Sorghum arundinaceum **(Desv.) Stapf.**	Poaceae	Herb	NA	Pioneer
Sporobolus pyramidalis **P. Beauv.**	Poaceae	Herb	NA	Pioneer
Synedrella nodiflora **Gaertn.**	Asteraceae	Herb	Green	Pioneer
Talinum triangulare **(Jacq.) Willd.**	Portulacaceae	Herb	NA	Pioneer
Tragia benthmii **Bak.**	Euphorbiaceae	Herb	NA	NA
Tridax procumbens **L.**	Asteraceae	Herb	NA	Pioneer
Urena lobata **L.**	Malvaceae	Herb	NA	Pioneer
Vernonia cinerrea (L.) Less.	Asteraceae	Herb	NA	Pioneer
Walteria indica **Linn.**	Sterculiaceae	Herb	NA	Pioneer
Xanthosoma sagittifolium **(L.) Schoott**	Araceae	Herb	NA	NA
Zea mays **L.**	Poaceae	Herb	NA	NA
Combretum hispidium **Laws**	Combretaceae	Liane	Green	NA
Maniophyton fulvrum **Mull. Arg.**	Euphorbiaceae	Liane	Green	NPLD
Usteria guineensis **Willd.**	Loganiaceae	Liane	Green	NPLD
Anthonatha macrophyla **P.Beauv.**	Caesalpinaceae	Sapling	Green	SB
Daniellia ogea **(Harms) Holland**	Caesalpinaceae	Sapling	Pink	Pioneer
Dienbollia pinnata **(Poir) Schum. & Thonn.**	Sapindaceae	Sapling	Green	NPLD
Diospyros viridicans **Hiem**	Ebenaceae	Sapling	Green	SB
Herittiera utilis **(Sprague) Sprague**	Sterculiaceae	Sapling	Red	NPLD
Macaranga barteri **Mull. Arg.**	Euphorbiaceae	Sapling	Green	Pioneer
Musanga cecropioides **R. Br.**	Cecropiaceae	Sapling	Green	Pioneer
Ochna staudtii **Engl. & Gilg.**	Ochnaceae	Sapling	Green	SB
Rauvolfia vomitoria **Afzel.**	Apocynaceae	Sapling	Green	Pioneer
Terminalia ivorensis **A. Chev.**	Combretaceae	Sapling	Scarlet	Pioneer
Treculia africana **Decne.**	Moraceae	Sapling	Green	NPLD
Trichilia prieuriana **A. Juss.**	Meliaceae	Sapling	Green	NPLD
Voacanga africana **Stapf.**	Apocynaceae	Sapling	Green	Pioneer
Allophylus africanus **P. Beauv.**	Sapindaceae	Seedling	Green	Pioneer
Drypetes floribunda **(Muell. Arg) Hutch**	Euphorbiaceae	Seedling	Green	NA
Ficus capensis **Thunb.**	Moraceae	Seedling	NA	NA

Table 7, continued

***Grossera vignei* Hoyle**	Euphorbiaceae	Seedling	Green	SB
***Macaranga heterophylla* (Mull. Arg.) Mull. Arg.**	Euphorbiaceae	Seedling	Green	Pioneer
***Macaranga hurifolia* Beille**	Euphorbiaceae	Seedling	Green	Pioneer
***Alchornea cordifolia* (Schum. & Thonn) Muell.Arg**	Euphorbiaceae	Shrub	Green	Pioneer
***Cassia occidentalis* L.**	Caesalpiniaceae	Shrub	NA	Pioneer
***Chromolaena odorata* (L.) King & Robinson**	Asteraceae	Shrub	Green	Pioneer
***Jatropha gossypiifolia* Linn.**	Euphorbiaceae	Shrub	NA	NA
***Manihot esculenta* Crantz.**	Euphorbiaceae	Shrub	NA	NA
***Securinega virosa* (Roxb. Ex Wild) Benth.**	Euphorbiaceae	Shrub	NA	Pioneer
***Sida cordifolia* L.**	Malvaceae	Shrub	NA	NA
***Sida rhombifolia* L.**	Malvaceae	Shrub	NA	Pioneer
***Spigelia anthelmia* l.**	Loganiaceae	Shrub	NA	Pioneer
***Starchytarpheta indica* (L.) Vahl.**	Verbenaceae	Shrub	NA	Pioneer
***Antiaris toxicaria* Leschen.**	Moraceae	Tree	Pink	NPLD
***Baphia nitida* Lodd.**	Papilionaceae	Tree	Green	SB
***Berlinia occidentalis* Keay**	Leguminosae	Tree	Gold	NA
***Carapa procera* DC.**	Meliaceae	Tree	Green	SB
***Ceiba pentandra* Gaertn.**	Bombaceae	Tree	Green	Pioneer
***Cola chlamydantha* K,Schum.**	Sterculiaceae	Tree	Red	SB
***Elaeis guineensis* Jacq.**	Palmaceae	Tree	Pink	Pioneer
***Gmelina arborea* Roxb.**	Verbanaceae	Tree	NA	NA
***Hallea ledermannii* (K. Krause) Verde**	Rubiaceae	Tree	Red	Swamp
***Mallotus oppositifolius* (Geisel.) Mull. Arg.**	Euphorbiaceae	Tree	Green	SB
***Morinda lucida* Benth.**	Rubiaceae	Tree	Green	Pioneer
***Pycnanthus angolense* (Welw.) Warb**	Myristicaceae	Tree	Pink	NPLD
***Solanum erianthum* D. Don.**	Solanaceae	Tree	Green	Pioneer
***Tectonia grandis* Linn.**	Verbanaceae	Tree	NA	NA
***Tetrapleura tetraptera* (Schum & Thonn.)**	Mimosaceae	Tree	Green	Pioneer

Distribution and abundance of plant species in the unmined and mined areas

The prevalence of the species in the unmined area ranged from 0.2% to 20.6% (Table 8). The species with relatively higher frequencies in the unmined area included *Spilanthes filicaulis* (20.6%), *Pteridium aquilinium* (18.6%), *Diplazium sammatii* (17.6%), *Sorghum arundinaceum* (17.6%), *Chromoleana odorata* (17.0%) and *Tridax procumbens* (16.6%). Other plants species of low frequency found in the unmined site included *Theobroma cacao* (1.0%), *Aningera altissima* (0.2%), *Ochna staudii* (0.2%) and *Zanthoxylum lemairei* (0.4%) (Table 8). The distribution of species in the mined area ranged between 58.4% and 0.2% (Table 9). Plant species which were relatively better distributed in the mined area included *Chromolaena odorata* (54.8%), *Echninochloa cruspavanis* (54.0%), *Helleria latifolia* (51.4%), *Euphorbia hirta* (46.2%), *Momordica charantia* (46.2%) and *Sporobolus pyramidalis* (45.4%). Other species of low distribution in the mined area included *Cola chlamydantha* (0.2%), *Solanum eranthium* (0.4%), *Treculia africana* (0.4%) and *Cyclosorus afer* (0.6%).

Table 8: *Density and frequency of plant species growing in the unmined area*

Species Name	Density (m^{-2})	Frequency (%)
***Acroceras zizanoides* (Kunth.) Dandy.**	0.093	8.0
***Aframomum melequeta* K. Schum**	0.003	0.6
***Afzelia africana* Sm.**	0.002	0.4
***Albizia ferruginea* (Guill & Perr.) Benth.**	0.003	0.6
***Albizia zygia* (DC.) J.F Machr.**	0.002	0.4
***Alchornea cordifolia* (Schum.&Thonn.) Muell.Arg**	0.005	1.0
***Allanblackia floridunda* A.Chev.**	0.004	0.8
***Allophylus africanus* P. Beauv.**	0.003	0.6
***Amphimas pterocarpoides* Harms.**	0.002	0.4
***Ananas sativa* Schult. f.**	0.005	1.0
***Aningeria altissima* (A. Chev) Aubrev. & Pellegr.**	0.001	0.2
***Anthocleista nobilis* (G..Don)**	0.001	0.2
***Anthonatha macrophyla* P.Beauv.**	0.002	0.4
***Antiaris toxicaria* Leschen.**	0.003	0.6

Table 8, continued

Antrocaryon micraster A. Chev. & Guillaum.	0.002	0.4
Aulacocalx jasminiflora Hook. f.	0.002	0.4
Bambusa vulgaris Schrad. ex Mendel	0.005	1.0
Baphia nitida Lodd.	0.004	0.8
Berlinia occidentalis Keay	0.002	0.4
Bertiera racemosa (G.Don) K. Schum.	0.002	0.6
Bidens pilosa Linn.	0.068	9.4
Blighia sapida Konig.	0.003	0.6
Bolbitis gemmifera (Hierm) C.Chr.	0.041	6.0
Bombax buonopozense P. Beauv.	0.002	0.4
Brachiaria deflexa (Schumach.) Hubbard ex Robyns	0.097	8.0
Calopogonium mucunoides Desv.	0.083	10.0
Calycobolus africanus (G.Don) Heine	0.013	1.0
Carapa procera DC.	0.004	0.8
Cassytha filiformis Linn.	0.062	6.2
Castanola paradoxa (Gilg) Schellenb	0.027	4.0
Ceiba pentandra Gaertn.	0.008	1.6
Celtis mildbraedii Engl.	0.003	0.6
Centrosema pubescens Benth.	0.118	11.6
Christiana africana DC	0.003	0.6
Chromolaena odorata (L.) King & Robinson	0.143	17.0
Chrysophyllum giganteum A. Chev	0.002	0.4
Cissus aralioides (Welw. ex Bak.) Planch.	0.094	7.6
Cissus cymosa Schum.& Thonn.	0.087	6.0
Citrus sinensis (l.) Osbeck	0.002	0.4
Cleistopholis patens (Benth.) Engl. & Diels.	0.003	0.6
Coffea abracteolata (Hiem) Brenan	0.069	3.4
Cola chlamydantha K,Schum.	0.002	0.4
Cola gigantea A. Chev.	0.003	0.6
Colacassia esculenta (Linn.) Schott.	0.018	2.0
Combretum hispidium Laws	0.027	2.0
Combretum racemosum P. Beauv.	0.081	9.6
Commelina benghalensis Linn	0.094	12.0
Cremaspora triflora (Thonn.) Schum.	0.023	10.0
Cussonia bancoensis Aubrev. & Pellegr.	0.002	0.4
Cyathula achyrantheides (H.B & K) Moq.	0.108	12.6

Table 8, continued

Cyathula prostrata (L.) Blume	0.071	11.6
Cyclosorus afer (Christ) Ching	0.110	11.8
Cyclosorus striatus (Schum.) Ching	0.050	5.4
Cylicodiscus gabuneensis Harms.	0.003	0.6
Dacryodes klaineana (Pierre). H.J. Lam	0.002	0.4
Dactyladenia dinklagei (Engler) G.T.Prance & F.White	0.003	0.6
Daniellia ogea (Harms) Holland	0.003	0.6
Desmodium adscendens (Sw.) DC.	0.073	3.4
Dialium aubrevillei Pellegr.	0.003	0.6
Dichapetalum jonstoni Engl.	0.047	4.0
Dienbollia pinnata (Poir.) Schum. & Thonn	0.002	0.4
Digitaria horizontalis Willd.	0.067	5.8
Dioscorea alata Linn.	0.002	0.4
Diospyros viridicans Hiem	0.003	0.6
Diplazium sammatii (Kuhn.) C. Chr.	0.137	17.6
Diplazium welwitschii (Hook.) Diels	0.075	12.0
Discoglypremna caloneura (Pax) Prain	0.002	0.4
Distemonanthus benthamianus Baill	0.002	0.4
Drypetes aubrevillei Leandri	0.002	0.4
Eclipta prostrata (Linn.) Linn.	0.079	4.6
Elais guineensis Jacq.	0.004	0.8
Emilia coccinea (Sims.) G. Don	0.038	2.6
Entandophragma angolense (Welw.) DC.	0.002	0.4
Entandophragma cylindricum (Sprague) Sprague	0.001	0.2
Eremospatha marocarpa (Man. & Wendl) Wendl.	0.025	3.8
Euclinia longiflora Salisb.	0.032	6.4
Euphorbia hirta L.	0.148	12.6
Ficus asperifolia Miq.	0.077	12.6
Ficus capensis Thunb.	0.012	2.4
Ficus craterostoma Mildbr. & Buretti	0.002	0.4
Ficus exasperata Vahl.	0.003	0.6
Fleurya aestuans Miq.	0.004	0.8
Funtumia elastica (Preuss) Stapf.	0.004	0.8
Geophila obvallata (Schum.) F. Didri	0.073	7.6
Geophila repens (Linn.) I.M.Johnston	0.066	6.0
Gilbertiodendro limba (Scott Elliot) J. Leonard	0.003	0.6
Glyphaea brevis (Spreng) Monach.	0.002	0.4

Table 8, continued

Grandiflorum cardiospermum **Sw.**	0.063	9.0
Grewia pubescens **P. Beauv.**	0.138	7.0
Griffornia simplicifolia **(Vahl. ex DC) Baill**	0.002	0.4
Guarea thompsoni **Sprague & Hutch**	0.002	0.4
Gynura sarmentosa **(Blume.) DC.**	0.046	6.6
Hannoa klaineana **Pierre & Engl.**	0.002	0.4
Harungana madagascariensis **Lam. Ex Poir.**	0.003	0.6
Herittiera utilis **(Sprague) Sprague**	0.003	0.6
Hexalobus crispiflorus **A. Rich**	0.002	0.4
Holarrhena floribunda **(G.Don) Dur. & Schinz.**	0.003	0.6
Hoslunda opposita **Vahl.**	0.037	3.0
Iodes africana **Welw. ex Oliv.**	0.008	1.2
Ipomoea aquatica **Forsk.**	0.033	7.3
Ipomoea herderifolia **Linn**	0.066	8.0
Ipomoea involucrata **P. Beauv.**	0.077	13.2
Ipomoea mauritania **Jacq.**	0.042	6.6
Jatropha gossypiifolia **Linn.**	0.033	5.0
Justicia flava **(Forsk) Vahl.**	0.055	8.0
Khaya ivorensis **A.Chev.**	0.002	0.4
Kigelia africana **(Lam.) Benth.**	0.005	1.0
Lantana camara **Linn.**	0.030	4.8
Ludwigia decurren **Walter**	0.036	5.6
Lycopodium cernum **Linn.**	0.095	14.4
Lygodium macrophylla **(Kuntz.) Sw.**	0.071	11.8
Macaranga barteri **Mull. Arg.**	0.010	2.0
Macaranga heterophylla **(Mull. Arg.) Mull. Arg.**	0.011	2.2
Macaranga hurifolia **Beille**	0.007	1.4
Mallotus oppositifolius **(Geisel.) Mull.Arg.**	0.003	0.6
Mammea africana **Sabine**	0.003	0.6
Manihot esculenta **Crantz.**	0.011	1.2
Maniophyton fulvrum **Mull.Arg.**	0.009	2.0
Mareya micrantha **(Benth.) Mull. Arg.**	0.002	0.4
Margaritaria discoidea **(Baill.) Webster**	0.002	0.4
Melochia corchorifolia **L.**	0.084	11.6
Mikania scandens **(Burm.f.) Robinson**	0.041	4.0
Milicia excelsa **(Welw.) Berg.**	0.004	0.8
Milletia zechiana **Harms**	0.003	0.6

Table 8, continued

Mimosa pudica **L.**	0.119	11.0
Mitragyna **sp.**	0.003	0.6
Morinda lucida **Benth.**	0.003	0.6
Musanga cecropioides **R. Br.**	0.009	1.8
Mussaenda elegans **Schumach & Thonn.**	0.037	4.4
Mussaenda tristigmatica **Cummins**	0.045	6.6
Nephrolepis bisserata **(Swartz.) Schott.**	0.127	15.8
Nesogordonia papaverifera **(A. Chev.) R. Capuron**	0.002	0.4
Newbouldia laevis **(P.Beauv.) Seeman ex Bureau**	0.003	0.6
Nuclea diderrichii **(De Wild) Merr**	0.002	0.4
Ochna staudtii **Engl. & Gilg.**	0.001	0.2
Oldenlandia corymbosa **Linn.**	0.073	9.4
Pachypodanthium standtii **Engl. & Diels.**	0.001	0.2
Pachystela brevipes **Engl.**	0.004	0.8
Palisota hirsuta **(Thunb.) K. Schum.**	0.050	7.8
Panicum laxum **Sw. Pr.Br.**	0.071	8.0
Panicum maximum **Jacq.**	0.097	14.8
Parinari excelsa **Sabine**	0.002	0.4
Parkia bicolor **A.Chev.**	0.001	0.2
Paspalum scrobiculatum **L.**	0.075	11.2
Pauridiantha afzelii **(Hiern.) Brem.**	0.042	5.8
Pavetta corymbosa **(SC.) F.N.Williams**	0.003	0.6
Pentaclethra macrophyla **Benth.**	0.005	1.0
Pentadesma butyracea **Sabine**	0.002	0.4
Petersianthus macrocarpus **(Beauv.) Liben**	0.005	1.0
Phyllantus amarus **Schum. et Thonn.**	0.055	8.8
Physalis angulata **Linn.**	0.079	7.2
Piper guineense **Schumach. & Thonn.**	0.045	7.6
Piper umbellatum **L.**	0.046	6.6
Piptadeniastrum africanum **(Hook f.) Brenan**	0.004	0.8
Pityrogramma calomelanos **(Linn.) Link**	0.085	11.6
Platostomi africanum **P. Beauv.**	0.047	3.8
Polygonium lanigerum **R.Br.**	0.047	8.0
Psydrax subcordata **DC.Bridon**	0.001	0.2
Pteridium aquilinum **(Linn.) Kuhn.**	0.215	18.6
Pycnanthus angolensis **(Welw.)**	0.003	0.6

Table 8, continued

Warb.		
***Raphia hookeri Mann.*& Wendi**	0.002	0.4
***Rauvolfia vomitoria* Afzel.**	0.002	0.4
***Richardia brasiliensis* Gomez**	0.059	6.6
***Ricinodendron heudolotii* (Baill) Pierre ex Pax.**	0.002	0.4
***Rinorea welwitschii* (Oliv.) O.Ktze**	0.002	0.4
***Sarcophrynium brachystachys* (Benth.) SSSchum Schum.**	0.036	4.4
***Schrankia leptocarpus* DC.**	0.051	8.0
***Schwenkia americana* L.**	0.048	6.4
***Sclerea verrucosa* Wild.**	0.062	10.0
***Scoparia dulcis* Linn.**	0.085	15.4
***Secamone afzelii* (Schult) K. Schum**	0.076	11.2
***Setaria barbata* (Linn.) Kunth**	0.052	8.8
***Sida acuta Burm*.f.**	0.033	7.6
***Smilax kraussiana* Meisn.**	0.036	6.8
***Solanum erianthum* D. Don**	0.004	0.8
***Sorghum arundinaceum* (Desv.) Stapf.**	0.053	17.6
***Spigelia anthelmia* L.**	0.098	12.6
***Spilanthes filicaulis* (Schum. And Thunn.) C.D.Adams**	0.067	20.6
***Sporobolus pyramidalis* P.Beauv.**	0.090	10.4
***Synedrella nodiflora* Gaertn.**	0.039	3.6
***Tabernaemontana africana* DC.**	0.004	0.8
***Terminalia ivorensis* A. Chev.**	0.004	0.8
***Terminalia superba* A. Chev.**	0.003	0.6
***Tetracera alnifolia* Willd.**	0.025	4.8
***Tetrapleura tetraptera* (Schum & Thonn.)**	0.002	0.4
***Thalia geniculata* L.**	0.060	8.8
***Theobroma cacao* L.**	0.004	0.1
***Thespisia populnea* (L.) Soland. ex Correa**	0.002	0.4
***Tragia benthamii* Bak**	0.082	7.4
***Treculia africana* Decne.**	0.002	0.4
***Trema orientalis* (L.) Blume**	0.002	0.4
***Tretrorchidium didymostemom* (Baill.) Pax & Hoffm**	0.002	0.4
***Trichilia monadelpha* (Thonn.) De Wild**	0.004	0.8
***Trichilia prieuriana* A. Juss.**	0.002	0.4
***Tridax procumbens* L.**	0.191	16.6
***Triplochiton scleroxylon* K.Schum.**	0.002	0.6

Table 8, continued

Turraenthus africanus **(Weiw. ex C. DC.) Pellegr.**	0.002	0.4
Tylophora sylvatica **Decne.**	0.035	3.0
Uapaca guineensis **Muell. Arg.**	0.003	0.6
Urena lobata **Linn.**	0.050	7.8
Usteria guineensis **Wild.**	0.022	3.2
Vernonia conferta **Benth.**	0.007	1.2
Voacanga africana **Stapf.**	0.003	0.6
Voacanga thouarsii **Roem & Schult.**	0.004	0.8
Waltheria indica **Linn.**	0.165	15.0
Xylia evansii **Hutch.**	0.002	0.4
Xylopia aethropica **(Dunal) A. Rich**	0.025	2.8
Zanthoxylum gilletii **(De Wild) Waterman**	0.003	0.6
Zanthoxylum lemairei **(De Willd.) Waterman**	0.002	0.4

Source: Field study (2017)

The densities of species in the unmined area were generally low (Table 8). Plant species with relatively higher density values included *Pteridium aquilinum* (0.215), *Tridax procumbens* (0.191), *Waltheria indica* (0.165), *Euphorbia hirta* (0.148), *Chromolaena odorata* (0.148) and *Grewia pubescens* (0.138). Species with least density value of 0.01 in the unmined area included *Ochna staudii* and *Aningeria altissima* (Table 8). The values for the density of species in the mined area ranged from 0.002 to 4.368 (Table 9). Plant species such as *Chromolaena odorata* (4.368), *Sporobolus pyramidalis* (2.136), *Echinochloa cruspavonis* (1.500), *Panicum maximum* (1.395) and *Commelina benghalensis* (1.350) had relatively higher density values in the mined area (Table 9). *Solanum erianthum* (0.002), *Hallea ledermannii* (0.002), *Cyclosorus afer* (0.003), *Berhinia occidentalis* (0.003) and *Antiaris africana* (0.003) had low density values (Table 9).

Table 9: *Density and frequency of plant species growing in the mined area*

Species name	**Density (m^{-2})**	**Frequency (%)**
***Acroceras zizanoides* (Kunth.) Dandy**	0.33	19.8
***Ageratum conyzoides* L.**	0.37	17.0
***Alchornea cordifolia* (Schum. & Thonn) Muell.Arg**	0.05	2.0
***Allophylus africanus* P. Beauv.**	0.01	3.0
***Anchomanes difformis* (BIume) Engl.**	0.36	30.4
***Andropogon gayanus* Kunth.**	0.40	3.0
***Aneilema beniniense* (P. Beauv.) Kunth.**	0.67	31.4
***Anthonatha macrophyla* P.Beauv.**	0.01 .	1.6
***Antiaris toxicaria* Leschen.**	0.01	0.6
***Aspilia africana* (Pers.) C.D.Adams**	1.01	35.6
***Asystasia gigantica* (L.) T. Anders.**	0.61	20.0
***Baphia nitida* Lodd.**	0.04	0.8
***Berlinia occidentalis* Keay**	0.01	0.6
***Bidens pilosa* L.**	0.79	37.0
***Boerhavia diffusa* L.**	0.19	20.4
***Bracharia deflexa* (Schumach.) Hubbard ex Robyns.**	1.15	38.6
***Bryophylum pinnatum* (Lam.) Kutz.**	0.43	22.4
***Brillantaisia nitens* Lindau**	1.03	39.0
***Calopogonium mucunioides* Desv.**	0.42	16.6
***Capsicum frutescens* L.**	0.01	3.6
***Carapa procera* DC.**	0.01	0.8
***Cardiospermum grandiflorum* Swartz.**	0.39	20.4
***Cassia occidentalis* L.**	0.08	1.4
***Ceiba pentandra* Gaertn.**	0.01	0.6
***Centrosema pubescens* Benth.**	0.83	39.0
***Chromolaena odorata* (L.) King & Robinson**	4.37	58.4
***Cissus aralioides* (Welw. ex Bak.) Planch.**	0.61	43.4
***Coffea abracteolata* (Hiem) Brenan**	1.35	20.0
***Coix lacryma-jobi* L**	0.92	13.0
***Cola chlamydantha* K,Schum.**	0.01	0.2
***Combretum hispidium* Laws**	1.10	35.8
***Combretum racemosum* P. Beauv.**	0.54	15.0
Commelina benghalensis L.	1.35	28.8
***Crotalaria retusa* Linn.**	0.12	16.0
***Cyathula achyranthoides* (H.B.& K.) Moq.**	1.11	40.2

Table 9, continued

Cyclosorus afer (Christ) Ching.	0.01	0.6
Cynodon dactylon (L.) Pers.	1.14	41.0
Cyperus rotundus L.	1.39	25.8
Dactyloctenium aegyptium (L.) P.Beauv.	0.97	29.0
Daniellia ogea (Harms) Holland	0.01	1.4
Desmodium adscendens (Sw.) DC.	0.97	21.4
Desmodium scopiurus (SW.) Desv.	1.32	35.6
Dieffenbachia seguire Schott.	1.45	42.2
Dienbollia pinnata (Poir) Schum. & Thonn.	0.01	1.0
Digitaria horizontalis Willd.	0.97	33.0
Diospyros viridicans Hiem	0.01	0.8
Dissotis rotundifolia (Sm.) Triana	1.13	41.0
Drypetes floribunda (Muell. Arg) Hutch	0.01	0.8
Echinochloa cruspavonis (Kunth) Schult.	1.50	54.0
Elaeis guineensis Jacq.	0.02	4.2
Eleusine indica (L.) Gaertn.	0.22	13.6
Emilia coccinea (Sims) G.Don.	1.05	29.0
Eregeron floribundus (H.B &K.) Sch. Bip	0.61	30.2
Euphorbia heterophylla L.	0.90	33.2
Euphorbia hirta L.	1.83	46.2
Euphorbia prostrata L.	0.42	37.0
Ficus asperifolia Miq.	0.65	23.0
Ficus capensis Thunb.	0.01	0.6
Fleurya aestuans Miq.	0.14	29.4
Fluerya ovalifolia (Schum. & Thonn.) Dandy	1.06	41.6
Gmelina arborea Roxb.	0.01	1.0
Grossera vignei Hoyle	0.01	0.8
Hallea ledermannii (K. Krause) Verde	0.01	0.4
Herittiera utilis (Sprague) Sprague	0.01	1.2
Hewittia sublobata L	0.70	30.0
Hibiscus esculentus L.	0.01	1.4
Hilleria latifolia (Lam) H. Walt	0.67	51.4
Hydrolea globra Schum. & Thonn.	0.77	36.6
Hyptis suaveolens Poir	1.36	44.0
Imperata cylindrica (L.) Beauv.	1.10	38.2
Indigofera macrophylla Schum. & Thonn.	0.49	26.8
Iodes africana Welw. ex Oliv.	0.44	20.0
Ipomoea cairica (L.) Sweet	0.81	37.4
Ipomoea involucrata L.	0.60	27.6
Ischaemum rugosum Salisb.	0.79	23.8
Jatropha gossypiifolia Linn.	0.53	35.2
Leptochloa caerulescens Steud.	0.37	40.0
Ludwigia decurren Walter.	0.84	23.0
Lycopersicum esculentum Mill.	0.02	2.8

Table 9, continued

***Lycopodium* sp.**	0.01	0.8
***Macaranga barteri* Mull. Arg.**	0.01	1.6
***Macaranga heterophylla* (Mull. Arg.) Mull. Arg.**	0.01	0.6
***Macaranga hurifolia* Beille**	0.01	2.0
***Mallotus oppositifolius* (Geisel.) Mull. Arg.**	0.07	14.0
***Manihot esculenta* Crantz.**	0.01	1.2
***Maniophyton fulvrum* Mull. Arg.**	0.78	29.0
***Mariscus althernifolia* Vahl.**	0.96	31.4
***Melanthera scandens* (Schum. & Thonn.) Roberty**	0.93	42.2
***Melochia corchorifolia* L.**	1.01	35.0
***Microglossa afzelii* O. Hoffm.**	1.23	41.4
***Mimosa nigra* L.**	0.34	22.0
***Mimosa pudica* L.**	0.28	19.0
***Mollugo verticillata* L.**	0.81	38.0
***Momordica charantia* L.**	0.45	23.8
***Momordica foetida* Schum. &Thonn.**	0.94	46.2
***Morinda lucida* Benth.**	0.01	2.5
***Musa paradisiaca* L.**	0.01	2.4
***Musanga cecropioides* R. Br.**	0.01	1.0
***Mussaenda elegans* Schum. & Thonn.**	0.10	15.2
***Nephrolepis bisserata* (Swartz) Schott.**	0.44	17.2
***Ochna staudtii* Engl. & Gilg.**	0.01	2.0
***Oldenlandia corymbosa* L.**	0.52	11.2
***Operculina macrocarpa* (Linn.) Urban**	0.14	4.0
***Palisota hirsuta* (Thunb.) K. Schum.**	0.82	18.6
***Panicum laxum* Jacq.Sw. PR.Br.**	0.61	33.0
***Panicum maximum* Jacq.**	1.40	33.2
***Paspalum conjugatum* Berg.**	0.69	21.4
***Paspalum scrobiculatum* L.**	1.15	37.4
***Pauzolzia guineensis* Benth**	0.63	27.2
***Pennisetum polystachion* (L.) Schult.**	0.89	41.2
***Pergularia daemia* (Forsk.) Chiov.**	0.62	23.0
***Phyllantus amarus* Schum. et Thonn.**	0.42	17.4
***Physalis angulata* L.**	0.77	26.8
***Physalis micrantha* Link**	0.68	22.4
***Platostomi africanum* P. Beauv.**	0.96	28.4
***Polygonium lanigerum* R.Br.**	0.75	16.0
***Pycnanthus angolense* (Welw.) Warb**	0.004	0.8
***Rauvolfia vomitoria* Afzel.**	0.003	0.6
***Richardia brasiliensis* Gomez**	0.925	31.2
***Rottboellia cochinchinensis* (Lour.) W.Clayton**	0.355	22.6
***Schrankia leptocarpus* DC.**	0.467	24.8

Table 9, continued

Schwenckia americana L.	0.709	39.0
Scoparia dulcis Linn.	0.501	28.8
Sclerea verrucosa Wild.	0.600	32.2
Secamone afzelli (Schult) K. Schum.	0.111	15.4
Securinega virosa (Roxb. Ex Wild) Benth.	0.299	22.2
Selaginella mysorus (Sw.) Alston	0.030	3.6
Setaria barbata (Lam) Kunth.	0.620	36.0
Sida acuta Burn. F.	0.410	18.4
Sida cordifolia L.	0.991	19.0
Sida rhombifolia L.	0.480	19.6
Smilax kraussiana Meisn.	0.625	40.0
Solanum erianthum D. Don.	0.002	0.4
Solanum nigrum L.	0.238	36.0
Solanum torvum Sw.	0.358	19.0
Sorghum arundinaceum (Desv.) Stapf.	0.464	34.0
Spigelia anthelmia l.	1.076	37.8
Sporobolus pyramidalis P. Beauv.	2.136	45.4
Starchytarpheta indica (L.) Vahl.	0.156	12.0
Synedrella nodiflora Gaertn.	0.420	18.0
Talinum triangulare (Jacq.) Willd.	0.170	9.5
Tectonia grandis Linn.	0.005	1.0
Terminalia ivorensis A. Chev.	0.004	0.8
Tetrapleura tetraptera (Schum & Thonn.)	0.004	0.8
Tragia benthmii Bak.	0.692	36.6
Treculia africana Decne.	0.002	0.4
Trichilia prieuriana A. Juss.	0.004	0.8
Tridax procumbens L.	0.367	23.0
Tylophora sylvatica Decne.	0.232	15.6
Urena lobata L.	0.569	17.5
Usteria guineensis Willd.	0.006	1.2
Vernonia cinerrea (L.) Less.	1.113	20.4
Voacanga africana Stapf.	0.003	0.6
Walteria indica Linn.	0.726	37.2
Xanthosoma sagittifolium (L.) Schoott	0.883	19.8
Xlyopia aethropica (Dunal.) A. Rich.	0.301	17.6
Zea mays L.	0.046	2.2

Source: Field study (2017)

Overview of plant life forms in the unmined and mined areas

Six plant life forms were recognized amongst the species in the unmined study area (Table 10). These were trees, herbs, shrubs, climbers, lianes and ferns. The group with the highest number of species in the unmined study area was the trees which accounted for 52.15% of all the species encountered (Table 10). The herbs followed with 27.75% of the species. The next group of species was the climbers which comprised 9.09% of the species. Following the climbers were the ferns, lianes and shrubs with 4.31%, 3.83% and 2.87% of the species respectively (Table 10).

Table 10: *Life form of plant species growing in the unmined study area*

Life form	Number of species	Proportion of species (%)
Tree	109	52.15
Herbs	58	27.75
Shrub	6	2.87
Climber	19	9.09
Liane	8	3.83
Fern	9	4.31
Total	**209**	**100**

Source: Field study (2017)

In the mined study area, eight life forms were recognized amongst the species (Table 11). These were trees, herbs, shrubs, climbers, seedlings of trees, lianes, ferns and saplings. The dominant plant life form was the herb, constituting 56.05% of all the species in the mined area. The climbers followed with 12.01% of the species identified. Next to the climbers were the trees and saplings accounting for 9.56% and 8.28% of the species respectively.

Table 11: *Life form of plant species growing in the mined study area*

Life form	Number of species	Proportion of species (%)
Tree	15	9.56
Herb	88	56.05
Shrub	10	6.37
Climber	19	12.10
Seedling (of a tree)	6	3.82
Liane	3	1.91
Fern	3	1.91
Sapling	13	8.28
Total	**157**	**100**

Source: Field study (2017).

These were followed by the shrubs, involving 6.37% of the species. The next group of species was the tree seedling which came up with 3.82% of the species encountered. Following the tree seedlings were the lianes and ferns. Each group accounted for 1.91% of the species in the mined area (Table 11).

Ecological status of plant species in the unmined and mined study areas

The ecology of the species with respect to the presence of canopies and gaps and other influences on the flora showed that the dominant guild in the unmined plant community was the Pioneers, forming 44.98% of all the species (Table 12). The Non-Pioneer Light Demanding (NPLD) and the Shade bearers constituted 16.27% and 13.87% of the species respectively. The least guild identified in the unmined study area was the swamp (1.91%). The guilds of 48 plant species (forming 22.97% of identified species) were not available (Table 12).

Table 12: *Ecological guild of plant species growing in the unmined area*

Ecological guild	**Number of species**	**Proportion of species (%)**
Pioneer	94	44.98
Shade bearer	29	13.87
NPLD	34	16.27
Swamp	4	1.91
Not Available	48	22.97
Total	**209**	**100**

Source: Field study (2017)

The guild of species in the flora of the mined study area showed that Pioneers formed 59.24% of the species (Table 13). The remaining guilds, Shade bearers, Non-Pioneer Light Demanding and Swamps showed up as 6.37%, 5.73% and 1.27% of the species respectively. The guild of 27.39% of the species encountered in the mined area was not available (Table 13).

Table 13: *Ecological guild of plant species growing in the mined area*

Ecological guild	Number of species	Proportion of species (%)
Pioneer	93	59.24
Shade Bearer	10	6.37
NPLD	9	5.73
Swamp	2	1.27
Not Available	43	27.39
Total	**157**	**100**

Source: Field study (2017)

Diversity of plant species in the unmined and mined study areas

The diversity of species in the unmined area was found to be high (Table 14). The Shannon-Weiner Index gave a mean value of 4.62 ± 0.03 whilst the Simpson`s Index gave a mean value of 0.98 ± 0.01. The Eveness of the species had a mean value of 0.51 ± 0.02.

Table 14: *Diversity of plant species in the unmined study area*

	Quadrat (200m x 200m) Number					
Diversity Index	**1**	**2**	**3**	**4**	**5**	**Mean**
Shannon-Weiner (H^1)	4.64	4.62	4.65	4.60	4.59	4.62± 0.03
Simpson`s (D)	0.99	0.98	0.96	0.98	0.99	0.98± 0.01
Eveness (E)	0.50	0.53	0.52	0.54	0.51	0.51± 0.02

Source: Field study (2017)

The diversity of plant species in the mined area was high. The Shannon-Weiner Index gave a mean value of 4.54 ± 0.02 whilst the Simpson`s Index had a mean value of 0.98 ± 0.01 (Table 15). The mean value for the Eveness of the species was 0.40 ± 0.01.

Table 15: *Diversity of plant species in the mined study area*

	Quadrat (200m x 200m) Number					
Diversity Index	**1**	**2**	**3**	**4**	**5**	**Mean**
Shannon-Weiner (H^I)	4.50	4.56	4.55	4.55	4.54	4.54±0.02
Sampson`s (D)	0.97	0.99	0.96	0.99	0.99	0.98±0.01
Eveness (E)	0.39	0.40	0.39	0.40	0.42	0.40±0.01

Source: Field study (2017)

Star –rating of plant species in the unmined and mined study areas

The star-rating of the plant species in the unmined study area showed that there were no black star species (Table 16). However, blue (3.83%), gold (1.91%), green (52.15%), red (3.83%), pink (7.18%) and scarlet (2.87%) species were recorded. The study revealed the dominance of green star species in the unmined area. Fifty nine species forming 28.23% of the plant species identified in the unmined area have not been star rated (Table 16).

Table 16: *Star –rating of plant species growing in the unmined area*

Star –rating	**Number of species**	**Proportion of species (%)**
Blue	8	3.83
Scarlet	6	2.87
Gold	4	1.91
Red	8	3.83
Pink	15	7.18
Green	109	52.15
Not Available	59	28.23
Total	**209**	**100**

Source: Field study (2017)

The conservation status of species in the mined area revealed that most of the species (59.87%) were not star rated (Table 17). Out of the 63 species which were star rated, 53 species were green (33.76%). The star- ratings of the other species showed up as blue (0.64%), scarlet (0.64%), gold (0.64%), red (1.91%) and pink (2.54%). The blue, scarlet, gold, red, and pink star rated species were distributed in 10 plant species in the mined area (Table 17) and also found in 41 species in the unmined area (Table 16).

Table 17: *Star - rating of plant species growing in the mined study area*

Star - rating	**Number of species**	**Proportion of species (%)**
Blue	1	0.64
Scarlet	1	0.64
Gold	1	0.64
Red	3	1.91
Pink	4	2.54
Green	53	33.76
Not Available	94	59.87
Total	**157**	**100**

Source: Field study (2017)

Some indices of plant species in the unmined and mined study areas

Analysis of the Shannon-Weiner (H^1) diversity values showed that there was a significant difference ($p < 0.05$) between the H^1- unmined and and H^1-mined Shannon (H^1) values (Table 18).

Table 18: *Indices of plant species in the unmined and mined study areas*

Index	Mined	Unmined	*t*-test	*p*-value
GHI All Star	31.84±1.44	59. 33±0.50	-40.37	0.000
GHI Trees Only	54.89±1.46	64.42±0.63	-13.41	0.000
EI All Star	20.88±1.75	32.66±0.93	-13.27	0.000
EI Trees Only	41.84±3.07	46.15±0.89	- 3.02	0.039
PI	137.48±2.89	132.77±1.76	3.12	0.021
Shannon (H^1)	4.54 ±0.02	4.62 ±0.02	-5.16	0.001

Source: Field study (2017)

For both the Genetic Heat Index (GHI) and Economic Index (EI) of all star rated species, there were significant differences ($p < 0.05$) between the GHI`s and EI`s of plant species of the unmined and mined sites (Table 18). The analysis of the GHI and EI of only trees in the study area showed that there were significant differences ($p < 0.05$) between the GHI`s and the EI`s of the plant species in the unmined and mined areas. There was a significant difference ($p < 0.05$) between the Pioneer Index (PI) values for the flora of the unmined and mined areas (Table 18).

Similarity of the flora of the unmined and mined areas

Comparative study of the flora of the unmined and mined study areas showed that the Similarity ratio (SR) was 0.033519 and the Sorenson`s Index (SI) was 0.4808.

Assessment of nutrients and heavy metals in unmined and mined soils

The results in Table 19 indicate a high degree of variability in the values of the soil nutrients and heavy metals. The lowest concentrations of Cu, Pb and pH were recorded at a mined site in Dunkwa (DK58), unmined site in Pokukrom (UPK3) and unmined site in Buabenso (UBU3) respectively; whilst the highest concentrations were observed at unmined site in Buabenso (UB10) and mined sites in Akropong (AK1 and AK10) respectively. The minimum (0.199 $\text{cmol}_c\ \text{kg}^{-1}$) and maximum (1.836 $\text{cmol}_c\ \text{kg}^{-1}$) concentrations of Na were recorded at mined site in Nyamebekyere (NB75) and unmined site in Buabenso (UBU 11), respectively. The values of the lowest and highest concentrations of phosphorous were recorded at mined sites in Kyekyewere (KKW36) and (KKW24); potassium at mined site in Nyamebekyere (NB75) and unmined site in Buabenso (UBU5); Ca at mined site in Nyamebekyere (NB79) and unmined site in Buabenso (UBU6); Mg at mined site in Nyamebekyere (NB79) and unmined site in Buabenso (UBU6); organic carbon at mined site in Kyekyewere (KKW31) and unmined site in Akropong (UAK1); and Cadmium at mined sites in Pokukrom (PKK96) and Nyamebekyere (NB73) respectively. The lowest concentrations of nitrogen, mercury and arsenic were observed at mined site in Nyamebekyere (NB82), unmined site in Akropong (UAK6) and mined site in Dunkwa (DK57) respectively; similarly, the highest concentrations of nitrogen, mercury and arsenic were recorded at unmined site in Buabenso (UBU4), mined site in Kyekyewere (KKW31) and unmined site in Buabenso (UBU3) respectively.

Table 19: *Descriptive statistics of nutrients and heavy metals in soils of the study area*

Parameter	**Na** (cmolkg^{-1})	**N** (%)	**P** (ugg^{-1})	**K** (cmolkg^{-})	**Ca** (cmolkg^{-1})	**Mg** (cmolkg^{-1})	**OC** (%)	**pH**	**EC** (dSm^{-1})	**Cu** (mgkg^{-1})	**Cd** (mgkg^{-1})	**Pb** (mgkg^{-1})	**Hg** (mgkg^{-1})	**As** (mgkg^{-1})
Mean	0.63	0.08	12.99	0.07	2.46	0.24	0.96	5.11	0.03	1.20	1.46	1.26	0.05	0.09
Std. Deviation	0.37	0.06	12.51	0.04	2.85	0.28	0.67	0.21	0.02	0.54	2.68	1.02	0.05	0.08
Skewness	1.07	1.06	1.92	1.76	2.44	4.57	2.27	-0.01	2.12	0.17	2.69	1.00	1.12	1.20
Kurtosis	0.79	0.11	4.02	4.72	7.62	26.29	5.99	0.52	4.63	-0.55	5.91	0.17	0.31	0.93
Minimum	0.20	0.01	0.84	0.02	0.07	0.03	0.19	4.60	0.01	0.10	0.02	0.02	0.01	0.01
Maximum	1.84	0.28	61.82	0.28	17.72	2.14	3.60	5.80	0.12	2.69	10.22	3.82	0.19	0.32

Source: Field study (2016)

Correlation of nutrients and heavy metals in soil

Na and K (r = 0.866) likewise Mg and Ca (r = 0.706) were highly correlated (Table 20). Exchangeable aciditity strongly correlated with both K (r = 0.576) and Na (r = 0.674). Other variables that were strongly correlated included Na and Ca (r = 0.534), P and N (r = 0.536) and K and N (r = 0.633) (Table 20).

Table 20: *Pearson product moment correlation coefficients of nutrients and heavy metals in soil*

	Pearson product moment correlation coefficient														
	Na	N	P	K	Ca	Mg	OC	EXCH ACID	pH	EC	Cu	Cd	Pb	Hg	As
Na	1														
N	**.730****	1													
P	.294**	**.536****	1												
K	**.866****	**.633****	.227*	1											
Ca	**.534****	**.562****	.337**	.538**	1										
Mg	.407**	.426**	.133	.414**	**.706****	1									
OC	.307**	.433**	.326**	.309**	.072	.045	1								
EXCH ACID	**.674****	**.554****	.144	**.576****	.471**	.415**	.169	1							
pH	-.014	.011	.153	-.019	.016	-.117	.021	-.125	1						
EC	.134	.149	.071	.126	.333**	.327**	-.019	.083	.226*	1					
Cu	.287**	.286**	.190*	.340**	.487**	.344**	-.212*	.294**	-.059	.215*	1				
Cd	-.281**	-.264**	-.109	-.271**	-.254**	-.218*	-.010	-.137	-.050	-.146	-.333**	1			
Pb	-.150	-.003	-.028	-.048	.016	-.032	-.155	-.140	.179	-.118	.234**	-.152	1		
Hg	.050	-.050	-.164	.120	.170	.173	-.218*	.072	-.097	.004	.190*	-.115	.042	1	
As	.077	.175	.109	.102	.333**	.189*	-.177	.194*	-.079	.113	.263**	-.082	-.012	.249**	1

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

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

Source: Field study (2016)

Table 21: *The proportion of the total variance in soil data explained by the extracted principal components*

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.61	30.74	30.74	4.61	30.74	30.74	4.01	26.75	26.75
2	1.96	13.09	43.84	1.96	13.09	43.84	1.68	11.22	37.97
3	1.45	9.64	53.48	1.45	9.64	53.48	1.67	11.10	49.08
4	1.19	7.90	61.38	1.19	7.90	61.38	1.47	9.78	58.85
5	1.01	6.72	68.10	1.01	6.72	68.10	1.39	9.25	68.10
6	.85	5.64	73.74						
7	.79	5.25	78.98						
8	.73	4.83	83.81						
9	.60	4.00	87.82						
10	.52	3.45	91.27						
11	.40	2.65	93.92						
12	.37	2.46	96.38						
13	.23	1.55	97.93						
14	.22	1.45	99.38						
15	.09	.63	100.00						

Extraction Method: Principal Component Analysis.

From table 21, the soil data consisting of nutrients and trace metals in the study area was a 5-component system since five components had Eigen values greater than 1. The analysis also shows that PC1 accounted for approximately 27% of the variance in the data while PC2 accounted for 11%. In total, about 50% of the variance in the data was explained by the first 3 components. The linear factors that are used to form the PCs are shown in Table 21 while plots of the proportion of variance associated with each PC, and the commulative total variance are shown on the Scree plot (appendix M). For all sites, approximately 68% of the total variation was explained by the first 5 of the 16 PCs.

Table 22: *Matrix showing the five components retained as part of the PCA*

Component Matrix[a]

	Component				
	1	2	3	4	5
Na	**.847**	-.244	-.144	-.125	-.199
N	**.826**	-.295	.093	-.101	.158
P	.446	-.341	.396	.026	.554
K	**.817**	-.152	-.125	-.183	-.226
Ca	**.809**	.240	.073	.178	.094
Mg	.673	.259	-.089	.249	-.103
OC	.287	**-.739**	.024	-.027	.024
EXCH ACID	.716	-.075	-.323	-.057	-.067
pH	-.024	-.093	**.731**	.180	-.184
EC	.310	.200	.330	**.698**	-.277
Cu	.529	.517	.184	-.183	.084
Cd	-.396	-.231	-.290	.296	.292
Pb	-.053	.321	.515	-.590	.018
Hg	.136	.564	-.295	-.102	-.082
As	.296	.460	-.114	.167	**.592**

Extraction Method: Principal Component Analysis.
Source: Field study (2016)

From Table 22, it is discernible that 5 components were extracted from the unrotated component matrix. Na, N, K, Ca and exchangeable acidity had strong positive factor loadings on component 1. Only OC had strong factor loadings on component 2 however the direction was negative. Component 3 had pH loading strongly and positively on it. Electrical conductivity had strong positive factor loadings on component 4 whereas As had the strongest positive factor loadings on component 5.

Table 23: *Matrix showing the five rotated components in three-dimensional space*

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
Na	**.913**	-.026	.128	.036	.028
N	**.746**	.190	.457	.106	.023
P	.213	.338	**.780**	.100	.043
K	**.879**	-.017	.054	.120	.017
Ca	**.622**	.491	.050	.123	.335
Mg	.580	.338	-.162	-.014	.353
OC	.380	-.310	**.579**	-.212	-.097
EXCH ACID	**.772**	.148	-.032	-.091	-.057
pH	-.182	-.211	.341	.333	**.552**
EC	.133	.118	-.041	-.087	**.876**
Cu	.340	.472	-.146	.495	.129
Cd	-.351	.036	.105	-.553	-.160
Pb	-.170	.028	.020	**.822**	-.122
Hg	.138	.299	-.560	.121	-.065
As	.048	**.828**	-.031	-.036	-.011

Rotation Method: Varimax with Kaiser Normalization.

Source: Field study (2016)

From table 23, Na, K, N, Ca and exchangeable acidity have strong factor loadings on component 1. This component may be classified as the component that primarily measures much of the variations in the variables. Only Arsenic (As) has strong positive factor loading on component 2. Phosphorus and organic carbon have strong positive factor loadings on component 3; component 4 is mainly Pb whereas EC and pH have strong factor loadings on component 5 and represent the physicochemical parameters in the soil.

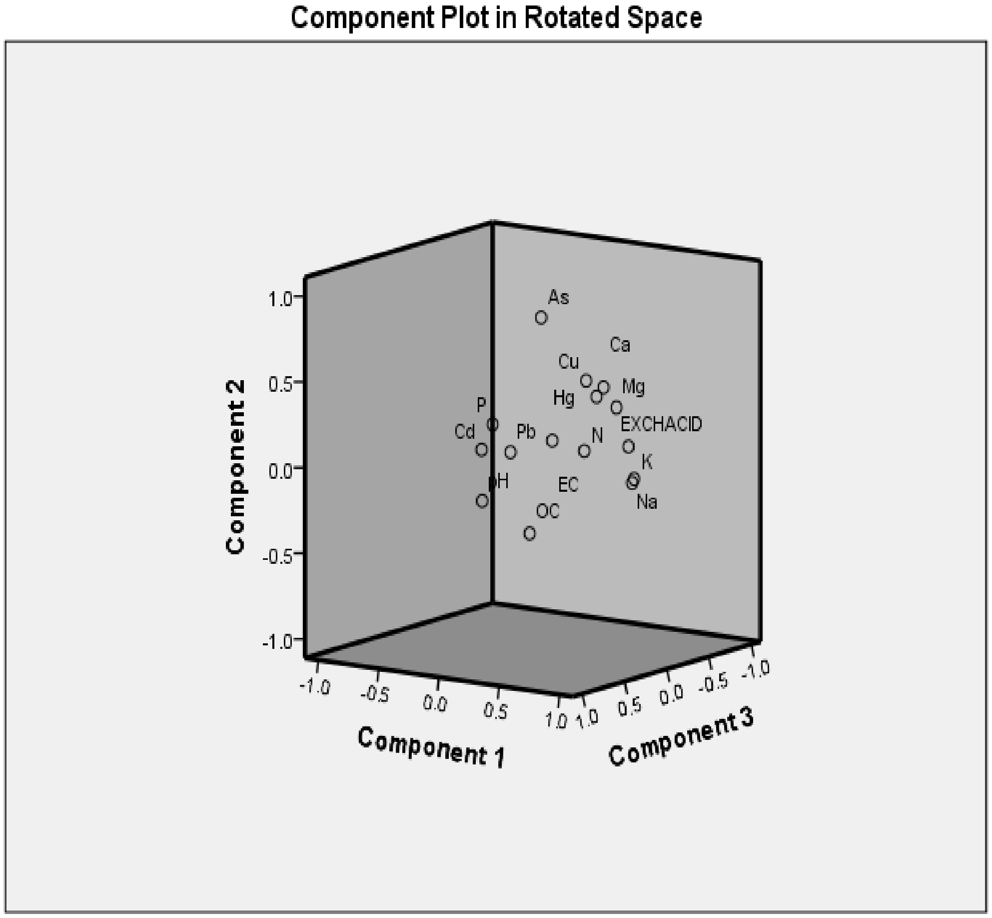
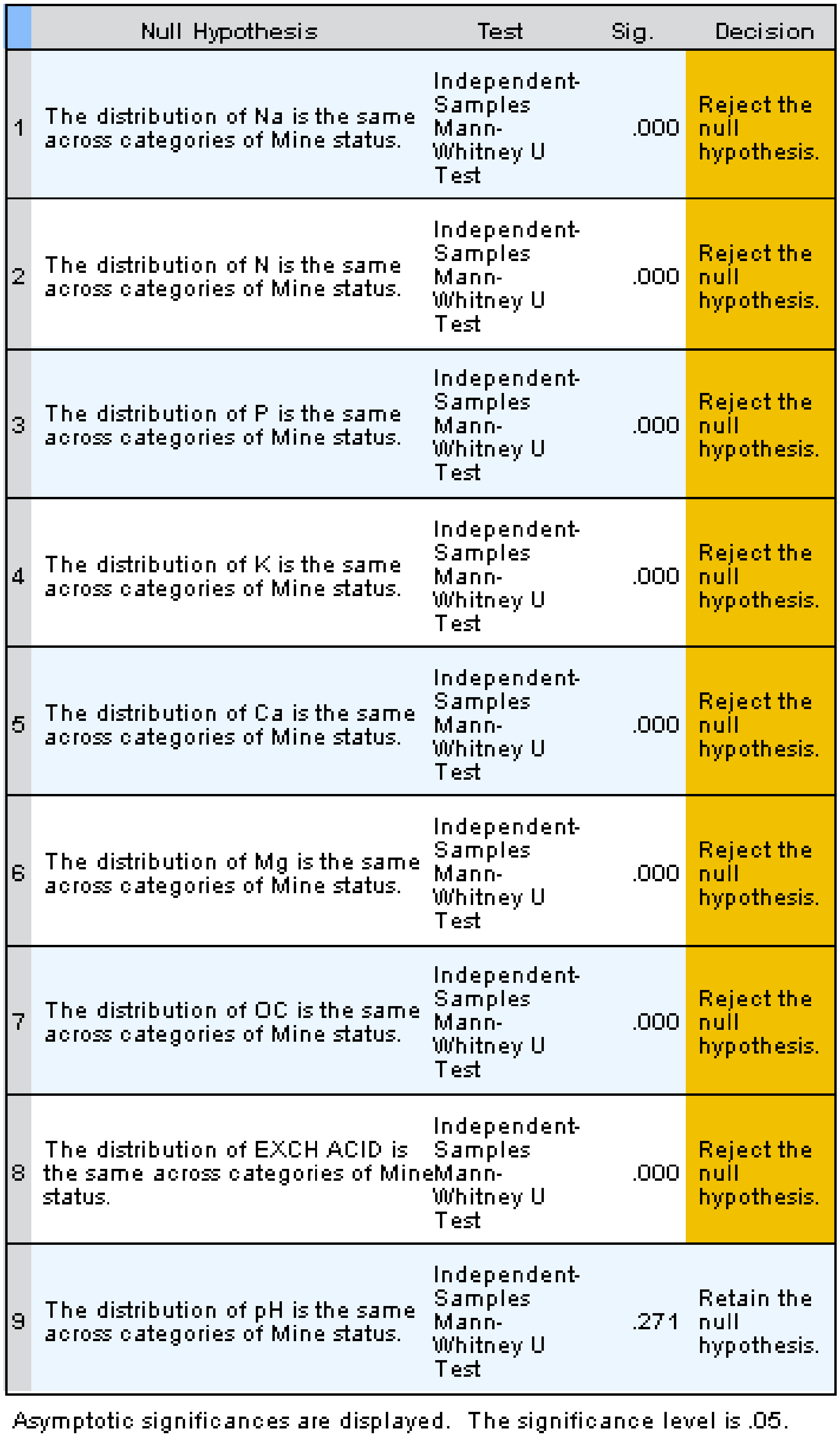


Figure 3: Loading plots showing the orientation of the soil variables in three-dimensional space

The plot above shows the items (variables) in the rotated factor space. It is possible to interactively rotate it to see how the items (variables) are organized in the common factor space. It is discernible from Figure 3 that K and Na are closer in 3-dimensional space based on their concentrations in the soil sample. Similar trends were observed for P, Cd, and pH as well as for Cu, Mg and Hg. The rest of the parameters do not exhibit any distinct patterns in terms of their orientation in three dimensional space.

Soil parameters in the unmined and mined soils

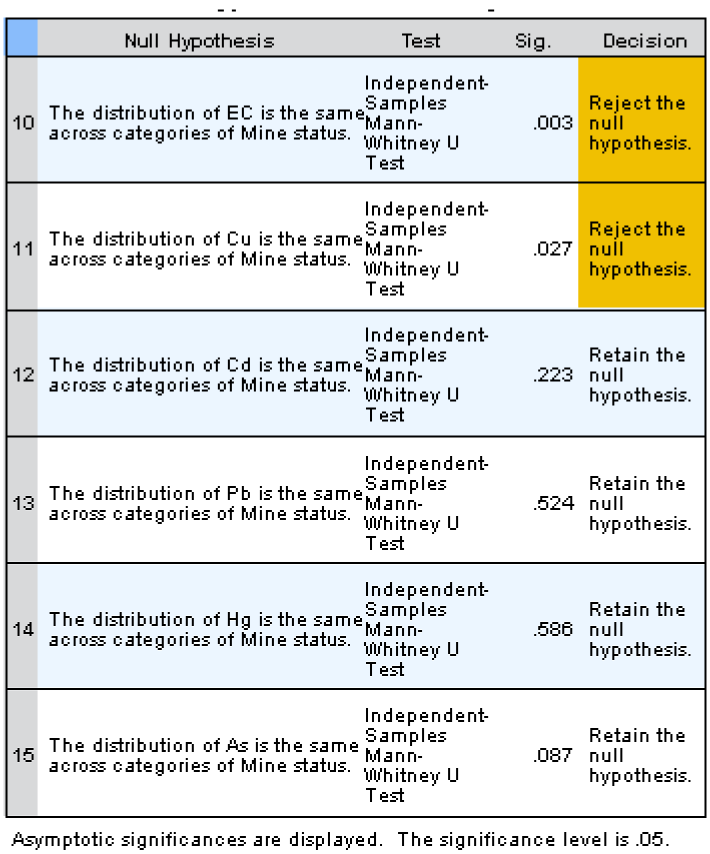
The distribution of soil parameters across the unmined and mined soils were analysed and from Figure 4, there were significant differences ($p < 0.05$) in the distribution of copper (Cu), electrical conductivity (EC), exchangeable acidity, organic carbon (OC), magnesium (Mg), sodium (Na), calcium (Ca), potassium (K), phosphurous (P) and nitrogen (N) between soils of unmined and mined sites. There were higher concentrations of Cu, OC, Mg, Na, Ca, K, P, N and EC in the unmined soils as compared to that of the mined soils.



	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Na is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
2	The distribution of N is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
3	The distribution of P is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
4	The distribution of K is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
5	The distribution of Ca is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
6	The distribution of Mg is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
7	The distribution of OC is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
8	The distribution of EXCH ACID is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
9	The distribution of pH is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.271	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 4: Comparison of the distribution of soil parameters in the mined and unmined sites



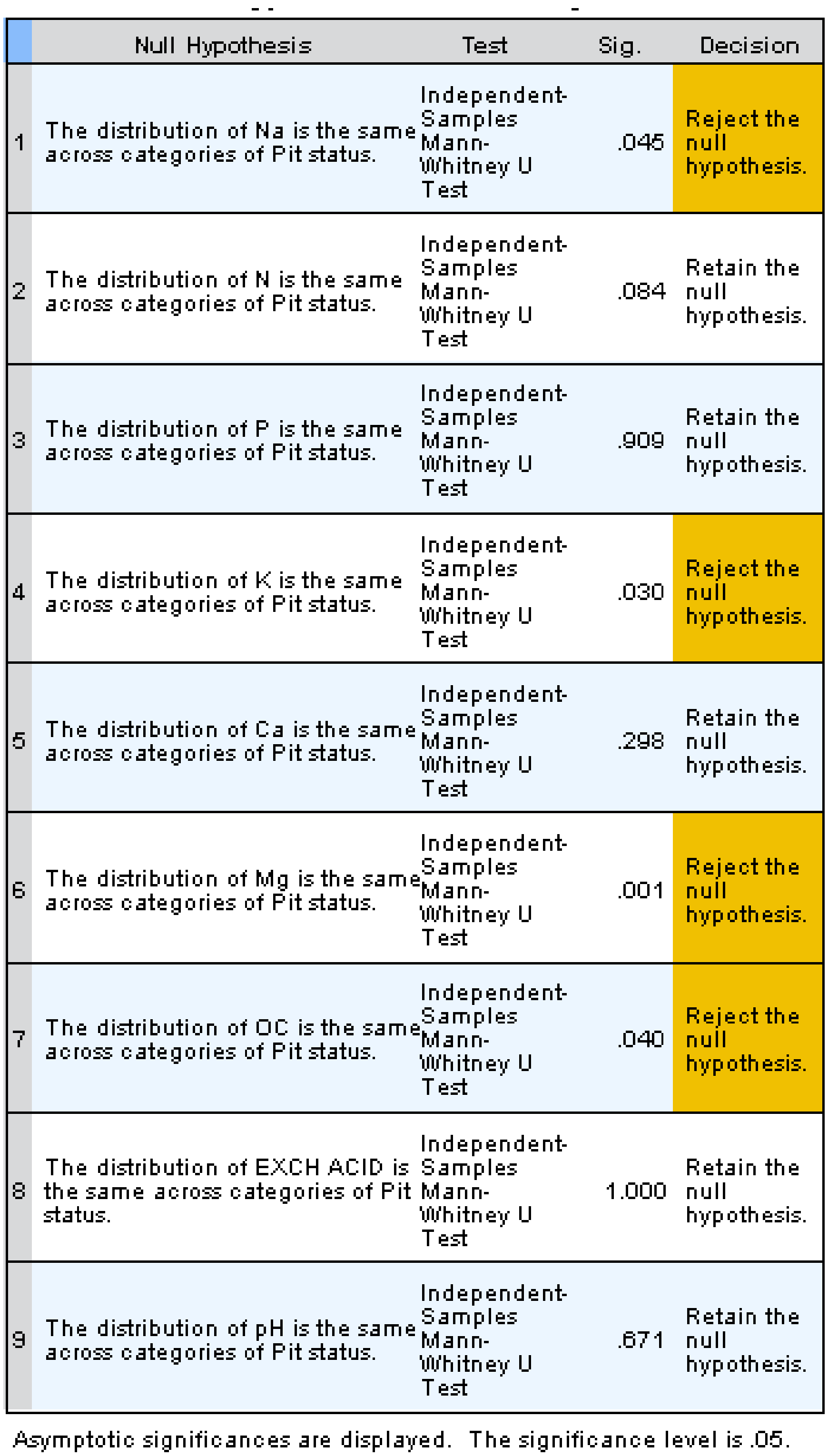
	Null Hypothesis	Test	Sig.	Decision
10	The distribution of EC is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.003	Reject the null hypothesis.
11	The distribution of Cu is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.027	Reject the null hypothesis.
12	The distribution of Cd is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.223	Retain the null hypothesis.
13	The distribution of Pb is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.524	Retain the null hypothesis.
14	The distribution of Hg is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.586	Retain the null hypothesis.
15	The distribution of As is the same across categories of Mine status.	Independent-Samples Mann-Whitney U Test	.087	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 4 continued: Comparison of the distribution of soil parameters in the mined and unmined sites

Distribution of soil parameters across mined sites with filled and unfilled pits

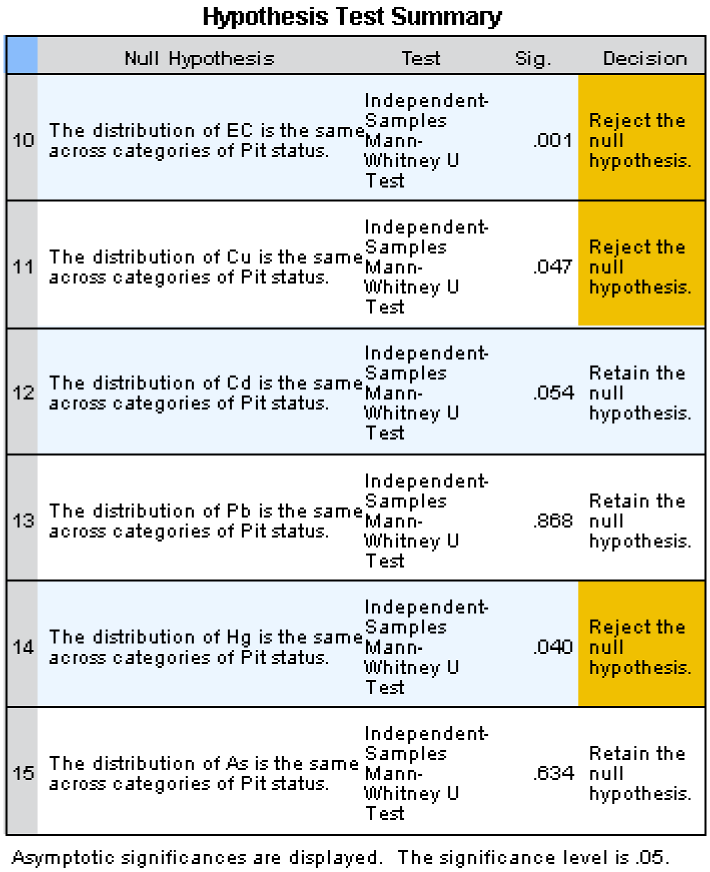
The results from the distribution of soil parameters across mined sites with two categories of pit status (filled and unfilled pits) indicated that there were differences in the distribution of seven soil parameters between mined sites with filled pits and mined sites with unfilled pits (Figure 5). There were significant differences ($p < 0.05$) in the distribution of sodium (Na), potassium (K), magnesium (Mg), organic carbon (OC), electrical conductivity, copper (Cu) and mercury (Hg) between soils of mined areas with filled and unfilled pits. The concentrations of Hg, EC, Mg, K, Na and Cu were higher in the soils of mined sites with unfilled pits; and the level of OC in the soils was relatively higher in the mined sites with filled pits.



	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Na is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.045	Reject the null hypothesis.
2	The distribution of N is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.084	Retain the null hypothesis.
3	The distribution of P is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.909	Retain the null hypothesis.
4	The distribution of K is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.030	Reject the null hypothesis.
5	The distribution of Ca is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.298	Retain the null hypothesis.
6	The distribution of Mg is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.001	Reject the null hypothesis.
7	The distribution of OC is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.040	Reject the null hypothesis.
8	The distribution of EXCH ACID is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	1.000	Retain the null hypothesis.
9	The distribution of pH is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.671	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 5: Distribution of soil parameters in mined sites with filled and unfilled pits



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
10	The distribution of EC is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.001	Reject the null hypothesis.
11	The distribution of Cu is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.047	Reject the null hypothesis.
12	The distribution of Cd is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.054	Retain the null hypothesis.
13	The distribution of Pb is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.868	Retain the null hypothesis.
14	The distribution of Hg is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.040	Reject the null hypothesis.
15	The distribution of As is the same across categories of Pit status.	Independent-Samples Mann-Whitney U Test	.634	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 5 continued: Distribution of soil parameters in mined sites with filled and unfilled pits

Soil quality index scores by location

The result of the soil quality index (SQI) scores by location for the whole sampled area showed that out of the maximum SQI score of 18, no sampling location had commulative score less than 2. Similarly, no sampling location had a commulative score of greater than 8 (Table 24).

Table 24: *Soil quality index based on sampling location*

SQI Score	Number of locations	Percent
2	2	1.7
3	15	12.5
4	29	24.2
5	34	28.3
6	25	20.8
7	12	10.0
8	3	2.5
Total	**120**	**100.0**

Source: Field study (2017)

Fifteen locations representing 12.5% had a commulative score of 3. The maximum SQI score of 8 in this study was obtained in three locations. Thirty four locations forming 28.3% of the sampling sites had a SQI score of 5 (Table 24).

Table 25: *Percentage SQI of unmined and mined soils*

Location	Number of sites	Percentage SQI
Unmined Pokukrom	3	33.3
	3	38.9
	2	44.4
Unmined Dunkwa	4	27.8
	1	16.7
	2	33.3
Unmined Buabenso	8	27.8
	6	33.3
	1	44.4
Unmined Akropong	7	33.3
	1	38.9
Mined Dunkwa	2	38.9
	3	33.3
	7	27.8
	2	22.2
	2	16.7

Mined Pokukrom	1	11.1
	3	16.7
	4	22.2
Mined Nyamebekyere	11	22.2
	5	16.7
Mined Kyekyewere	6	16.7
	9	22.2
	8	27.8
	3	33.3
Mined Akropong	2	22.2
	7	27.8
	7	33.3

Source: Field study (2016)

The percentage SQI of the unmined soils ranged from 16.7% to 44.4% and that for the mined soils occurred between 16.7% and 38.9% (Table 26). There were more sampling sites with relatively higher SQI values in the unmined soils as compared to the mined soils (Table 25). The average SQI values of the unmined and mined soils were 33.8% and 24.2% respectively.

Table 26: *Correlations of SQI and soil parameters (n=120)*

	Total SQI	N	Ca	OC	pH	Cu	Cd	Pb
Total SQI		**.535****	**.552****	**.584****	.095	.218*	.370**	.354**
N	**.535****	1	.444**	.393**	-.247**	-.139	.064	-.129
Ca	**.552****	.444**	1	.225*	.237**	-.352**	.093	-.121
OC	**.584****	.393**	.225*	1	-.202*	.048	-.012	.083
pH	.095	247**	.237**	-.202*	1	.009	-.043	-.187*
Cu	.218*	.139	-.352**	.048	.009	1	-167	.201*
Cd	.370**	.064	.093	-.012	-.043	-167	1	.024
Pb	.354**	-129	-.121	.083	-.187*	.201*	.024	1

**. *Correlation is significant at the 0.01 level (2-tailed).*
*. *Correlation is significant at the 0.05 level (2-tailed).*

From Table 26, organic carbon (OC), Ca and N were strongly correlated with total SQI. All three correlations were statistically significant at an alpha level of 0.01. Although the correlations between total SQI and Cu, Cd, Pb were statistically significant, they were not strong. Similarly, although there were a number of statistically significant correlations among most of the variables, none were strong.

Spatial distribution of soil quality index (SQI) across sampling locations

This section presents the SQI distribution at unmined and mined areas (Figures 6, 8 and 9 for the unmined areas; and Figures 10, 11, 12 and 13 for the mined areas whilst Figure 7 shows the SQI for both the umined and mined areas). The SQI scores at the unmined areas ranged from 3 to 8 with SQI of sites located in Pokukrom (UPK) and Buabenso (UBU) having the highest value (8) while that of a site in Dunkwa (UDK) having the least SQI value of 3. For the mined areas, SQI values ranged between 3 and 7 with the site showing the highest SQI value located in Dunkwa. The mined sites that had the least SQI values were located in Pokukrom, Nyamebekyere and Kyekyewere locations.

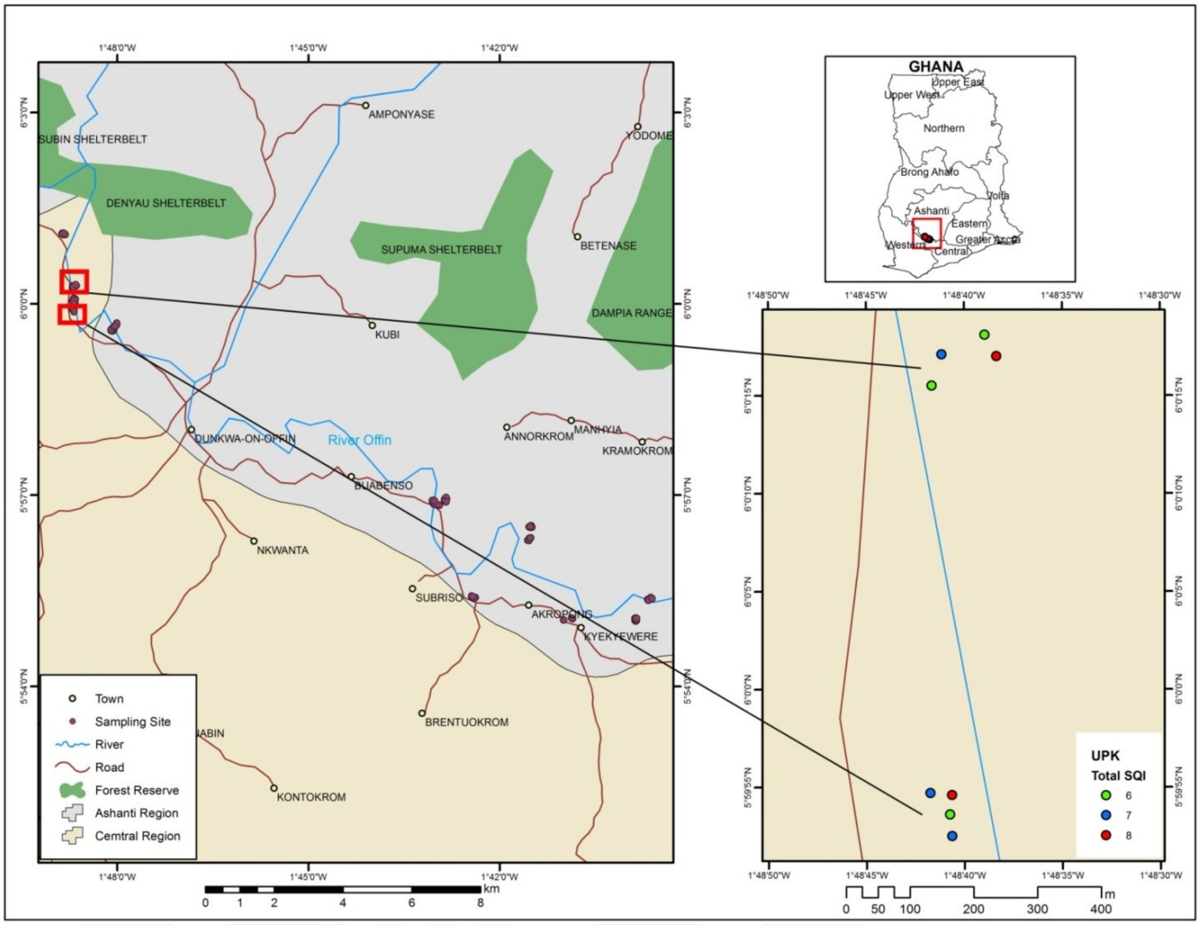


Figure 6: Soil quality index (SQI) scores of sites in the UPK sampling location

The SQI scores for the sampling sites in the unmined Pokukrom (UPK) location showed that the total SQI score ranged from 6 to 8 (Figure 6). Two sampling sites had SQI score of 8, three sites obtained SQI score of 7 and three other sites had SQI score of 6.

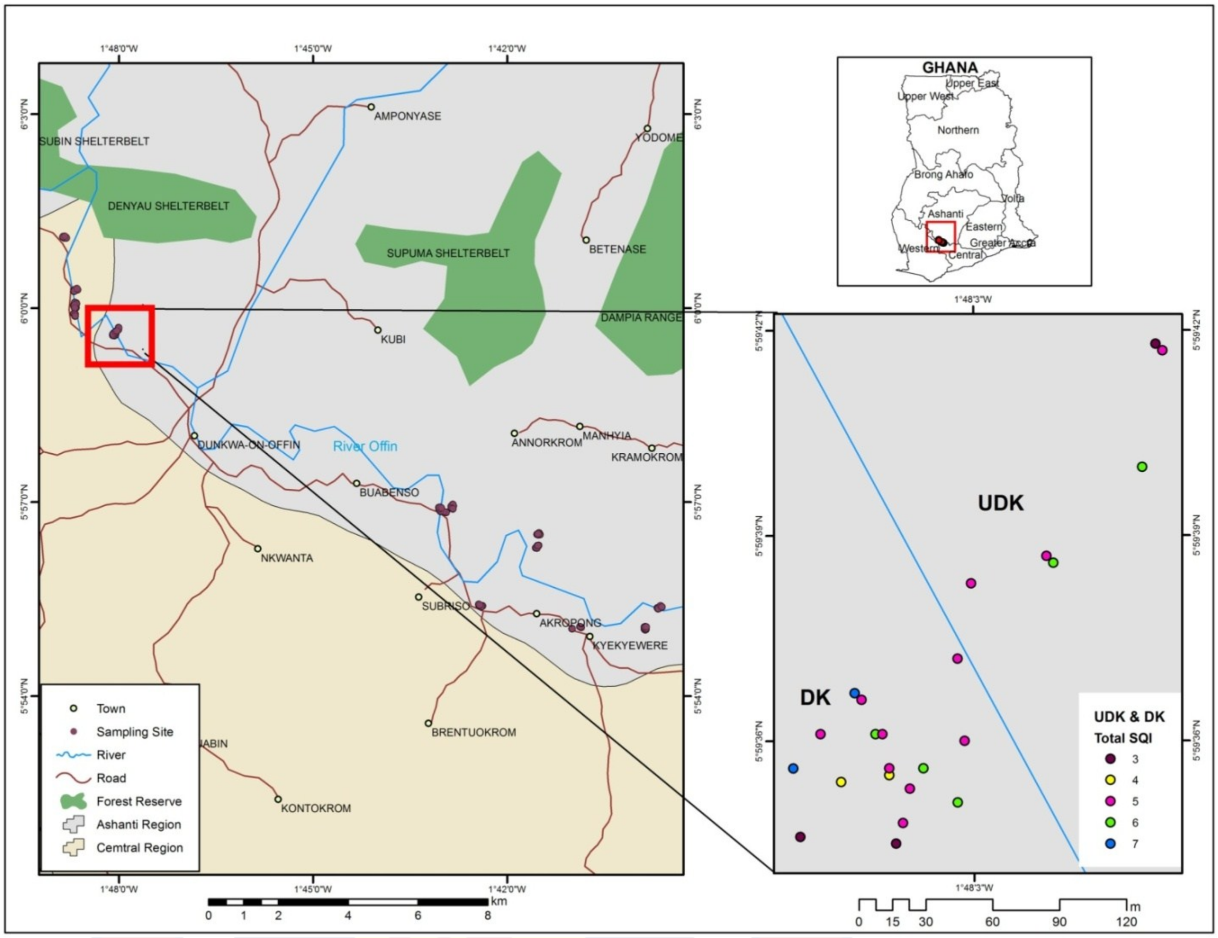


Figure 7: Soil quality index (SQI) scores of sites in the UDK and DK sampling locations

Four of the seven sampling sites in the unmined Dunkwa (UDK) location had SQI score of 5 (Figure 7). One sampling site had SQI score of 3 and the other two sites obtained SQI score of 6 each. The SQI scores of the 16 sampling sites in the mined Dunkwa (DK) location showed that two sites had SQI score of 7. Three of the sites obtained SQI score of 6, seven sampling sites had SQI score of 5, two sites obtained SQI score of 4 and another two sites had SQI score of 3 (Figure 7).

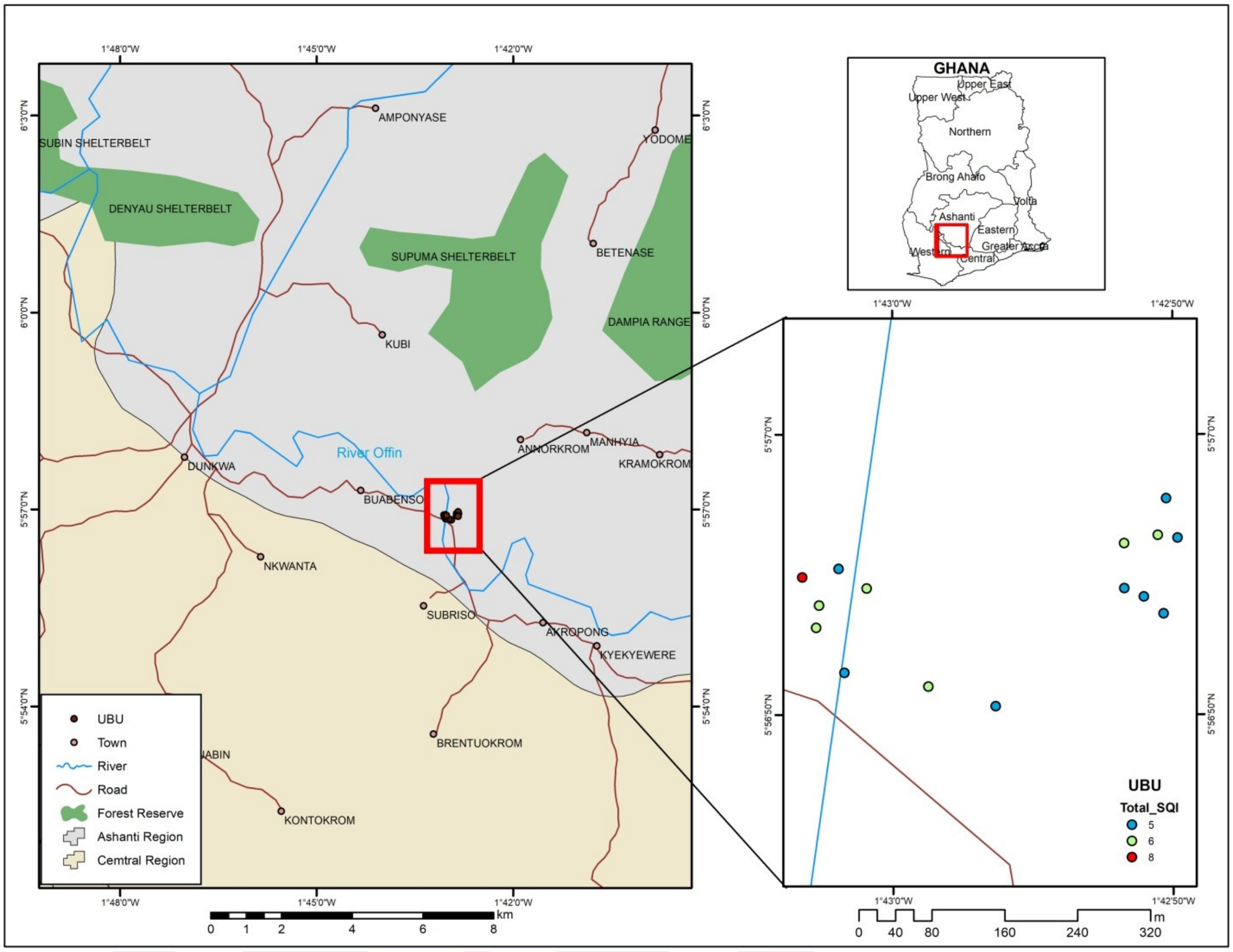


Figure 8: Soil quality index (SQI) score of sites in the UBU sampling location

The results of the SQI scores for the 15 sampling sites in the unmined Buabenso location showed that eight sampling sites had a score of 5, six sites obtained SQI score of 6 and one of the sampling sites had SQI score of 8 (Figure 8).

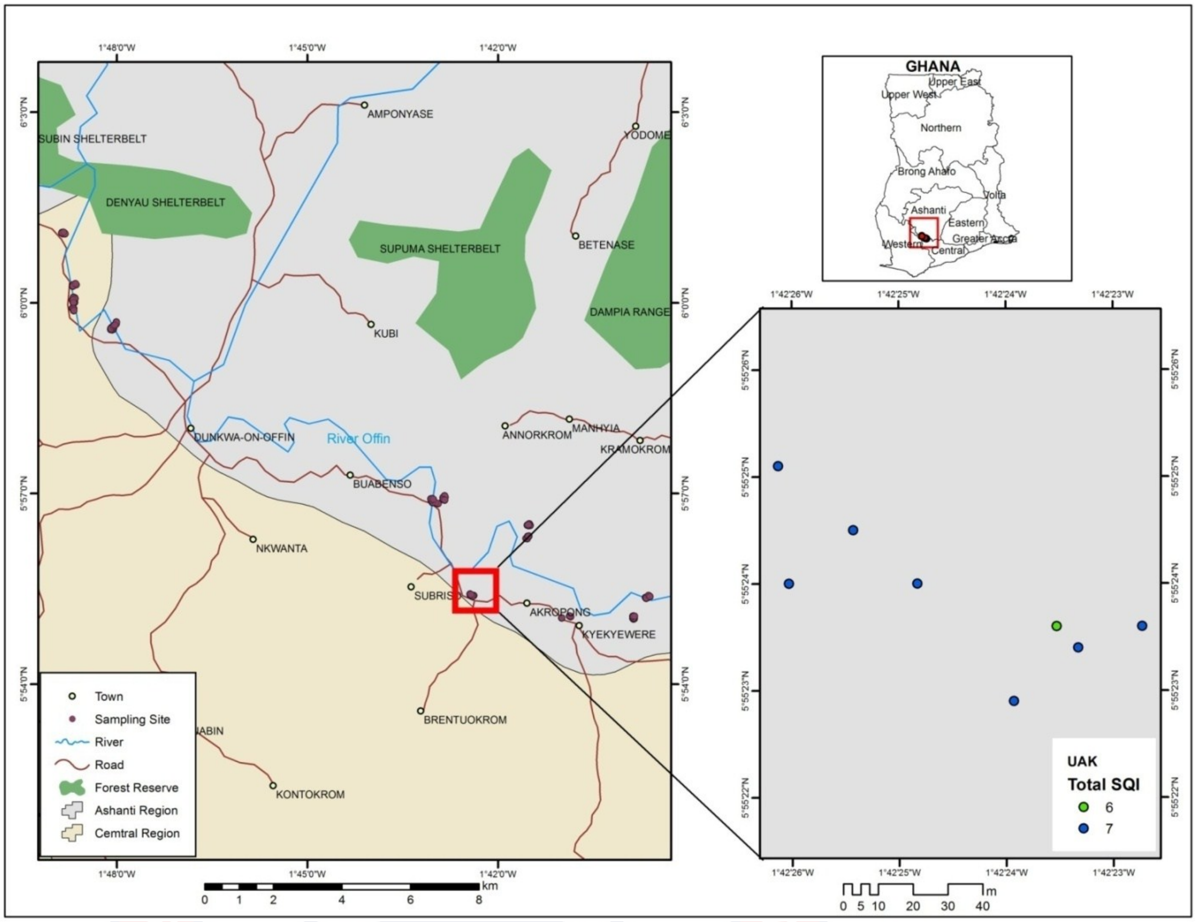


Figure 9: Soil quality index (SQI) score of sites in the UAK sampling location

The SQI scores of sampling sites in the unmined Akropong location ranged between 6and 7 (Figure 9). Seven of the sites had SQI score of 6 and the remaining site obtained a score of 7.

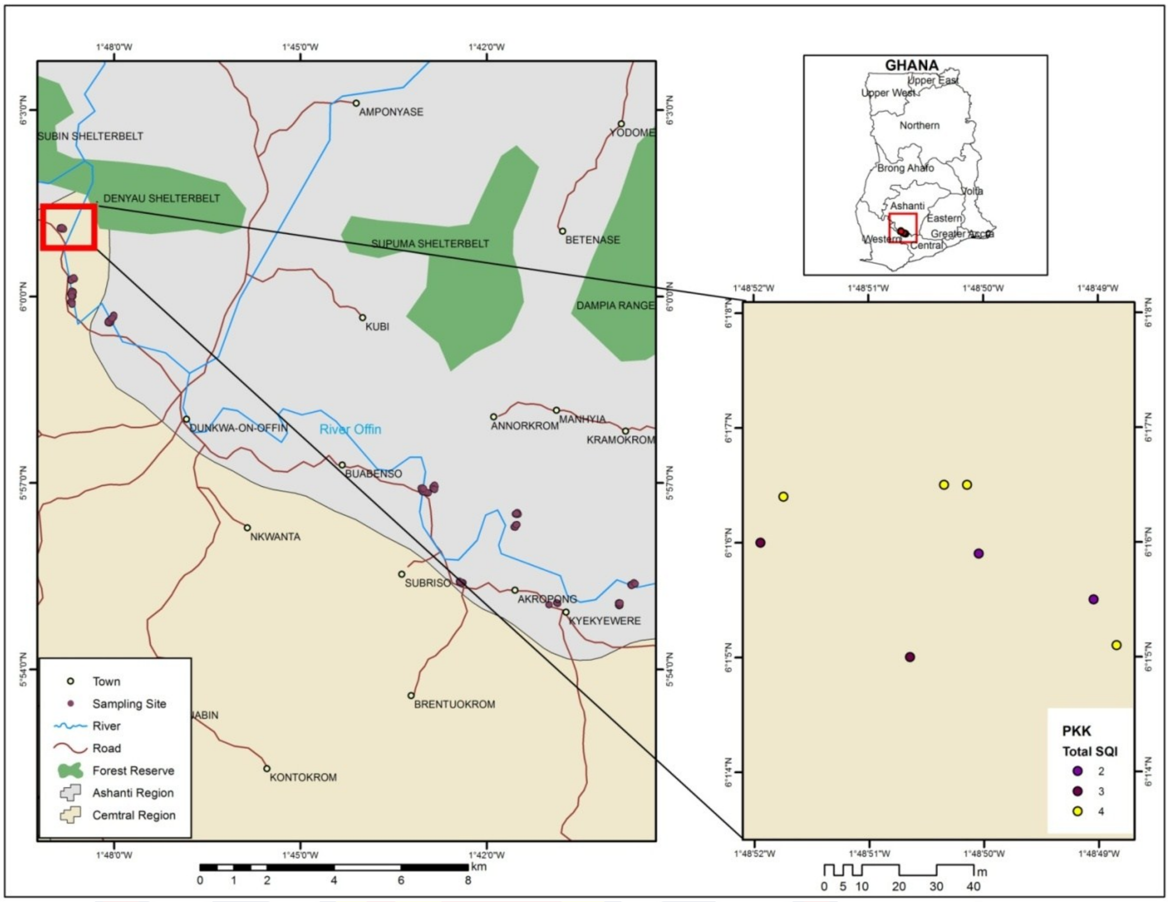


Figure 10: Soil quality index (SQI) score of sites in the PKK sampling location

Three different SQI scores were obtained from the mined Pokukrom (PKK) sampling location. One of the sampling sites had SQI score of 2, three of the sites had SQI score of 3 and the four remaining sampling sites had SQI score of 4 (Figure 10).

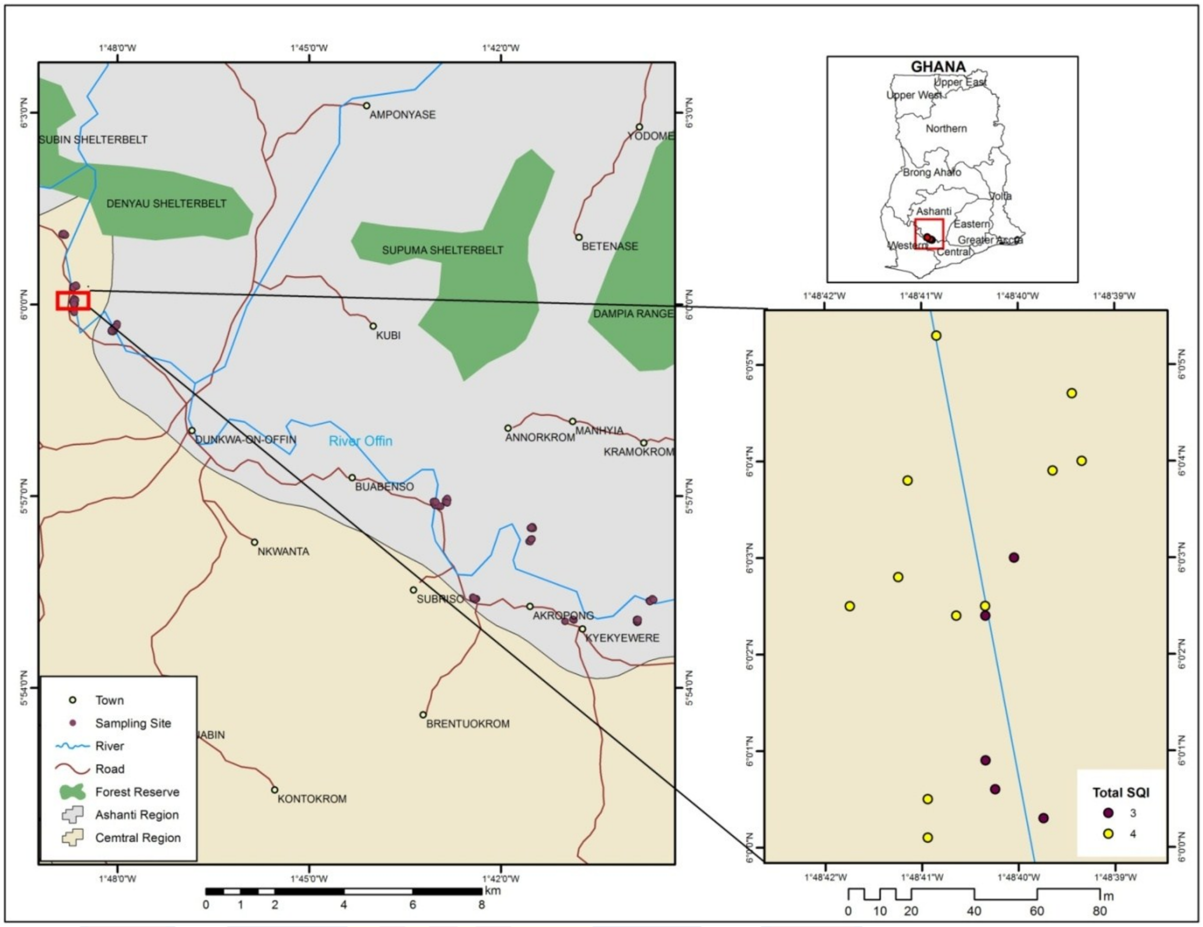


Figure 11: Soil quality index (SQI) score of sites in the NB sampling location.

The unmined Nyamebekyere sampling location had 16 sampling sites. Eleven of the sampling sites had SQI score of 4 and the remaining five sites obtained SQI score of 3 (Figure 11).

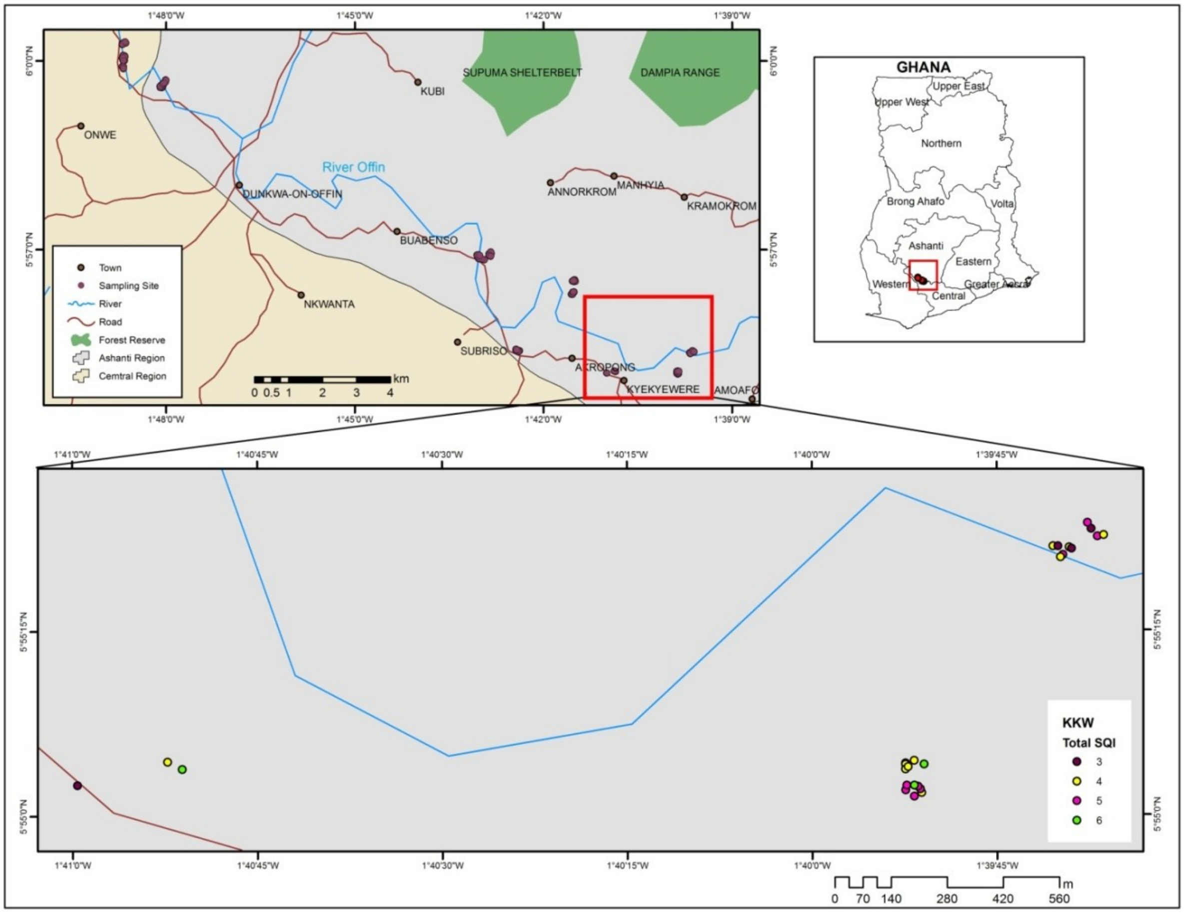


Figure 12: Soil quality index (SQI) score of sites in the KKW sampling location

The SQI scores for the sampling sites in the mined Kyekyewere (KKW) location ranged from 3 to 6 (Figure 12). Six of the sampling sites had SQI score of 3, and nine sites obtained SQI score of 4. Similarly, eight of the sampling sites had SQI score of 5 whilst the remaining three sites obtained SQI score of 6 (Figure 12).

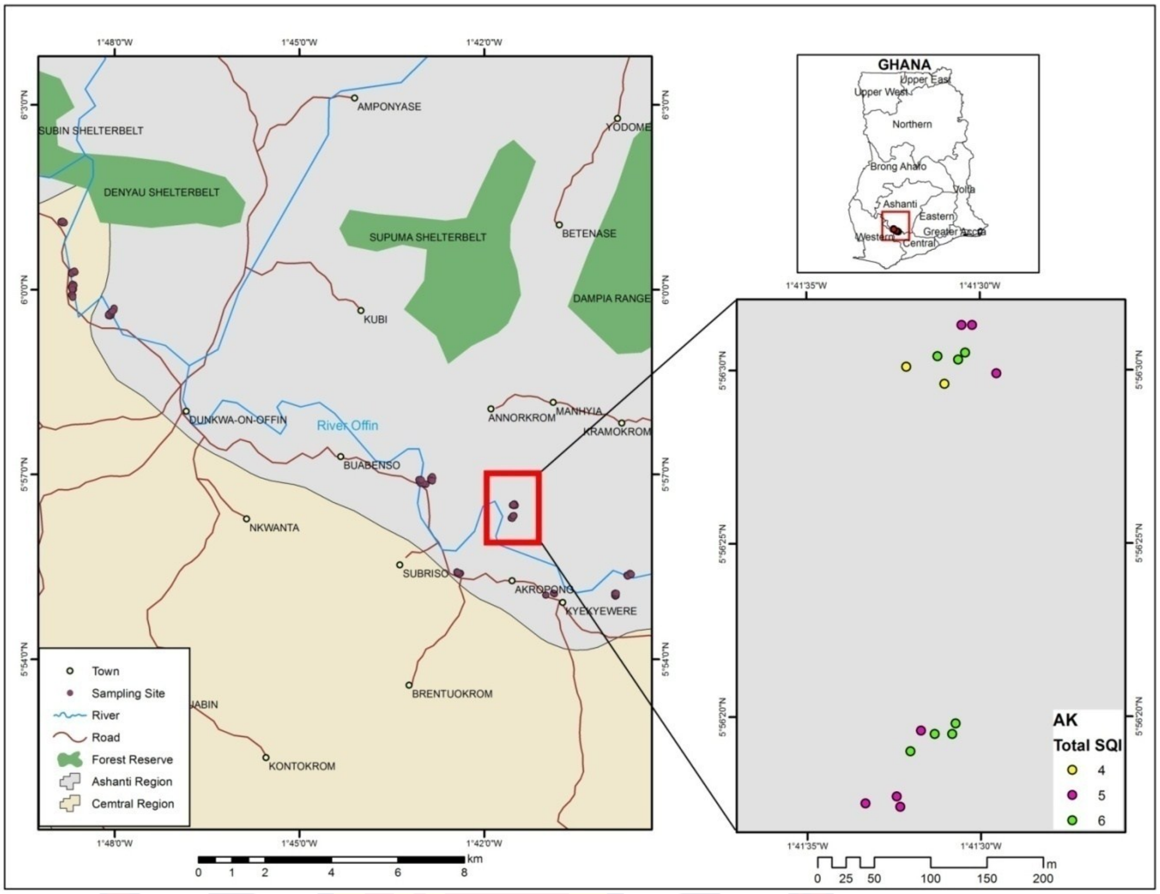


Figure 13: Soil quality index (SQI) score of sites in the AK sampling location

Out of the 16 sampling sites in the mined Akropong sampling location, two of the sampling sites had SQI score of 4 (Figure 13). Seven of the sampling sites obtained SQI score of 5 and the remaining seven sites had SQI score of 6.

Spatial distribution of heavy (trace) metals in the unmined and mined areas

The distrubtion of heavy metals Cu, Pb, As, Cd and Hg in the unmined and mined sites have been presented in Figure 14.

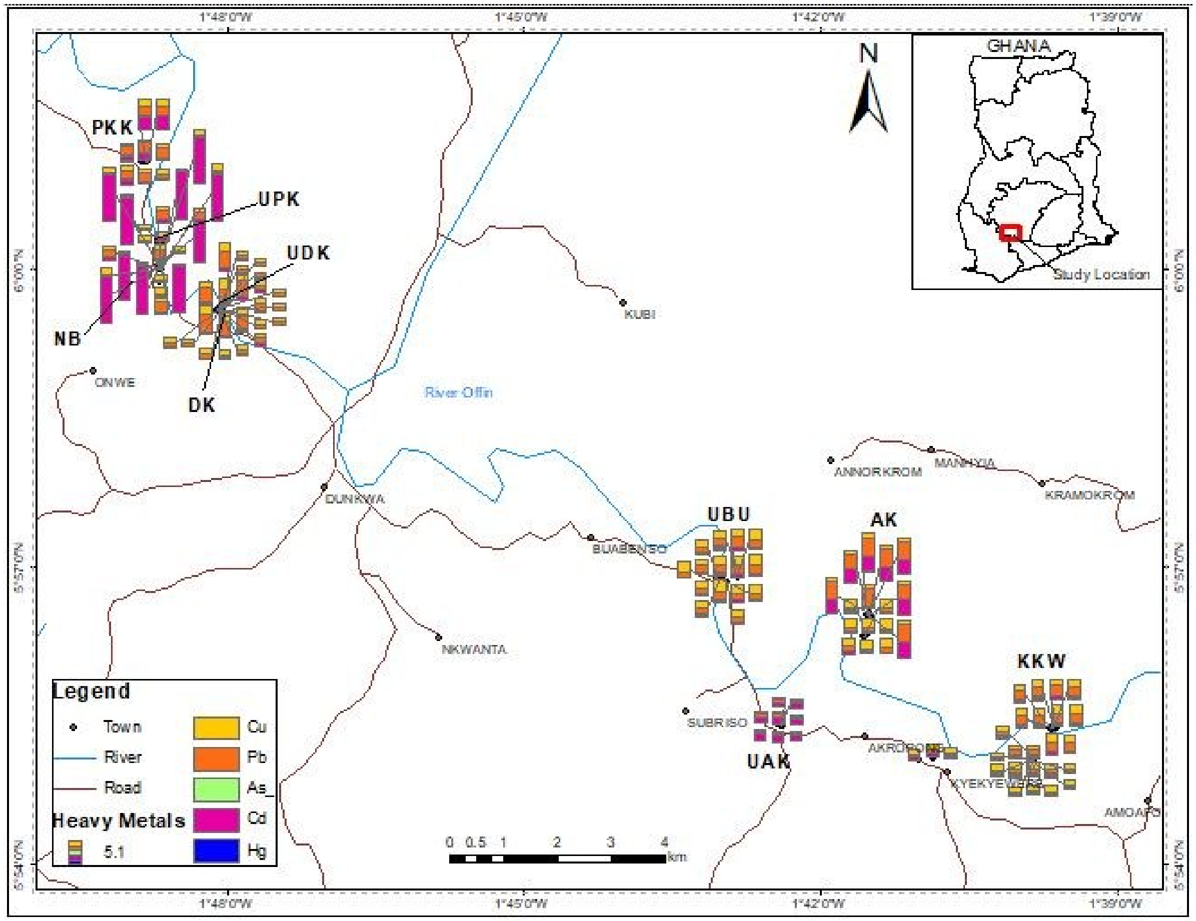


Figure 14: Spatial distribution of heavy (trace) metals in the unmined and mined areas

The spatial distribution of heavy (trace) metals in the study area showed an increase in the levels of cadmium (Cd) in some mined areas (Pokukrom (PKK) and Nyamebekyere (NB) as compared to the unmined areas (Pokukrom (UPK) and Buabenso (UBU) (Figure 14). For example, there was marked increase of Cd in the mined area of Pokukrom (PKK) as compared to the adjacent unmined area of Pokukrom (UPK) and also, the dominant heavy metal in the mined area of Nyamebekyere (NB) was Cd (Figure 14). In the Akropong site, the dominant heavy metal in the unmined area (UAK) was Cd with traces of lead (Pb). However, in the mined area of Akropong (AK), there was increase in Pb levels and introduction of copper (Cu) (Figure 14). The study showed an introduction and in some instances increase in the levels of arsenic (As) in mined areas of Dunkwa (DK) and Kyekyewere (KKW) as compared to the unmined areas of Dunkwa (UDK) and Buabenso (UBU). Though Lead (Pb) and Cu were observed in almost all the unmined sites (except unmined area of Akropong (UAK) of the study area, there were marked increases in the levels of Pb and Cu in most of the mined areas (AK, KKW, PKK and DK) (Figure 14). Mercury (Hg) was hardly observed in the mined and unmined study areas.

Spatial distribution of nutrients in the unmined and mined soils

The spatial distributions of calcium, sodium, magnesium; and nitrogen, phosphorous and potassium have been presented in Figures 15 and 16 respectively.

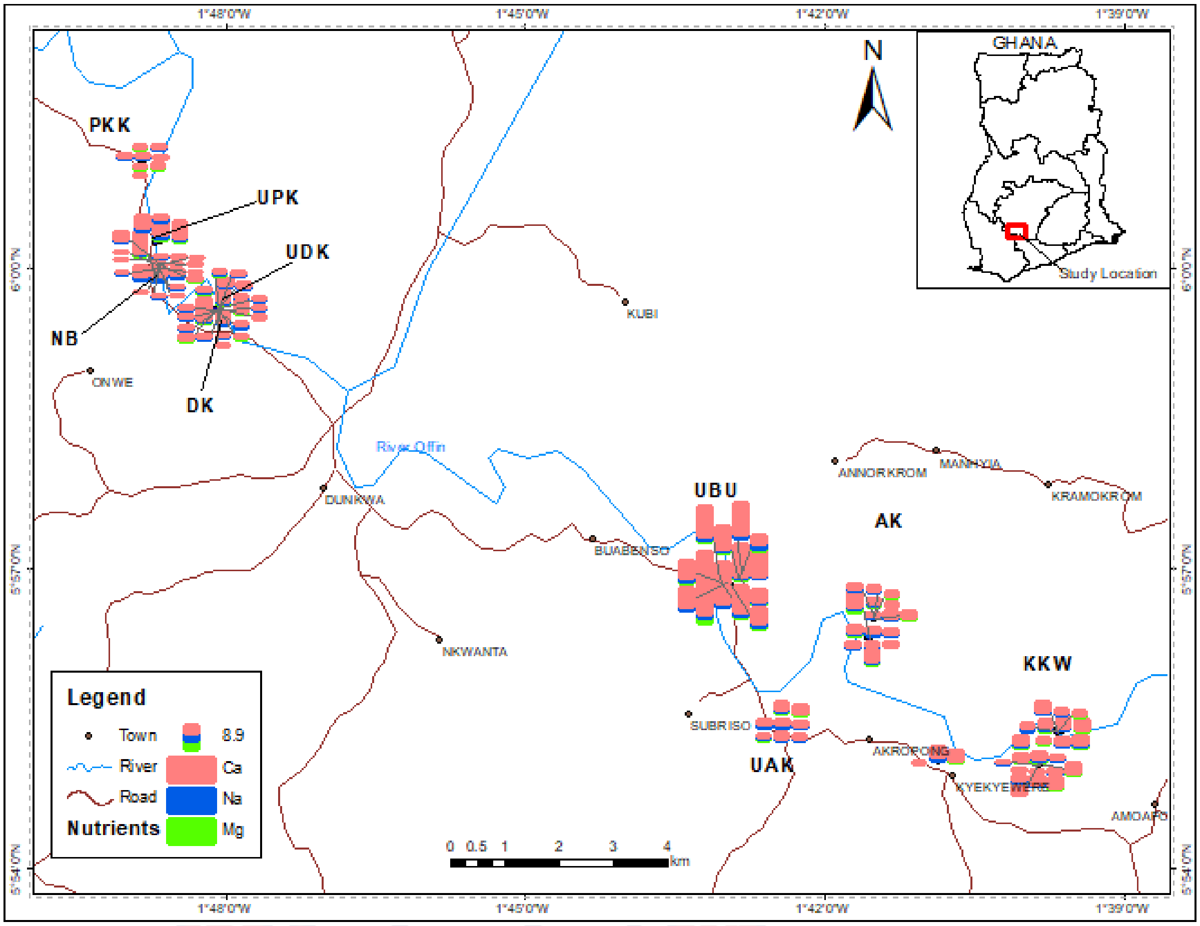


Figure 15: Spatial distribution of calcium, sodium and magnesium in the unmined and mined areas.

The distribution of Ca, Na and Mg in the study area generally showed the dominance of calcium followed by sodium and then magnesium (Figure 15). Areas where mining activities had taken place relatively had lower contents of calcium (KKW and PKK) as compared to unmined sites (UBU and UPK). Though the contents of sodium were generally low in the unmined areas (UBU, UAK and UDK), mining activities caused further reduction in the contents of sodium (KKW, AK and DK). Small-scale mining activities generally resulted in the reduction of the contents of magnesium. The contents of magnesium in the unmined soils (UBU and UPK) were relatively higher as compared to the mined soils (KKW and PKK). However, mining activities slightly increased the contents of magnesium in Akropong (AK) as compared to the unmined area in Akropong (UAK).

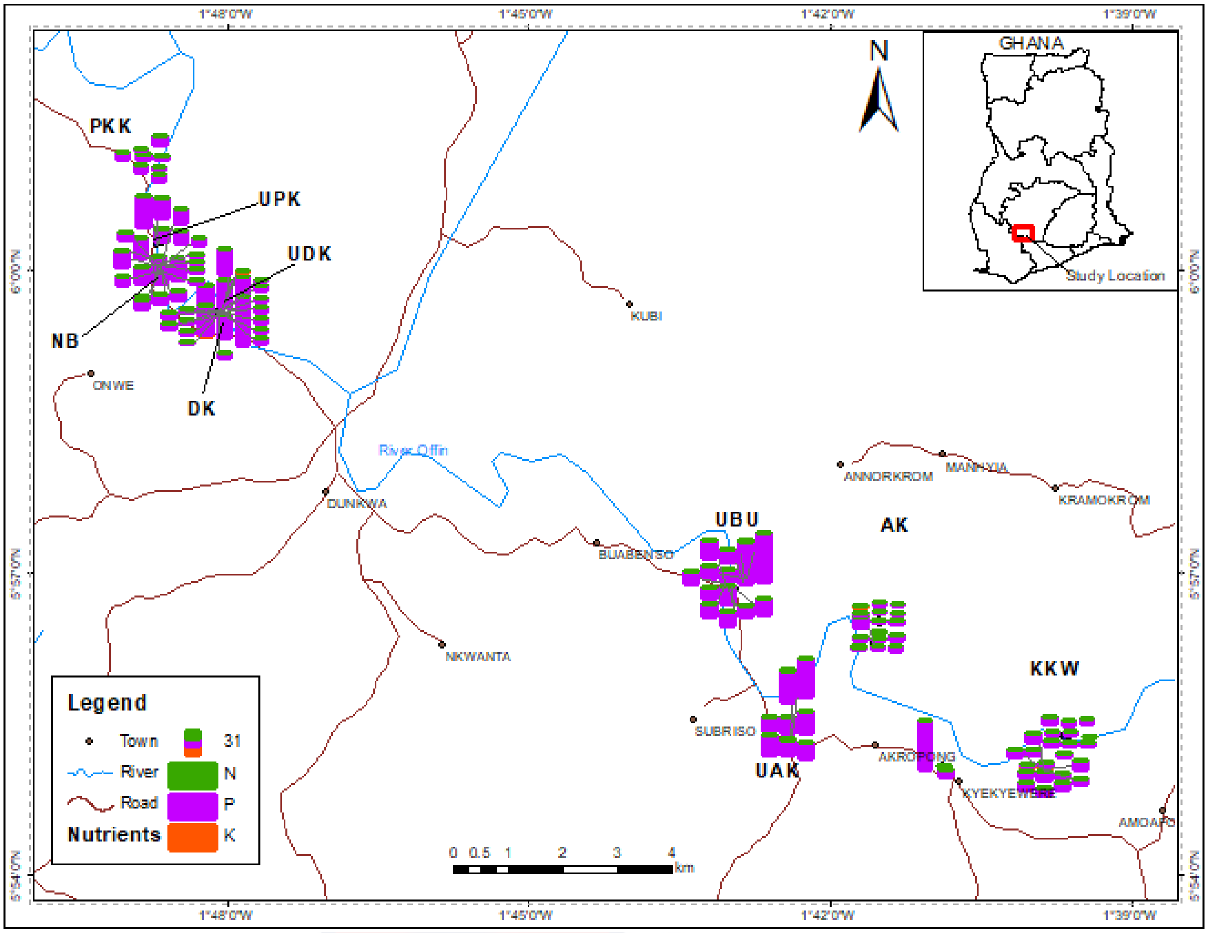


Figure 16: Spatial distribution of nitrogen, phosphorus and potassium in the study area

The spatial distribution of nitrogen, phosphorus and potassium in the study area generally showed relatively higher occurrence of phosphorus, followed by nitrogen and then potassium (Figure 16). The contents of phosphorus in the soils were relatively higher in the unmined areas of Akropong (UAK) and Pokukrom (UPK) as compared with adjacent mined sites of Akropong (AK) and Pokukrom (PKK).

Again, the contents of phosphorus in the mined area of Kyekyewere (KKW) were lower than that of unmined site in nearby Buabenso (UBU).

Potassium contents in the soils were very low in both the the mined and unmined study areas (Figure 16). The change in occurrence and content of potassium in the mined areas of Pokukrom (PKK) and Dunkwa (DK) as compared to the adjacent unmined areas of Pokukrom (UPK) and Dunkwa (UDK) were almost negligible. The occurrence and distribution of nitrogen generally did not differ in the unmined areas of Akropong (UAK) and Dunkwa (UDK) as compared to the adjacent mined areas of Akropong (AK) and Dunkwa (DK). Similarly, the distribution and occurrence of nitrogen in the unmined area of Buabenso (UBU) and the nearby mined area of Kyekyewere (KKW) were about the same (Figure 16).

Effect of years of fallow of mined site on the concentration of nutrients and heavy metals in soil

It is discernible from Table 27 that the number of years that mined soil laid fallow (0-5 years) does not influence Na, P, K, and Hg levels in the soil. However, the number of years that the mined soil laid fallow influences pH, EC, texture, and OC. Similarly, years of fallow influenced the levels of Mg, Ca, Cd, Cu, Pb and As in the soil. The relationship between years of fallow of mined site and the following, OC, texture and Cd showed that as the number of years that mined site remained fallow increases, the contents of OC and Cd increase; and in the negative relationship, the concentrations of pH, Ca, Mg, Cu, Pb, As and EC in the soil reduce.

Table 27: *Influence of fallow years of mined land on soil nutrients*

Variable	Coef.	SE	*P*-Value	[95%	CI]
pH	-0.04417	0.013502	**0.002**	-0.07104	-0.0173
Na	-0.02671	0.014077	0.061	-0.05472	0.001308
P	0.176907	0.481164	0.714	-0.78064	1.134454
K	-0.0029	0.002054	0.161	-0.00699	0.001185
Ca	-0.25781	0.07723	**0.001**	-0.41151	-0.10412
Mg	-0.0178	0.00816	**0.032**	-0.03404	-0.00156
OC	0.071987	0.021065	**0.001**	0.030066	0.113907
EC	-0.00547	0.001606	**0.001**	-0.00867	-0.00228
Texture	0.50477	0.082087	**0.000**	0.341412	0.668128
Cu	-0.10087	0.029141	**0.001**	-0.15887	-0.04288
Cd	0.757246	0.193625	**0.000**	0.371921	1.142572
Pb	-0.23195	0.061218	**0.000**	-0.35378	-0.11013
Hg	-0.00198	0.003865	0.610	-0.00967	0.005714
As	-0.01998	0.004448	**0.000**	-0.02883	-0.01112

Source: Field study (2017)

Socio-demographic characteristics of small-scale gold miners in the study area

The ages of miners ranged from 32 to 65 years with an average of about 47 years. Some small-scale goldminers have worked in the industry for as many as 35 years whereas others have lived in the same community almost all their entire life (Table 28).

Table 28: *Socio-demographic attributes of small-scale gold miners*

Attributes of respondents	mean	min	max	std deviation	skewness	Kurtosis
Age (years)	47.01422	32	65	6.335447	0.124965	3.058365
Monthly income (GhC)	5550	1800	14000	2015	1.071892	4.815147
Residence in study area (years)	15.86256	1	64	17.39061	1.355401	3.249972
Years of experience in mining	11.45498	2	35	6.286161	1.194668	4.16556

Source: Field study (2016)

The minimum monthly income for respondents was 1800 Ghana Cedis which was about one-tenth of the highest monthly earnings of some goldminers. Based on the sociodemographic attributes of miners, none of the characteristics (age, monthly income, length of stay in the community, years of experience in mining) were negatively skewed. Age of miners, monthly income, length of stay in the community, and years of experience in goldmining followed a leptokurtic distribution, that is, sharper than a normal distribution, with values concentrated around the mean and thicker tails. This means high probability for extreme values.

Measure of association between reported number of effects of goldmining and demographic characteristics of small-scale goldminers

The small-scale goldminers identified four main effects of goldmining on the natural and human environment although to varying degrees. These effects include air pollution (mostly suspended particulate matter), degradation of land and vegetation, water pollution, and noise pollution. The distribution of responses on the number of effects of goldmining on the environment based on compositional factors is shown in Table 29.

Table 29: *Perception on multiple effects of gold mining on the environment (n=211)*

Respondent attributes	Number of effects				Inferential Statistics
	0	2	3	4	
					Pearson chi2(9) = 21.8790
Educational attainment					Pr = 0.009
No formal education	8.3	4.2	50.0	37.5	Cramér's V = 0.1872
Primary	13.3	16.7	36.7	33.3	
Secondary	1.2	8.1	34.9	55.8	
Tertiary	0.0	10.3	32.4	57.4	
					Pearson chi2(3) = 2.2686
Gender					Pr = 0.519
Female	0.0	13.6	45.5	40.9	Cramér's V = 0.1037
Male	3.7	9.0	35.5	51.9	
Marital Status					Pearson chi2(12) = 18.8367

					Pr = 0.093
Single	0.0	0.0	0.0	100.0	Cramér's V = 0.1725
Married	3.9	9.9	34.3	51.9	
Separated	0.0	0.0	100.0	0.0	
Divorced	0.0	0.0	44.4	55.6	
Widowed	0.0	18.2	54.6	27.3	
Position in the household					Pearson chi2(3) = 6.6842 Pr = 0.083
Non-head	0.0	23.5	47.1	29.4	Cramér's V = 0.1780
Head	3.6	8.3	35.6	52.6	
Number of people in household					Pearson chi2(6) = 8.7084 Pr = 0.191
one to three	3.9	0.0	26.9	69.2	Cramér's V = 0.1437
four to five	1.9	11.4	34.3	52.4	
six or more	5.0	10.0	42.5	42.5	
					Pearson chi2(6) = 9.6572
Ethnicity					Pr = 0.140
Fante	6.3	18.8	37.5	37.5	Cramér's V = 0.1513
Twi	5.2	8.3	34.4	52.1	
Others	0.0	7.2	38.6	54.2	
					Pearson chi2(6) = 15.5780
Religion					Pr = 0.016
Christian	0.8	9.4	35.2	54.7	Cramér's V = 0.1921
Muslim	0.0	9.7	41.9	48.4	
Others	11.5	9.6	36.5	42.3	
Experience in current job					Pearson chi2(3) = 10.1621 Pr = 0.017
Up to 2 years	6.5	14.5	43.6	35.5	Cramér's V = 0.2195
3 or more years	2.0	7.4	33.6	57.1	

Source: Field studies (2016)

All the small-scale miners mentioned at least two effects of mining on the environment simultaneously (Table 29). The measure of association showed significant relationship between education attainment and number of multiple effects reported by small-scale miners. The chi-square statistic reported for this relationship firmly rejects the null hypothesis that education attainment and perception on environmental effects of goldmining are independent. However, the Cramér's V statistic was less than 0.3 indicating that the association between the two measures was not strong. Similarly, religious beliefs and number of years of experience in small-scale goldmining both showed associations with several of the effects reported by small-scale miners. However, the chi-square statistic reported for perception on environmental effects of goldmining and ethnicity, gender, number of people in the household and marital status failed to reject the null hypothesis that these attributes and perception on environmental effects of goldmining are independent. Interestingly, although almost all respondents were in support of reclamation, there was widespread lack of support for payment for reclamation after goldmining has ceased. Thus, about 88% of respondents were not willing to pay for reclamation.

CHAPTER FIVE

DISCUSSION

Introduction

This chapter situates the results of the study within the context of existing knowledge. It commences with a discussion on the diversity, abundance and distribution of species; ecological and conservation status of plant species in the unmined and mined areas. The similarity of the plant species in the unmined and mined flora have been discussed indicating the implication of biodiversity conservation in the study area. This section also dicusses how small-scale mining activities have affected the concentrations and distribution of heavy metals and nutrients in unmined and mined areas, mined land of different fallow years and pit conditions; and soil quality in the study area. This chapter ends with an evaluation on the perception of small-scale miners on environmental effects of gold mining.

Floral richness and diversity at the study site

The unmined study area showed higher number of species, genera and families relative to the mined area (Tables 6 and 7). This suggested that intact moist semi-deciduous forests (unmined area) tend to have plant species reserves as observed by Kothandaram & Sundarapandian (2017). In this study, 69 species were found growing only in the mined area (Table 7). The loss of canopy and creation of gaps in the mined area could have led to growth of many secondary plant species, especially herbs (Sahoo, Panda, & Acharya, 2017). This could have accounted for the 84,246 individuals distributed in 157 species in the mined area and the 6745 individuals distributed in 209 species in the unmined area (Appendices K and L). According to Sundarapandian & Karoor (2013), environmental and anthropogenic changes in forest ecosystems affect plant community structure and species composition. Small-scale mining activities in the study area caused ecological changes in the forest ecosystem leading to reduction in plant species composition and abundance.

The dominant plant families in the unmined area were the Euphorbiaceae (18species), Rubiaceae (18 species) and Asteraceae (10 species); and that of the mined area were Poaceae (22 species), Euphorbiaceae (17 species) and Asteraceae (11 species) (Tables 6 and 7). This conformed with observations by Duah-Gyamfi, Kyereh, Adam, & Swaine (2014) who noted that the Euphorbiaceae, Rubiaceae and Moraceae were among the five dominant families in their study of a tropical forest in Ghana. In another study conducted on plant species in a tropical West African forest in Sierra Leone National Park (Gola Rainforest National Park), the Fabaceae, Euphorbiaceae and Sterculiaceae families were dominant (Laurin *et al.*, 2013). According to Kothandaraman & Sundarapandian (2017), the Euphorbiaceae was the dominant plant family in two forest areas in the Tropical Deciduous Forest of Kanyakumari Wildlife Santuary in India. The Papilionaceae, Moraceae, Sterculiaceae and Sapindaceae were listed as the dominant plant families in a tropical forest ecosystem in south-western Nigeria (Eludoyin *et al.*, 2017). According to a study done by Naidu & Kumar (2016) and Sundarapandian & Karoor (2013) on tropical forest ecosystems, the Euphorbiaceae and Combretaceae were the top-most contributors to species diversity while the Poaceae and Fabaceae were most dominant families in terms of abundance. In this study, the Euphorbiaceae, Rubiaceae and Asteraceae contributed most to species diversity while Asteraceae, Poaceae and Euphorbiaceae were abundant in both the unmined and mined areas. High species richness is typical of many tropical forests (Antonelli & Sanmartin, 2011; Tarakeswara, Premavani, Suthari, & Venkaiah, 2018).

The distribution of the species into life forms in the unmined area showed that trees were the most dominant (52.15%) followed by herbs with 27.75% of the species (Table 9). The dominance of tree species in the unmined area is typical of the ecosystem under study (Magurran, 2013). It was also observed that the dominant life forms in the mined area were the herbs (56.06%) which were followed by climbers with 12.10% of the species (Table 10). The observed differences in the vegetation structure of the two areas could be due to anthropogenic characteristics (small-scale mining activities) (Kothandaraman & Sundarapandian, 2017). This finding corroborated with Tchouto (2004) who observed in Cameroon tropical forest that the numbers of herbaceous species and climbers increase with the degree of floral disturbance.

The most dominant tree families encountered in the unmined area were the Euphorbiaceae (12 species distributed in 10 genera) and Rubiaceae with 10 species distributed in 9 genera (Appendix K). This observation is in agreement with the findings by Fonge *et al*. (2013) and Attua & Pabi (2013) who stated that the Rubiaceae was the dominant tree family in tropical forests in Mount Cameroon and Northern Forest -Savanna Ecotone of Ghana respectively. Laurin *et al.* (2013) in their study on a tropical West African forest in Sierra Leone National Park (Gola Rainforest National Park), identified the Euphorbiaceae, Fabaceae and Sterculiaceae as dominant tree families. The marked presence of the Euphorbiaceae and Rubiaceae in the unmined area is a feature common to most tropical forests (Ifo *et al.*, 2016) however, this observation contradicts the findings of Pappoe, Armah, Quaye, Kwakye, & Buxton (2010) who identified the Meliaceae, Sterculiaceae, Mimosaceae and Moraceae as dominant tree families in a study conducted in the tropical forest of the Kakum National Park in Ghana.

The species richness of a forest ecosystem depends on the number of species per unit area. The situation where there are more species per unit area, the species richness tends to be high (Eludoyin *et al.*, 2017). The species richness values of 82 tree species/ ha for the unmined area and 7 tree species/ ha for the mined area were lower as compared to 552 tree species ha^{-1} obtained in a tropical forest in Kade in Ghana (Hall & Swaine, 1981b) and 93 tree species ha^{-1} observed in a tropical forest in Tanzania (Kacholi, 2014). However, the species richness of trees obtained from the unmined study area (82 tree species ha^{-1}) was higher than the 60-70 tree species ha^{-1} (Lawson, 1985), and 28 tree species ha^{-1} (Addo-Fordjour, Obeng, Anning, & Addo, 2009) obtained in West African Tropical Forests. The study site with relatively higher species richness was the unmined area with Margalef richness value of 23.53 whiles the mined site had a Margalef richness value of 13.75.

The presence of many species with low density and frequency values in the unmined area (Table 8) was due to the fact that most of the plant species are rare (Magurran, 2013). The rarity of majority of the species in the unmined area may be due to strong density-dependency in the area, poor dispersal of species and the presence of resource gradient leading to abundance distribution variation of species (Fonge *et al*., 2013; Tarakeswara *et al*., 2018). The anthropogenic disturbances as a result of small-scale mining probably led to the destruction of canopies and creation of gaps in the mined area leading to the preponderance of herbaceous species with relatively higher densities and frequencies (Table 9). The floristic richness of species in a forest zone could be influenced by the geographical location of the area, favourable climatic conditions and the level of anthropogenic disturbances (Laurin *et al*., 2013; Eludoyin *et al*., 2017)

The frequency values obtained from plant species of two floral plots could be used to compare the plant communities and detect changes in the composition of the vegetation over time (Smith, Bunting, & Hironka, 1986). In addition to the number of plant species found only in the mined area (69 species) and that for only the unmined area (121 species) contributing to the observed changes in the composition of the vegetation, the differences in the frequency values of plant species common to the mined and unmined areas could give further indication of the level of variation in the vegetation structure of the two study areas.

Species diversity influences the functioning of a floral community (Borogayary, Das, & Nath, 2018). Plant communities with higher species diversity tend to have greater stability. The quantitative understanding of species diversity values give information needed for comparing and prioritizing among plant communities (Vermuelen & Koziell, 2002). The study showed that the mean Shannon-Weiner diversity index (H^1) value of the unmined area (4.62 ± 0.03) was higher than the mean Shannon-Weiner diversity index (H^1) value for the mined area which was 4.54 ± 0.02. However, the mean Simpson`s diversity values (D) for the unmined area (0.98 ± 0.03) and the mined area (0.98 ± 0.01) were approximately the same (Tables 14 and

15). The Shannon-Weiner index (H^1) is used for the determination of abundance-based diversity and the functional characteristics of the most abundant species (Laurin *et al.*, 2014). The significant difference between the H^1-unmined and H^1mined (Table 18) could indicate that the two areas are environmentally different from each other (Magurran, 2013) and could have accounted for the differences in species diversity and abundance between the flora of the unmined and mined areas. A forest community is said to be rich if it has a Shannon-Weiner diversity (H^1) value greater than or equal to 3.5 and sites with less than 3.5 are said to be relatively poor in diversity (Fonge *et al.*, 2013). The Shannon-Weiner diversity index (H^1) is influenced more by richness and less by evenness (Magurran, 2013) and this could explain the relatively higher H^1 values obtained in both the unmined and mined study areas. Moreover, the H^1 for both unmined and mined areas obtained in this study were higher than the 3.6 recorded for a relatively undisturbed semi-deciduous forest type in Ghana (Addo-Fordjour *et al.*, 2009). This shows that despite the small-scale mining activities, plant species diversity has not been adversely altered much in the study area.

The relatively lower Shannon (H^1) value in the mined area was probably due to anthropogenic activities such as small-scale mining, farming and hunting (Fonge *et al.*, 2013). Work done by Tom-Dery, Dagben, & Cobbina (2012) in Northern Ghana indicated that small-scale mining activities caused degradation of the flora leading to reduction in the diversity of plant species. The unmined area is dominated by trees (52.15%) and tropical trees tend to be highly species diverse (Pappoe *et al.*, 2010). The diversity in tropical trees is due to habitat suitability, differences in biogeography and anthropogenic pressures (Sundarapandian & Karoor, 2013). Shannon diversity index (H^1) increases with increasing species richness and species diversity (Kacholi, 2014). The study showed a decline in tree species richness (7 tree species/ ha) and diversity (4.54 ± 0.02) in the mined area and this could be attributed to small-scale mining activities in the area. According to Swamy, Dutt, Murthy, Mishra, & Bargali (2010), many tropical forests have lost the potential for self maintenance due mainly to anthropogenic activities. Small-scale mining activities at the mined site could have altered the ecological factors over the area leading to the differences in the diversity, density and distribution of plant species between the unmined and mined areas (Khan *et al.*, 2017).

The Evenness (E) value for species in the unmined area (0.51 ± 0.02) was higher than that for the mined area (0.40 ± 0.01) (Tables 14 and 15). Thus, the number of individuals within a species is fairly constant in the unmined area (high equitability) as compared to the large disparity between the numbers of individuals within each species in the unmined area (low equitability). The equitability and Simpson`s diversity of 0.50 to 0.54 and 0.96 to 0.99 in the unmined area (Table 14) imply that between 50% to 54% of the species were equitably distributed in the unmined area (Magurran & Henderson, 2003; Pappoe *et al.*, 2010) while between 96% to 99% of the species in the flora may be of different species. The equitability and Simpson`s diversity of 0.39 to 0.42 and 0.97 to 0.99 in the mined site (Table 15) indicate that between 39% to 42% of the species were equitably distributed in the mined area while between 97% to 99% of the flora may be of different species (Magurran & Henderson, 2003; Pappoe *et al.*, 2010). Small-scale mining activities reduced the relative abundance of species in the mined area and relatively fewer species dominated the mined area.

Ecological guild of plant species in the study area

The classification of all plant species obtained in the study into guilds showed that Pioneers had 187 species, Non-Pioneer Light Demanding (NPLD) obtained 43 species, Shade-Bearers consisted of 39 species and 6 species were found in the Swamp ecological category (Tables 12 and 13). The totality of Pioneers and NPLD (230 species) in the study area could underpin the existence of gaps in the study area (Hawthorne, 1993).

The relative abundance of Pioneers and NPLD in the unmined area (128 species) as compared to the 102 species (Pioneers and NPLD) in the mined area (Tables 12 and 13), was due to the dominance of tree species (109 species) in the unmined area as compared to the 15 tree species in the mined area (Tables 10 and 11). Small-scale mining activies caused destruction of the flora in the mined area, especially tree species. According to Hawthorne and Abu-Juam (1995) and (Hawthorne, 1993), most lianes and timber species (trees) are NPLD and Pioneers.

A high pioneer index value gives a good indication of the "secondariness" of an area of a forest and most forests in Ghana are secondary in terms of species composition (Hawthorne & Gyakari, 2006). The significant difference ($p < 0.05$) between the pioneer index values of the unmined and mined areas (Table 18) indicates higher disturbance of the flora of the mined area. This was due to anthropogenic activities such as the small-scale mining at the mined site. The high number of plant species in the unmined area which were pioneers was due to the preponderance of tree species (52.15%) and for the mined area, the high number of pioneers was due dominance of herbs (56.05%) (Tables 10 and 11). Anthropogenic disturbances (eg. small-scale mining) in the mined area could have led to higher incidence of sunlight in the forest floor which is needed for the effective growth and development of herbs (Oduro, Duah-Gyamfi, Acquah, & Agyeman, 2012). The relative high number of herbs found in the mined area as compared to the unmined area suggest that more time is needed for the expected flora compositional shift to take place naturally (Oduro *et al.*, 2012). In this study, number of Shade-Bearers was higher in the unmined area than the mined area (Tables 12 and 13). This corroborated with Hawthorne (1993) that closed canopies of forest (mainly in the unmined area) favour Shade-Bearers and NPLD species as the seeds of these guilds germinate in the shade of undisturbed forest.

Conservation status of plant species in the study area

The dominance of green star species in the study area (Tables 16 and 17) is in conformity with forests ecosystems in Ghana (Hawthorne & Abu-Juam, 1995; IUCN, 2004; Hawthorne & Gyakari, 2006). Green star species are common and of no particular conservation concerns in Ghana. The relatively high number of star-rated plant species (especially trees) in the unmined area (Table 16) than the mined area (Table 17) could be due to anthropogenic activities especially small-scale mining.

The absence of black star species and a few blue and gold star gold star species in the study conform with the generally rare nature of these species in Ghana (Hawthorne & Gyakari, 2006), and the presence of 8 blue and 4 gold (unmined area) and 1 blue and 1 gold (mined area) could be due to serious exploitation and destruction of these species. The relatively higher presence of pink stars in the unmined area (Table 16) could be that use of some pink star species have not been fully explored by the community members yet (Hawthorne & Abu-Juam, 1995).

The significant ($p < 0.05$) difference of genetic heat index (GHI) between all star rated species of the unmined and mined areas (Table 18), shows that the level of destruction of species of high conservation value is more pronounced in the mined area. This is further supported by the significant ($p < 0.05$) difference of GHI between tree species in the unmined and mined areas (Table 18). The high GHI of the unmined area as compared to the mined area shows that unmined area was relatively undisturbed and had more exciting and rare species (Tchouto, Yamefack, de Boer, & De Wilde, 2006; Hawthorne & Jongkind, 2006). The pioneer index (PI) values for both star species and trees in the mined area were higher and significantly ($p < 0.05$) different from those of the unmined area (Table 18). The relatively low GHI and high PI values of the mined area shows that the mined area is rich in pioneer plant species (mostly herbs) but poor in plant species with high conservation value (Tchouto *et al*, 2006) and the converse pertains in the unmined area. The higher PI value of the mined area as compared to the unmined area (Table 18) is an indication of relatively heavy disturbance of the flora of the mined area which is likely due to small-scale mining activities. The GHI of trees (64.42 ± 0.634) for the unmined area was lower than the documented values of 301 for the Ankasa Conservation Area and 269 for the Neung North Forest Reserve both in Ghana. This shows that the forest ecosystem of the unmined study area falls in the low conservation or bioquality category (Hawthorne & Abu-Juam, 1995). This is in line with observations by Hawthorne and Abu-Juam (1995) that undisturbed moist deciduous forest (as found in the study area) tend to have low to moderate GHI values as compared to wet evergreen forests.

The abundance based similarity measure (Ifo *et al*, 2016) used in determining Sorenson`s similarity index and the Similarity ratio allowed for measurement of the degree to which the species composition of the unmined and the mined areas was similar (Chao, Chadzen, Codwell, & Shen, 2006). The similarity in terms of species numbers between the unmined and mined areas showed that Similarity ratio was 0.033519 and the Sorenson`s index was 0.4808. The 0.4808 value for the Sorenson`s index means about 48% of the species are common to the unmined and mined areas. The low index values suggest that similarity is generally low compared with difference in the floristic composition between the unmined and mined areas. The dominace of the floristic difference might have occurred because of small-scale mining activities in the study area.

Implications of biodiversity conservation in the study area

The study on the flora of the unmined and mined areas has revealed that small-scale mining has contributed to the reduced numbers of plant species of higher conservation value in the mined areas; caused reduction in species diversity and richness; reduced the economic and commercial value of species in the mined area; and increased destruction of canopies leading to the preponderance of herbaceous species in the mined areas. The study provides important information on the abundance and distribution of plant species (especially tree species) which can be targeted and prioritized and used for the formulation of site-specific strategies for conservation of biological diversity and restoration of degraded/mined areas in a moist semi-deciduous forest located in the environs of Dunkwa East Municipality of Ghana.

Distribution of heavy metals, physicochemical properties and nutrients in mined and unmined soils

Physico-chemical properties of soil (eg. pH, organic carbon etc.) affect the mobility and pathways of nutrients and pollutants in the soil. It is therefore necessary to assess these soil physico-chemical properties in order to determine their mutual relationships which influence the use of these soils for other activities such as sustainable agriculture (Tariq, Shafiq, & Chotana, 2016).

Although copper (Cu) is needed for biochemical processes in crops, very high concentration of Cu is detrimental to human health (Tariq *et al.*, 2016). The range of concentration of Cu for this study (0.10 to 2.69 mg kg^{-1}) (Table 19) was below the FAO/WHO (2001) prescribed value of 100 mg kg^{-1} and European Union (2002) value of 50 mg kg^{-1} for agricultural purposes. The mean concentrations of Cu in the unmined and mined soils in the study area were 1.40 ± 0.14 mg kg^{-1} and 1.12 ± 0.06 mg kg^{-1} respectively. These concentrations are far lower than the findings by Kpan *et al.* (2014) who reported that the mean concentration of Cu in small-scale mined soils in some towns in the Dunkwa East Municipality was 63.26 mg kg^{-1}. Mohamad *et al.* (2017) and Ali , Elhagwa, Elfaki , & Sulieman (2017) obtained Cu concentration ranges of 150.7-805.2 mg kg^{-1} and 4.85-34.65 mg kg^{-1} in gold mined soils of Romania and Sudan respectively.

The concentration of lead (Pb) in soil samples in the study area ranged from 0.02 to 3.82 mg kg^{-1} (Table 19). The concentrations of Pb in the soils of the study area were lower than the FAO/WHO (2001) permissible Pb levels (50. 00 mg kg^{-1}) in agricultural soils. The mean concentration of Pb in the unmined soils was 1.23 ± 0.02 mg kg^{-1} and that for the mined soils was 1.28 ± 0.04 mg kg^{-1}. The observed concentration of Pb in the soils of the area could be due to lower concentration of Pb in the parent rocks and use of fuels that do not contain Pb. In a study done by Kpan *et al*. (2014) in soils of small-scale mining towns in the Dunkwa East Municipality of Ghana, the mean concentration of Pb was 95.13 mg kg^{-1} exceeding the FAO/WHO guidelines. The finding by Antwi-Agyei, Hogarth, & Foli (2009) showed that the average Pb concentration in soils around tailing dams in Obuasi, Ghana was 24.22 mg kg^{-1}; this value was lower than the FAO/WHO standard. According to Lo *et al.* (2012) outbreak of Pb poisoning among children in two villages in Zamfara State in Nigeria was due to gold mining activities.

The concentration of cadmium (Cd) in the soils of the study area varied between 0.02 and 10.22 mg kg^{-1} (Table 19). The mean concentrations of Cd in the unmined and mined soils were 0.56 ± 0.05 mg kg^{-1} and 1.87 ± 0.13 mg kg^{-1} respectively and these concentrations were below the FAO/WHO (2001) permissible limit of 3 mg kg^{-1} for agricultural soils but that for the mined soil was greater than the threshold limit of 1.0 mg kg^{-1} for the European Union (Toth, Hermann, da Silva, & Montanarella, 2016). The concentrations of Cd (2.46 to 3.58 mg kg^{-1}) in some mined sites of Nyamebekyere could pose health risk as higher amounts of Cd in soils could result in relatively higher amounts of Cd in leavy vegetables and cabbages (Mahmud, Hassan, Hassan, Mandal, & Rahmam, 2018; Huang *et al*., 2017). This finding is in line with Mohamad *et al*. (2017) who obtained concentrations of Cd in mined soils ranging from 1.1 mg kg^{-1} to 10.6 mg kg^{-1} in Romania. Long-term exposure to Cd through soil and food intake can cause cancer and organ system toxicity (Rahimzadeh, Rahimzadeh, Kazemi, & Moghadamnia, 2017)

The mean concentration of As in soils of the unmined area (0.11 ± 0.01 mg kg^{-1}) and mined area (0.08 ± 0.10 mg kg^{-1}) were lower than the mean concentrations obtained by researchers working on gold mined soils in Wantia (23.14 mg kg^{-1}) and Fel (10.73 mg kg^{-1}) in Kombo-Laka in Cameroon (Leopold, Danala, Zo'o, & Jung, 2016). Arsenic occurs naturally and is widely distributed in the earth`s crust (Mensah *et al.*, 2015).

Historically, small-scale mining for gold often leads to high mercury (Hg) levels in the soils of mined areas (Toth *et al.*, 2016). The concentration of Hg in the soils of the study area ranged from 0.01 mg kg^{-1} to 0.19 mg kg^{-1} (Table 19) and lies within the permissible limit of the FAO/WHO (2001) value of 2.00 mg kg^{-1} (Fosu-Mensah, Addae, Yirenya-Tawiah, & Nyame, 2017). This corroborated with work done by

Basu *et al*. (2015) who observed that some gold mined soils in Ghana had lower Hg concentration than the guideline values. The concentrations of Hg in the unmined and mined soils were 0.04 ± 0.01 mg kg^{-1} and 0.05 ± 0.01 mg kg^{-1} respectively. The mean Hg concentration of 0.141 mg kg^{-1} obtained in small-scale mined soils in Dunkwa East Municipality by Kpan *et al.* (2014) was higher than that of this study (0.05 mg kg^{-1}). This could probably mean that the use of Hg for small-scale mining activities on the field in the study area is generally going down. However, the concentrations of mercury in soils of some of the mined areas in Kyekyewere were closer to the FAO/WHO permissible limit. The affected sampling sites included KKW31 (0.191 mg kg^{-1}), KKW30 (0.185 mg kg^{-1}), KKW34 (0.184 mg kg^{-1}), KKW44 (0.184 mg kg^{-1}) and KKW32 (0.173 mg kg^{-1}). Mercury is an environmental pollutant of most small-scale mining areas and can lead to serious adverse alterations in the human body tissues (Basu *et al*., 2015; Esdaile & Chalker, 2018).

The order of abundance of heavy metals (trace metals) in the unmined soils of the study area was Cd > Pb > Cu > As > Hg and that for the mined soils was Cu > Pb > Cd > As > Hg. Small-scale mining activities could have influenced the change in the order of abundance of the heavy metals between unmined and mined soils. This conforms to with work done by Oladipo *et al*. (2014) who indicated that mining activities caused elevations and reductions in concentrations of some heavy metals.

The pH of soils in the whole study area ranged from 4.60 to 5.80 (Table 19). Soil pH is considered as a master variable influencing the chemical, physical and biological properties of soil (Chakraborty, 2015) and a pH level of 6 - 7 is normally suitable to maintain productivity of crops. The pH levels obtained in soils of the unmined study area ranged from 4.60 to 5.80 and that for the mined area varied from 4.60 to 5.20. The increase in the concentrations of Pb, Cd and Hg in the mined soils could have influenced the relatively lower pH levels of the mined areas.The low pH of soils in both unmined and mined areas were similar to pH values (5.20 - 6.60) obtained by Leopold *et al.* (2016) who studied the effects of gold mining on soils in the Fel mined area and 4.00 - 6.20 in Wantia mined area in Kombo – Laka Area of

Cameroon. The relatively lower pH levels in the mined areas collaborated with the findings by Oladipo *et al*. (2014) that mining activities caused reduction in soil pH in the unmined areas of Awo (6.50), Itagunmodi (6.70) and Ijero-Ekiti (6.80) to 5.10, 5.30 and 3.50 respectively.

The concentrations of sodium (Na) in the soils of the study area were between 0.20 and 1.84 cmol$_c$ kg^{-1} (Table 19). Low Na concentration in soil is considered beneficial for growth and development of many plants (Kaur, Kaur, & Nayyar, (2015). Plants have different salt tolerance levels and high concentration of Na in the soil can result in low productivity of crops and also lead to sodium dispersion making agricultural soils unsuitable for growing crops (Bortolini, Giordani, Tuccia, Maistrello, & Vanin, 2018). The concentration of Na in the unmined soil was 0.99 ± 0.32 cmol$_c$ kg^{-1} and that for the mined soil was 0.46 ± 0.24 cmol$_c$ kg^{-1}. If the concentration of Na in an agricultural soil is greater than 2 cmol$_c$ kg^{-1}, then it is on the very high level; lower concentration of Na ranges from 0.1 to 0.3 cmol$_c$ kg^{-1} and moderate levels of Na in agricultural soils occurs between 0.3 to 0.7 cmol$_c$ kg^{-1} (Hazelton & Murphy, 2007).

High electrical conductivity (EC) in agricultural soils adversely influence crop yield and soil living organisms (Bortolini *et al.*, 2018; Kaur *et al.*, (2015). In this study, the maximum and minimum EC values in the soils of the whole study area were 0.120 dS m^{-1} and 0.010 dS m^{-1} respectively (Table 19). For surface soils (0- 30 cm), EC values of 4- 8 dSm^{-1}, 8- 16 dS m^{-1} and > 16 dS m^{-1} are considered as moderately saline, saline and very strongly saline, respectively (Bortolini *et al.*, 2018; Kaur *et al.*, (2015). The EC in unmined soils (0 – 30 cm) was 0.03 ± 0.01 dS m^{-1} and that of the mined (0- 30 cm) area was 0.028 ± 0.02 dS m^{-1}. The finding in this study is in line work done by Leopold *et al.* (2016) in Cameroon which showed that EC in the mined soils of Fel ranged from 0.098 to 0.257 dS m^{-1} (mean value of 0.166 dS m^{-1}) and that of Wantia also ranged from 0.119 to 0.189 dS m^{-1} (mean value of 0.15 dS m^{-1}). The EC values of gold mined soils in Dar- Mali locality in Sudan ranged from 0.13 to 20.9 dS m^{-1} indicating that soils in that area varies from non- saline to extremely saline soils at different sites (Ali *et al.*, 2017).

The concentration of calcium (Ca) in the soils of the study area ranged from 0.070 to17.726 cmol$_c$ kg^{-1} (Table 19); and that of the unmined and mined soils were 4.87 ± 1.74 cmol$_c$ kg^{-1} and 1.35 ± 0.22 cmol$_c$ kg^{-1} respectively. The relatively higher concentration of Ca in the unmined soil could be due to small-scale mining activities in the area. According to Oladipo *et al*. (2014), gold mining generally reduces the level of calcium in the soil as the levels of calcium concentration in Itagunmodi and Ijero-Ekiti areas in Nigeria reduced from 41.82 cmol$_c$ kg^{-1} to 22.48 cmol$_c$ kg^{-1} and from 29.57 cmol$_c$ kg^{-1} to 14.96 cmol$_c$ kg^{-1} in Itagunmodi and Ijero-Ekiti respectively. Moreover, the calcium concentration in the mined soils differed significantly ($p <$ 0.05) from that of the control (unmined) soils. For agricultural soils, calcium concentration less than 5.0 cmol$_c$ kg^{-1} is considered low, between 5- 10 cmol$_c$ kg^{-1} as moderate and greater than 20 cmol$_c$ kg^{-1} as very high (Hazelton & Murphy, 2007).

Magnesium (Mg) is an important element in many physiological and biological processes in plants and thus supports growth and development and also serves as defence mechanism during abiotic stress periods in plants (Zörb, Senbayram, & Peiter, 2014). The concentration of Mg in the study area varied from 0.03 to 2.14 cmol$_c$ kg^{-1} (Table 19); and that for the unmined and mined areas were 0.39 ± 0.11 cmol$_c$ kg^{-1} and 0.16 ± 0.01 cmol$_c$ kg^{-1} respectively. This observation in the study collaborated with workdone by Oladipo *et al*. (2014) that small-scale mining activities caused reduction in the concentration of Mg in soils of Awo, Itagunmodi and Ijero-Ekiti areas in southern Nigeria. The concentrations of Mg in the soils of unmined and mined areas for this study were within the low range of 0.03 to 1.0 cmol$_c$ kg^{-1} for agricultural soils (Hazelton & Murphy, 2007).

Gold mining activities generally have adverse effect on the concentration of nitrogen (N) in the soil (Oladipo *et al*., 2014). In this work, the concentration of N in the whole study area varied from 0.01% to 0.28% (Table 19). According to Hazelton & Murphy (2007) when the concentration of N in agricultural soils is between 0.05 to 0.15%, it is considered low; between 0.15 to 0.25% as medium; 0.25 to 0.50% as high and > 0.5 of nitrogen as very high level. Thus the concentration of N in the soils of the study area was low. The concentration of N in the unmined soil in this study was 0.15 ± 0.03% and that for the mined soil was 0.04 ± 0.021%. The significant difference (p < 0.05) between the nitrogen levels of the mined and unmined soils (Figure 4) in this study could be due to small-scale mining activities as this observation was in line with the finding by Eludoyin et al. (2017) who stated that small-scale mining activities caused a significant (p< 0.05) loss of soil nitrogen in southwestern Nigeria.

Soil potassium (K) is related to the parent material that formed the soil and the degree of weathering (Adams & Shin, 2014). Potassium is important for growth and development in plants as it promotes movement of water and nutrients (Adams & Shin, 2014). Generally, the concentration of K in the soils of the whole study area ranged from 0.02 to 0.28 $\text{cmol}_c\ \text{kg}^{-1}$ (Table 19). The concentration of K in the unmined soils was 0.12 ± 0.01 $\text{cmol}_c\ \text{kg}^{-1}$ and that for the mined soil was 0.05 ± 0.02 $\text{cmol}_c\ \text{kg}^{-1}$. The significant difference (p <0.05) between K in the unmined and that of the mined soils of the study area suggests that small-scale mining activities caused reduction of K in the mined soils. This finding is in line with observation made by Eludoyin *et al.* (2017) that the level of K in relatively undisturbed soils (0.12 $\text{cmol}_c\ \text{kg}^{-1}$) was higher than that of mined soils (0.07 $\text{cmol}_c\ \text{kg}^{-1}$) in southern Nigeria. According to work done by Dorgbetor *et al.* (2012) on the quality of mined soils in Obuasi, Ghana, the level of K in the unmined soils (0.16 $\text{cmol}_c\ \text{kg}^{-1}$) got reduced in the mined soils (0.10 $\text{cmol}_c\ \text{kg}^{-1}$). Agricultural soils with K concentrations between 0.128 and 0.256 $\text{cmol}_c\ \text{kg}^{-1}$ are considered to have low level of K; and when the level of K ranges from 0.256 to 0.641 $\text{cmol}_c\ \text{kg}^{-1}$, it is considered adequate (Hazelton & Murphy, 2007).

The concentration of phosphorus (P) in the soils of the entire study area, varied from 0.84 to 61.82 $\mu\text{g g}^{-1}$ (Table 19). The concentration of P in the mined soils was 7.008 ± 4.170 $\mu\text{g g}^{-1}$ and that of the unmined soils was 25.855 ± 7.801 $\mu\text{g g}^{-1}$. This observation is in line with Oladipo *et al.* (2014) who reported that gold mining activities reduced the levels of available P in unmined soils of Awo (101.04 $\mu\text{g g}^{-1}$), Itagunmodi (78.89 µg g^{-1}) and Ijero-Ekiti (60.50 µg $^{-1}$g) to 86.64 µg $^{-1}$g (Awo), 53.90 µg g^{-1} (Itagunmodi) and 49.13 µg g^{-1} (Ijero-Ekiti) respectively. The concentration of P in the mined soils in the present study was lower than the prescribed level of P for agricultural soils which ranges from 25 to 35 µg g^{-1} (Hazelton & Murphy,2007). However, the mean concentration of P in the unmined soils was within the optimal range of 10.9 to 21.4 µg g^{-1} for agricultural soils.

Soil organic carbon is vital for the biological, chemical and physical functioning of agricultural soils (Bai *et al.*, 2013; Hazelton & Murphy, 2007). The concentration of organic carbon (OC) in the soils of the whole study area varied from 0.19 to 3.60% (Table 19). The concentration of OC obtained in the mined area (0.74 ± 0.23%) is within the low level range of 0.4 to 1.0% prescribed by Hazelton & Murphy (2007) for agricultural soils. However, the concentration of OC (1.44 ± 0.42%) in the unmined area falls within the moderate level of 1.0 to 1.8% for agricultural soils. In evaluating the quality of mined soils in Obuasi, Ghana, Dorgbetor *et al.* (2012) observed that gold mining activities caused reduction of OC in mined soils.

Though the concentrations of Na, Ca, Mg, exchangeable acidity (EA), N, P, K, EC and OC in the soils of the study area were generally below the prescribed agricultural levels (Hazelton & Murphy, 2007), small-scale gold mining activities further reduced their concentrations in the mined soils. Oladipo *et al*. (2014) also noted in south western Nigeria that soil properties such as N, OC, P and EC and exchangeable cations (Ca, K, Na and Mg) differed significantly ($p < 0.05$) between the soils of mined and unmined (control) areas.

Generally, the texture of surface soils (0-30 cm) in the unmined areas was either clay or clay loam; and that of the mined soils consisted mainly of sandy clay, sandy loam and sandy clay loam. This observation collaborated with work done by Eludoyin *et al*. (2017) that soils of artisanal mined areas are more of sandy loam particles. Small-scale gold mining activities often lead to reduction of soil compaction and destruction of molecular bonds of the silicate minerals in the soil resulting in more sandy particles (Spiegel, Keane, Metcalf & Veiga, 2015).

Soil properties in relation to anthropogenic activities (eg. small-scale mining, farming etc.) at the study site

Principal component 1 (PC1) accounted for 26.7% of the total variance, showing strong positive factor loadings on Na, K and exchangeable acidity (Table 23). This is an indication that the component relates predominantly to an unmined soil. This finding is supported by Ghose (2005) who states that nutrients levels are lower in mined soils compared with unmined soils. This component contained parameters that indicate contribution by nutrients which could be as a result of farming activities. The elements of the components further suggest that their elevated levels are primarily controlled by factors other than contamination induced by mining. Stock piling of mined soils often has adverse effect on the activities of soil microbes which further reduces the levels of nutrients in such soils. Excessive leaching, which is induced by mining also reduces the levels of nutrients in soils. Mining is one of the greatest contributors of heavy metals to soils (Dorgbetor *et al.*, 2012) and is likely to have an adverse impact on the availability of nutrients in the soil. Exchangeable Acidity is more elevated or it becomes abundant in organic soils because of increasing soil pH (Opala, Okalebo & Othieno, 2012). Organic contents of soils could be increased by rotten animal and plant debris. Marzaioli, D` Ascoli, De Pascale & Rutigliano (2010) further state that high K concentration are found in most cultivated soils and unlike phosphorus, which usually enters a soil through organic matter, it has been reported that potassium is mostly often found in the soil in inorganic forms, usually resulting from the mineral weathering of the rocks and parent material in the soil (Biro, Pradhan, Buchroither & Makeschin, 2013).

Principal component 2 (PC2), which gave 11.2% of the total variance was dominated by Arsenic. Arsenic could be identified as mining related pollutant and a characteristic of a mined soil. Ores from which gold is obtained are typically pyrites (FeS_2) or arsenopyrites (FeAsS). According to Xing, Brugger, Tomkins, & Shvarov (2019), a pile of mine tailings constitute one of the greatest threats for the high concentrations of As in soil. It has also been reported that bioavailable concentrations of heavy metals may become higher than the permitted critical levels in mine degraded soils, and this with time, could adversely affect availability of nutrients (Dorgbetor *et al.*, 2012). While studies have reported severe arsenic contamination in agricultural soils due to the flooding of the acid mining drainages produced by the mining activities, the distribution of the elements existing in the ore body is generally characterized by a high level of heterogeneity in the mine soils (Guo *et al.*, 2017). It has been reported that the contents of As is elevated in the soils of abandoned mining areas however, the situation is more intense in active mining areas (Guo *et al.*, 2017). Hotspots of As and other heavy metals have been found to correlate well with the spread of mining and processing activities; and if efforts are made to minimize contamination to soil, there may be little off-site impact from mining. Off-site impacts however vary not only with mining and pollution control efforts, but also with environmental factors that affect metal solubility and availability such as the type and content of metals, pH, redox reactions, and organics and other complexing ligands (Guo *et al*., 2017).

Principal component 3 (PC3) accounted for 11.1% of the total variation in the dataset. P was the only element that had a high positive loading in this component. This however could be attributed to agricultural sources in an unmined soil. P is usually found in phosphorus fertilizers commonly used by farmers in the study area. This result is supported by Guo *et al.* (2017) who found that P is primarily associated with intense application of phosphorus fertilizer. Nevertheless, the excessive use of fertilizers and manure could cause the elevated contents of P in the surface soils of unmined areas. P usually enters a soil through organic matter (Biro, Pradhan, Buchroithner, & Makeschin, 2013). However, organic matter in soils increases through decomposition of plant litter and animal manure which is a non-mining activity.

Pb had high positive factor loading on Principal component 4 (PC4) accounting for 9.7% of the variance, represented as mining. Mine tailings is noted to be one the highest contributors of Pb and other heavy metals in the soil (Armah, Obiri, Yawson, Pappoe, & Akoto, 2010). Studies have also reported that soils from permanent crops generally show lower values of Pb content (Marzaioli, D'Ascoli, De Pascale, & Rutigliano, 2010). Apart from lead released from mining and smelting activities, elevated levels of Pb could also be highly related to vehicles using Pb related fuels and traffic emissions. This is a clear indication that lead pollution could potentially have a non-mining source. Since lead is not degraded by microbial activity, it is persistent in the environment and accumulates in soils through leaching, deposition and erosion.

Electrical conductivity had strong positive loadings on Principal component 5 (PC5) and accounted for 9.2% of the variance, represented as a mining source. Mine tailings have high EC which could contaminate soils in mine site (Acheampong, Adiyiah, & Ansa, 2013). Other researchers have reported that mining activities result in elevated levels of heavy metals, which contribute significantly to the higher levels of EC in the soil (Amari, Valera, Hibiti, & Pretti, 2014). Contamination from non-mining sources such as poor irrigation, water quality and excessive use of fertilizer could also contribute significantly to higher EC in the soil. This finding supports Ghose (2005) to the effect that EC is higher in mined soils than adjacent unmined soils which could be as a result of mixing of soil horizons with tailings.

Spatial distribution of SQI and some heavy (trace) metals and nutrients in the study area

In this study, the unmined and mined soils had average SQI value of 33.8% and 24.2% respectively (Table 25). The SQI value of the unmined soil (33.8%) suggests that the poor quality of the soil of 66.2% relative to the optimum quality was due to the inherent poor soil properties (Dorgbetor *et al.*, 2012). Though the poor quality of the unmined soil is an inherent characteristic, the impact of small-scale mining activities on the soil further widened the difference in quality between the maximum obtainable (SQI value of 18) and the inherent quality as was reflected in the lower SQI values for soils in the mined areas. According to Asensio, Guala, Vega, & Covelo (2013), the quality of soils in gold mined areas tend to be low. In this study, the SQI for the mined soils was 9.6% less than the SQI value for the unmined soils. This is in line with work done by (Dorgbetor *et al.*, 2012) on gold mined soils in Obuasi, where they observed an SQI of the mined soils of 12.1% less than that of the unmined soils.

The Pearson`s Correlation Coefficient Matrix for nutrient variables and total SQI of the soil samples (Table 26) indicated a very strong correlation between OC and total SQI ($r = 0.584$; $p < 0.01$), Ca and total SQI ($r = 0.522$; $p < 0.01$) and N and total SQI ($r = 0.535$; $p < 0.01$). These strong positive correlations may indicate that in about 58.4%, 52.2% and 53.5% cases, the levels of OC, Ca and N in the soil were observed to have increased with increase in SQI values and vice versa respectively.

The spatial distribution of SQI in the unmined soil was generally uniform however, distribution of SQI in the mined sites showed that most of sites had relatively low SQI values (ranging between 2 and 4). This indicates that small-scale mining activities had caused reduction in the SQI of the mined soils (Dorgbetor *et al.*, 2012). The interpolation mapping of spatial spread of Cd, Pb, Cu, As and Hg in the unmined and mined areas as shown in Figure 14 indicated that the distribution of Cd is tilted with hotspots observed in the mined areas of Nyamebekyere (NB). Generally, the concentrations of Cd in the mined (PKK, AK (patch-like) sites were elevated as compared to adjacent unmined sites (UBU, UPK (dot-like) and these observations could be due to small-scale mining activities. According to work done by Olabanji, Oluyemi, Fakoya, Eludoyin, & Makinde (2015) mined soils are polluted with high concentrations of Cd.

The spatial distribution patterns of Cu, As and Pb were generally similar in the unmined and mined areas with elevated levels in the mined areas (Figure 14). This could be due to the geological background of the study area and small-scale mining activities (Xuan *et al.*, 2018).

The spatial distribution of Ca, Mg and Na in the study area indicated the dominance of Ca followed by Na and then Mg (Figure 15). Generally, the distribution Mg and

Na (dot-like) in the unmined soils got reduced in the mined soils (Figure 15) and this could be attributed to small-scale mining (Eludoyin *et al.*, 2017). Ramappa & Muniswamy (2017) working on spatial distribution of some soil elements around gold mine ore tailings, observed that control soils (unmined soils) had higher concentrations of K, Ca, Mg and Na than mined soils. Calcium was evenly distributed (patch-like) in the unmined areas (UBU, UAK, UPK and UDK) as well as the mined areas (KKW, AK, PKK, NB and DK) with relatively higher spots found in the unmined area of Buabenso (UBU) (Figure 15); and the spatial distribution of Mg in the Akropong sampling location indicated that the level of Mg in the mined area (AK) was slightly higher than that of the adjacent unmined area (UAK). These observations could be due the geological setting of the study area (Wei *et al.*, 2018).

The spatial distribution of phosphorus (P) which was tilted with relatively higher concentrations in unmined areas (UBU, UAK, UDK and UPK) as compared to the mined areas (KKW and AK) (Figure 16) collaborated findings by Eludoyin *et al.* (2017) and Oladipo, Olayinka, & Awotoye (2014). The soils of both the unmined and mined areas had very low to almost negligible levels of K in the study area (Figure 16). The spatial distribution pattern shows dot-like distribution of K in most parts of the unmined area to almost negligible levels in the mined areas (Figure 16). The very low concentration to almost negligible status of K in the study area could be due to the parent material lacking K^+ containing minerals such as micas and alkaline fieldspars, low pH of soil, nutrient lockout and highly weathered soils (Edmeades *et al.*, 2010; Wakeel, Gul, & Sanaullah, 2013). It can be observed from Figure 16 that the spatial distribution of N basically shows patch-like distribution in both the unmined and mined areas. This indicates that anthropogenic activities (eg. small-scale mining, farming etc.) had negative aggregation effect on N content of the soils in the study area (Xuan *et al.*, 2018).

Effect of years of fallow of mined site on the concentrations of nutrients and heavy metals in soil

Organic carbon (OC) improved with years of fallow (Table 27) and this could be as a result of the high biomass production and decay of organic matter or leaf litter accumulation over time. Costa & La Mantia (2005) reported an accumulation of litter and a subsequent increase in the carbon content of the soil following the processes of abandonment. This is evidenced by the lowest OC content recorded in the newly abandoned small scale mine sites. Some of these sites at the study area had a bare soil surface with no tree cover and hence had little or no accumulation of organic matter. This condition however creates a hostile environment where natural successional processes leading to the establishment of vegetation cover is much slower for the least fallow soils.

Gradual establishment of vegetation cover on backfills can lead to an increase in organic matter content and clay formation (Kumar & Kumar, 2013; Zhang, Wang, Bai, & Chunjuan, 2015). Plants, once established, increase soil organic matter, lower soil bulk density, make soil pH moderate and bring mineral nutrients to the surface and accumulate them in available form (Sheoran, Sheoran, & Poonia, 2010). Soil organic matter promotes macro soil aggregate formation, stability and nutrient retention (Shu *et al.* 2015; Six, Conant, Paul, & Paustan, 2002). With the increase in age of fallow, progressive increase in clay particle in mine spoil indicates progressive development of soil structural stability, aggregation and developed resistance to erosion (Baboo *et al.*, 2013). Length of time of fallow period leads to an increase in enzyme activities which further can be attributed to the accumulation of organic matter, formation of soil horizons and changes in nutrient concentration in the soil (Baldrian, Trogl, & Snajdr, 2008).

The elevated levels of cadmium in the soils of higher fallow years as compared to the soils of the lower fallow years could be due to the geochemical composition of the parent material and Cd inputs from diffuse anthropogenic sources such as atmospheric deposition (Yu *et al.* (2010). The bioavailability of cadmium is very high as compared to other heavy metals due to it higher solubility and low energy binding to soil component. Lower pH in soils increases the mobility and bioavailability of Cd in soils. Additionally, transformation of Cd from an immobile form to an easily bioavailable forms is enhanced by acidic soils (Yu *et al.*, 2010). As observed in this study, as the fallow years increase, pH reduces and Cd levels increase.

The comparatively lower pH content for the older fallow sites could be attributed to acidic parent materials such as pyrites (DEMA, 2014) and rainfall-associated leaching. Pyrite parent materials, which are predominant in the study area, may oxidize to sulphuric acid and significantly lower soil pH (Dent & Pons, 1995). The higher pH recorded for the younger fallow sites, could be due to carbonate bearing minerals (Ca/MgCaCO$_3$) which tend to increase and buffer pH as they weather and dissolve (Sheoran *et al.*, 2010). Elevation of organic matter decomposition on degraded soil increases soil pH, however, soil pH decreases with the length of time after restoration and this is because of litter inputs and exudates from roots and microbes (Kumar & Kumar, 2013).

The EC results indicate that the older reclaimed sites had high water soluble nutrients available for plant uptake because EC has been correlated to concentrations of nitrates, K, Na, Chlorides, ammonia etc. in the soil (Kumar & Kumar, 2013; Dent & Pons, 1995). These sites, for example, were enriched with organic matter, which improves soil water holding capacity and cation exchange than the younger reclaimed site. High levels of precipitation could flush soluble salts out of the younger reclaimed sites, which had no or limited vegetative cover and hence low conductivity levels.

The availability of Mg in the soil depends on factors such as the distribution and chemical properties of the source rock material and its grade of weathering, and site specific climatic and anthropogenic factors. Magnesium bound in the interlayers of silicates is not mobile and is only released into mobile fractions through weathering processes, which is regarded as a long-termed, slow process. Acidic soils promotes magnesium leaching

The reduction in copper concentrations as the years of fallow increased could be attributed to the uptake by the growing vegetation on the fallow soils. Additionally, rainfall could also facilitate the translocation of copper into deeper depths in the soil.

The Pb in the soil of the mined site was found to have decreased with the longer years of fallow sites. This is in support of Rodríguez, Ruiz, Alonso-Azcárate, & Rincón (2009), that acidic mining soils are contaminated with heavy metals hence the reduction in concentrations of the heavy metals in the soils as years of fallow increased with decreasing pH. Sauve, Mcbride, & Hendershot (1997) have also reported that low pH in mining soils increased the availability of heavy metal such as Pb in the soil.

The high arsenic contents of the least fallow soils may probably be due to the parent material. This assertion has earlier been stated by Kwon & Lee (2012) and Bowel, Alpers, Jamieson, & Nordstrom (2014) that soil arsenic maybe controlled by the lithology of the parent rock materials, weathering history, transport, biological activity and precipitation.

Distribution of soil properties across mined sites with filled and unfilled pits

The distribution of soil parameters in the filled and unfilled pits across mined sites indicated that there were significant differences ($p < 0.05$) in the distribution of soil parameters like sodium (Na), potassium (K), magnesium (Mg), organic carbon (OC), electrical conductivity, copper (Cu) and mercury (Hg). Concentrations of Na significantly decreased in the filled pits as compared to the unfilled pits. This difference could be as a result of filling the pits with washed tailings. Washing of the tailings removes significant amount of nutrients from the soil (Oladipo *et al*., 2014). Additionally, pilling of the tailings prior to filling enhances leaching of Na.

Concentrations of Mg and K were higher in the unfilled pits as compared to the filled pits. It was observed that the material used for filling the pits were washed tailings. Washing of tailings however leads to a substantial loss of nutrients either through leaching to deeper levels or as run off since tailings are loose soil particles. OC concentration was lower in the unfilled pit as compared to the filled pits (Oladipo *et al*., 2014; Eludoyin *et al*., 2017). This could be as a result of the high biomass production and decay of organic matter or leaf litter accumulation after the establishment of vegetation cover. Accumulation of litter after filling and abandoning the pits correspond to an increase of the carbon storage in soils. The bare unfilled pits however recorded lower concentrations of OC because sampled soils from the pit could be top soil eroded into the pit or breaches from the walls in the pit.

EC of the soils of the unfilled pits were higher than that of the filled pits. The lower values recorded in the filled pits could emanate from the tailings used for the filling as washed tailings lose soluble nutrients and salts. Concentrations of Cu in the unfilled pits were higher than the concentrations in the filled pits. With or without sorbing solutes, Cu could be leached into deeper layers or depth and groundwater in loose soils like the tailings used in filling the pits. Cu could also be absorbed by the growing vegetation on the filled pits (Leopold *et al*., 2016; Mohamad *et al*., 2017).

Hg concentrations in the unfilled pits were higher than the concentrations in the filled pits. Higher mercury concentrations in the unfilled pits could arise as a result of the onsite use of mercury for amalgamation in small scale mining (McQuilken, 2016). The low concentrations recorded in the filled pits could result from the absorption of Hg by plants in the soil. Hg in the filled pits could also be converted into methyl mercury by bacterial in the soil. Rainfall could also translocate Hg into deeper depth since tailings are not compact enough to hold water.

A major implication of the low obtainable SQI values, relatively low nutrients content and the increasing concentrations of some heavy metals in the soils of the study area is that there is the need to return the mined soil to its natural state as much as possible considering the rather poor inherent quality of soils in the study area.

Socio-demographic attributes of small-scale miners and the effects of goldmining on the environment.

The study showed that the mean age, mean monthly income, mean years of residence and the mean number of years of experience in goldmining of the respondents were 47 years, GH¢5,550, 16years and approximately 11 years respectively (Table 28). According to work done by Calys-Tagoe *et al.* (2015) on small-scale mining companies in Tarkwa, Ghana, the researchers indicated that mean ages of miners in four such entities were 34.1 years, 34.8 years, 30.9 years, and 33.7 years with their ages ranging from 17 to 72 years, 19 to 60 years, 18 to 55 years and 19 to 66 years respectively. In this study, the mean age of miners was 47.01 years with the ages of the miners ranging between 32 to 65 years (Table 28).

Calys-Tagoe, Clarke, Robins, & Basu (2017) also stated that the small-scale miners in their study in Tarkwa had worked in the area between 1 month and 30 years. This is in line with observation in this study where the small-scale miners have engaged in mining activities between 2 years and 35 years (Table 28). The monthly income of small-scale miners in this study ranged from GH¢1,800 to GH¢14,000 with mean monthly income of GH¢5,550 (Table 28). In a work done by Arthur *et al.* (2016) on small-scale miners in Prestea, Ghana, they reported that 33% of the miners involved in the study in 2014 indicated that they had monthly income ranging between GH¢401to GH¢500. As noted by Arifin, Sakakibara, & Sera (2017) engagement in small-scale mining activities generally lead to increase in monthly income of miners.

In this present study, the miners identified degradation of land and vegetation, water and noise pollution as the main effects of gold mining on the environment (Table 29). The small-scale miners mentioned 2 to 4 of the above environmental impacts simultaneously (Table 29). Out of the 200 small-scale miners involved in a study in Burkina Faso, almost half of this number acknowledged at least three impacts of small-scale mining on the environment (Sana, De Brouwer, & Hien, 2017).

Residents in a mining community in Amansie District in the Ashanti Region of Ghana indicated that the operations of small-scale miners cause land degradation, water pollution and atmospheric impact (Awatey, 2014). Three predictors namely, educational attainment, religious beliefs and number of years of experience in mining were significant in explaining the opinions of small-scale miners on the effects of mining on the environment (Table 29), however, the Cramer`s V statistic in each case was less than 0.3 indicating not strong association (Table 29). Nevertheless, researchers including Addai & Baiden (2014), Arthur *et al*. (2016), Mensah *et al*. (2016) and Calys-Tagoe *et al*. (2017) have reported that educational attainment and number of years of experience in mining influence the perception of small-scale miners on the impacts of mining on the environment.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter summarizes the study of the impacts of small-scale mining activities on vegetation and soil quality and the perception of small-scale miners on the effects of their activities on the environment in order to effectively sustain the productivity of the mined environment. The vegetation data was obtained from 1000 (20 m × 20 m) plots in unmined and mined areas. Soil samples were collected from 120 (50 m × 50 m) plots in unmined and mined areas and analysed for the nutrients, heavy (trace) metals and other physico-chemical parameters. The perceptions of small-scale miners were solicited through the use of questionnaire. The chapter also draws conclusions from the study findings and proposes some recommendations for policy makers and for further research.

Summary

Rehabilitation of mined environment is critical for survival of most inhabitants of mined communities in Ghana. The study (i) assessed the of impacts of small-scale mining activities on the vegetation/forest cover, (ii) determined the effects of small-scale mining activities, length of fallow of mined land and pit condition (filled and unfilled) on concentration and distribution of nutrients and heavy metals, (iii) assessed the geochemical distribution of heavy metals and nutrients of unmined and mined soils, and (iv) evaluated the perception of small-scale miners on environmental effects of gold mining in the study area.

The study identified a total of 278 plant species made up of 223 dicot species distributed in 63 families; 44 monocot species distributed in 13 families and 11 species of pteridophyta distributed in 8 families. The dicots (*Magnoliopsida*) derived from 6 subclasses and the most diverse were the Rosidae, Asteridae and Dillenidae. The monocots (*Liliopsida*) were distributed in 4 subclasses and the most diverse was the Commelinidae. One hundred and fifty seven species distributed in 140 genera and 54 families were identified in the mined study area whilst the 209 species encountered in the unmined area were found in 185 genera and 73 families. Eighty eight plant species identified in this study were common to both unmined and mined areas and these included *Chromolaena odorata*, *Morinda lucida*, *Musanga cecropioides*, *Jatropha gossypifolia*, *Euphorba hirta*, *Uteris guineensis* and *Heritteria utilis*. The number of plants found in only the mined site was 69 species and that for the unmined area only was 121 species. This is an indication of anthropogenic disturbances (small-scale mining) rendering the mined area unsuitable for growth and development of native species. The study identified 84,246 individual species in the mined area and 6745 individual species in the unmined area. The lost canopy and creation of gaps in the mined area led to growth of many species, mainly herbs. The dominant families in the unmined area were the Euphorbiaceae, Rubiaceae and Asteraceae and that for the mined area were Poaceae, Euphorbiaceae and Asteraceae. In terms of abundance, the Asteraceae followed by Poaceae and Rubiaceae were dominant in the unmined area whilst the Poaceae followed by Asteraceae and then Euphorbaiceae were dominant in the mined area. In descending order, the most abundant species in the unmined area were *Pteridium aquilinum* (215 species), *Tridax procumbens* (191 species), *Waltheria indica* (165 species) and *Euphorbia hirta* (151 species); and for the mined area, *Chromolaena odorata* (3128 species), *Sporobolus pyramidalis* (2136 species), *Euphorbia hirta* (1829 species), *Dieffenbachia sequire* (1452 species), *Panicum maximum* (1395 species) and *Commelina benghalensis* (1350 species) were abundant.

The prevalence of plant species in the unmined area ranged between 0.2% to 20.6% and that for the mined area ranged from 0.2% to 58.4%; and species of higher frequencies included *Spilanthes filicaulis* (20.6%), *Pteridium aquilinum* (18.6%), *Diplazium sammatti* (17.6%), *Sorghum arundinaceum* (17.6%), *Chromolaena odorata* (17.01%) and *Tridax procumbens* (16.6%) for the unmined area and

Chromolaena odorata (54.8%), *Echninochloa cruspavanis* (54.0%), *Helleria latifolia* (51.4%), *Euphorbia hirta* (46.2%) and *Momordica charantia* (46.2%) for the mined area. Plant species of low frequencies included *Aningeria altissima* (0.2%) and *Ochna staudii* (0.2%) in the unmined area and *Cola chlamydantha* (0.2%), *Solanum erianthum* (0.4%) and *Treculia africana* (0.4%) in the mined area. The densities of species in the study area were generally low. Species of relatively higher density values included *Pteridium aquilinum* (0.215), *Waltheria indica* (0.191), *Euphorbia hirta* (0.148) and *Chromolaena odorota* (0.148) for the unmined area; and *Chromolaena odorata* (4.368), *Sporobolus pyramidalis* (2.136), *Echinochloa cruspavonis* (1.500) and *Panicum maximum* (1.395) for the mined area.

Six plant life forms namely; trees, shrubs, herbs, climbers, lianes and ferns in the unmined area; and eight plant life forms namely; trees, herbs, shrubs, climbers, seedlings of trees, lianes, ferns and saplings in the mined area were identified from the study area. In descending order, the proportions of life forms were, trees (52.15%), herbs (27.75%), climbers (9.09%), ferns (4.31%), lianes (3.83%) and shrubs (2.87%) for the unmined area; and herbs (56.06%), climbers (12.01%), trees (9.56%), saplings (8.28%), shrubs (6.37%), seedlings of tree (3.82%), lianes (1.91%) and ferns (1.91%) in the mined area. The dominance of trees in the unmined area is typical of the ecosystem under study. The ecological guilds identified in the unmined area were Pioneers (44.98% of all species), Non-Pioneer Light Demanding (16.27%), Shade-Bearers (13.87%) and Swamp (1.91%). The guilds of 22.97% of the species in the unmined area were not available. The predominant guild in the mined area was Pioneers with 59.24% of all species encountered. The remaining guilds, Shade-Bearers, Non-Pioneer Light Demanding (NPLD) and Swamps showed up as 6.37%, 5.73% and 1.27% of the species respectively. The guilds of about 27% of the species identified in the mined area were not available. The total number of Pioneers and NPLD in the study underpins the existence of gaps in the study area and it is an indication of vegetation transformation and the opening of the forest canopy due mainly to small-scale mining activities. Though Pioneers were dominant in both areas, most of the Pioneers occurred as trees in the unmined area and as herbs in the mined area. In terms of conservation star rating status, Green Star, Pink Star, Blue Star, Red Star, Scarlet Star and Gold Star for the unmined area; and Green Star, Blue Star, Scarlet Star, Gold Star, Red Star and Pink Star in the mined area were identified in descending order of proportions. The absence of Black Star species is a concern for the conservation of species however, the occurrence of Gold and Blue Star species indicated the significance of the area in terms of conservation in the wake of degrading species diversity. Though six star rated species were identified in both study areas, they were distributed in 10 plant species in the mined area and in 41 plant species in the unmined area. This indicated higher conservation significance of the unmined area.

The Shannon- Weiner and Simpson diversity indices calculated for the study area indicated variability in terms of land use, although high species diversity values were observed in both the unmined and mined areas. The average of Shannon- Weiner and Simpson diversity values for the unmined area were 4.62 ± 0.03 and 0.98 ± 0.01; and that for the mined area were 4.54 ± 0.02 and 0.98 ± 0.01 respectively. The high diversity of plant species is typical of the tropical ecosystem. The significant difference ($p < 0.05$) between the Shannon- Weiner diversity values of the unmined and mined areas indicates that the two sites differ significantly in environmental conditions. The Evenness of species ranged from 0.50 to 0.54 (mean = 0.51 ± 0.02) in the unmined area; and from 0.38 to 0.42 (mean = 0.40 ± 0.01) in the mined area indicating that plant species are equitably distributed in the unmined area than the mined area. The Genetic Heat Index (GHI) of all star species in the unmined and mined areas were 59.33 ± 0.50 and 31.84 ± 1.44 respectively; and that for trees only were 64.42 ± 0.63 for the unmined area and 54.89 ± 1.46 for the mined area. The significant differences ($p < 0.05$) between the GHI`s of species in the unmined and mined areas show that flora of the unmined area is richer and has more exciting species. The Economic Indices (EI) of all star rated species in the unmined and mined areas were 32.66 ± 0.93 and 20.88 ± 1.75 and that for trees only were 46.15 ± 0.89 and 41.84 ± 3.07 respectively. At the economic level, the flora in the unmined area is commercially richer than the flora in the mined area due to the significant differences ($p < 0.05$) between the EI`s of the two areas. The mean value of the Pioneer Index (PI) for the mined area was 137.48 ± 2.89 and that for the unmined area was 132.77 ± 2.89. The two sites were observed to vary significantly ($p < 0.05$) with respect to the PI`s indicating that the flora in the mined area is more disturbed and secondary in terms of species composition.

The study showed high degree of variability of physico-chemical parameters, nutrients and heavy metals in the soil. The distribution of pH, Cu and Pb showed that their lowest concentrations occurred at PK 58 (mined site), UPK 3, UBU 3 (unmined sites) and highest concentrations at UB 10 (unmined site), AK 1 and AK 10 (mined sites) respectively. EC, P, K, Ca, Mg, OC, Cd had their lowest and highest concentrations at KKW 31 and AK 9; KKW 36 and KKW 24; NB 75 and UBU 5; NB 79 and UBU 6; NB 79 and UBU 6; KKW 31 and UAK 1; PKK 96 and NB 73; NB 82 and UBU 4; UAK 6 and KKW 3; and DK 57 and UBU 3 respectively. Heavy (trace) metals and nutrients in the soil which showed very strong correlation ($p < 0.01$) included; Mg and Ca (r = 0.866); Na and N (r = 0.730); Mg and Ca (r = 0.706); EA and Na (r = 0.674); K and N (r = 0.633); EA and K (r = 0.576); P and N (r = 0.536); and Na and Ca (r = 0.534).

Land use differences had influence on the concentrations of nutrients and heavy metals in the study area. Though the concentrations of Ca, Mg, Na, N, P, K and OC in the soils were generally below prescribed agricultural levels for both the unmined and mined sites, there were significant differences ($p < 0.05$) between the concentrations of these parameters in the unmined and mined soils. However, there were no statistically significant differences ($p < 0.05$) observed in the concentrations of Cd, Hg, Pb, As and Cu between the unmined and mined soils. The order of abundance of heavy (trace) metals in the unmined soil was Cd >Pb > Cu > As > Hg and that for the mined soil was Cu > Pb > Cd > As > Hg. The relationships between nutrients and heavy metals in the soils indicated very strong correlation between Na and K (r = 0.866; $p < 0.01$), Mg and Ca (r = 0.706; $p < 0.01$), Na and N (r = 0.7333;

$p < 0.01$), EA and Na (0.674; $p < 0.01$), K and N (0.6333; $p < 0.01$), Ca and N ($r = 0.562$; $p < 0.01$), P and N ($r = 0.536$; $p < 0.01$) and Na and Ca ($r = 0.534$; $p < 0.01$).

Both filled (back - filled) pits and non filled (void/ partial) pits in the mined areas influenced the distribution of nutrients and heavy metals in the soil. There were significant differences ($p < 0.05$) in the concentrations of Na, K, Mg, OC, Cu, Hg and the value of EC between the soils of mined areas with filled and unfilled pits. However, there were no statistically significant differences ($p < 0.05$) observed in the concentrations of N, P, Ca, EA, Cd, As and Pb between mined soils obtained from areas with filled and unfilled pits. The years that mined soil laid fallow influenced the distribution of EC, OC, Mg, Ca, Cd, Cu, Pb, As and pH in the soil. Years of fallow of mined soil had direct relationship with OC and Cd; and indirect relationship with Ca, Mg, As, pH, Pb, Cu and EC in the mined soil.

The soil data in the study area could be grouped into a five component system. Na, K and EA had strong factor loadings on Principal component 1 (PC1) which accounted for 26.7% of the total variance in the data. Principal component 2 (PC2) which accounted for 11.2% of the total variance was dominated by As. Phosphorous (P) had high positive factor loading on Principal component 3 (PC3) accounting for 11.1% of the variance in the data set. Principal component 4 (PC4) accounted for 9.7% of total variations in the data set and Pb was the only element with a high positive loading on this component whilst EC had a strong factor loading on Principal component 5 (PC5) and accounted for 9.2% of the total variance, both represented as mining source.

The quality of soils in the study area is generally low. The soil quality index (SQI) scores for the 120 sampling points ranged from 2 to 8, out of the maximum score of 18. The average SQI value for mined soils (24.2%) was 9.6% less than that of unmined soil (33.8%). Three soil nutrients had strong positive correlation with SQI; OC and total SQI ($r = 0.54$; $p < 0.01$), Ca and total SQI ($r = 0.522$; $p < 0.01$) and N and total SQI ($r = 0.535$; $p < 0.01$). Spatial distribution of SQI values in the unmined area was generally uniform with relatively higher SQI values observed in unmined areas of UPK (8), UBU (8) and UAK (7). Mined areas including PKK, NB and sections of KKW had low SQI values ranging between 2 and 4. The distribution of Cd in the study area was tilted with hotspots especially in the Nyamebekyere (NB) mined area with Cd concentration in the range of 9.6 mg kg^{-1} to 10.22 mg kg^{-1}. The spatial distribution patterns of As, Cu and Pb were generally similar in the unmined and mined areas but there were few elevated levels in the mined areas. Though the concentration of Hg was almost negligible in most parts of the study area, small-scale mining activities led to appreciable levels in mined areas of Kyekyewere (KKW) including KKW 31 (0.191 mg kg^{-1}), KKW 30 (0.185 mg kg^{-1}), KKW 34 (0.184 mg kg^{-1}) and KKW 32 (0.173 mg kg^{-1}). The distribution of Ca, Mg and K in the study area showed dominance of Ca, followed by N and then Mg. Ca was evenly distributed in both unmined (UBU, UAK, UPK and UDK) and mined (KKW, AK, PKK, NB and AK) areas with higher spots in UBU. Na and Mg showed dot-like distribution in the unmined areas with further reduction in the mined areas (PKK, DK etc.). The spatial distribution of P was tilted with higher levels of P in the unmined areas (UBU, UAK, UDK and UPK) as compared to the mined areas (KKW, AK etc.). The distribution of N was patch-like in both unmined and mined areas. K showed dot-like distribution in most parts of the unmined areas to almost negligible levels in the mined areas.

Small-scale miners alluded to 2 to 4 environmental impacts (land and vegetation degradation, water and noise pollution) simultaneously. Three predictors, educational attainment, religious beliefs and number of years of experience in mining were significant in explaining the opinions of small-scale miners on impacts of mining. However, the Cramer`s V statistic in each case was less than 0.3 indicating the association was not strong.

Conclusions

The findings of the study indicate that the study area is very rich and diverse in terms of plant species and the species in the unmined area are richer and more diverse than that of mined area. Plant families Euphorbiaceae, Rubiaceae and Asteraceae were the top-most contributors to species diversity whilst the Asteraceae, Poaceae and Euphorbiaceae were dominant in terms of abundance in the unmined area; and in the mined area the Poaceae, Euphorbiaceae and Asteraceae contributed most to diversity and abundance of species. Species wise, *Pteridium aquilinum*, *Tridax procumbens* and *Waltheria indica* in the unmined area and *Chromolaena odorata*, *Sporobolus pyramidalis* and *Euphorbia hirta* in the mines area were dominant. Trees and herbs were prominent in the unmined area whilst herbs and climbers were dominant in the mined areas.

Small-scale mining activities have adversely affected plant diversity, richness, conservation and economic value of species. Typical of a semi-deciduous forest, the study area contains many species of conservation and economic importance especially the unmined areas. The unmined area contains a number of individual trees found in varied species and plant families which are of great economic, conservation and ecological importance. The semi-deciduous forest has undergone a series of transformation due to small-scale mining activities and this has caused higher disturbance of the flora resulting in more secondary species in the mined area. This study revealed that small-scale mining activities have caused reduction in species diversity and richness, reduced number of species of higher conservation value, reduced the economic and commercial values of species; increased destruction of canopies and created more gaps leading to preponderance of herbaceous species in mined areas. The small-scale mining activities in the Dunkwa East Municipality have led to the transformation of the hitherto semi-deciduous forest area to lands unsuitable for any meaningful agricultural purpose which is the mainstay of the local inhabitants. Plant species which are of both local and international conservation priorities such as Gold and Blue species are largely facing some level of threat and extinction especially in the mined areas.

The destruction of native species in the mined area has provided conditions for the establishment of alien species to the forest ecosystem. Small-scale mining activities have caused reduction in the similarity of native species between the unmined and mined areas. The totality of Pioneers and Non-Pioneer Light Demanding (NPLD) species in the study area underpins the existence of gaps as a result of human interference especially in the mined areas. Due to their abundance and distribution, native tree species including *Macaranga hurifolia*, *Macaranga barteri*, *Macaranga heterophylla*, *Vernonia conferta*, *Pentaclethra macrophylla*, *Calycobolus africanus*, *Alchornea cordifolia*, *Carapa procera*, *Allanblackia floribunda*. *Pachystella brevipes*, *Baphia nitida* and *Piptadeniastrum africanum* could be exploited for regeneration in the mined areas.

Small-scale mining in the study area has and is largely affecting the quality of the soil supporting the vegetation growth. The mined soils are losing essential nutrients that are required for plant growth and establishment. The concentrations of important nutrients such as K, P, Ca, Mg, Na and OC and EC in the generally clay and loamy soils have been significantly reduced as a result of the small-scale mining activities. Within the study area, anthropogenic activities did not cause significant variation in the concentrations of heavy metals Cu, As, Hg, Pb and Cd between unmined and mined soils however, the increasing concentrations of some of these heavy metals in the mined area is of great concern. The soils of some mined areas of Nyamebekyere need immediate attention as present Cd concentrations are far beyond the acceptable levels by EPA Ghana, USEPA and EU for agricultural soils.

The soil material used in refilling (back filling) of mined pits, as part of mined land restoration process, influence the quality of mined soil as soils from mined sites with unfilled /partially filled pits tend to have higher levels of important nutrients such as K, Mg and Na.

The number of years that mined land remained fallow influenced the quality of soil because as the fallow years increased, the concentrations of OC and Cd increased ; and in the indirect relationship, as the fallow years increased the concentrations of Ca, Mg, pH, Cu, Pb, As and value of EC in the mined soil decreased.

The average SQI of unmined soils is greater than that of mined soils. The inherent soil quality of the study area is generally low and small-scale mining activities further reduced the quality of soils in the mined areas. The difference in quality between the unmined (33.8%) and mined (24.2%) soils was 9.6%. The spatial distribution of SQI in the unmined area was generally uniform with higher SQI values in the unmined sites of UPK, UAK, UBU and lower levels of SQI in mined sites of PKK, NB and sections of KKW.

The spatial distribution of heavy metals (Cu, As and Pb) in the soils of the study area were generally dot-like in the unmined and mined areas except Cd which had hot spots in Nyamebekyere. Mg, K and Na showed dot-like distribution in the unmined and mined areas further reducing in the mined areas. Ca and P had patch-like distribution in the soils of the unmined and mined areas with higher levels in the unmined areas whilst N showed uniform patch-like distribution in both the unmined and mined areas.

Small-scale miners at the study site acknowledged 2 to 4 impacts of mining simultaneously. Three predictors namely, educational attainment, religious beliefs and number of years of experience in mining were significant in explaining the opinions of small-scale miners on the effects of mining on the environment however, the associations were not strong (Cramer`s V less than 0.3).

Recommendations

The following recommendations are made hoping that they will improve the vegetation and soil quality and reduce the effects of small-scale mining activities in communities found in the environs of Dunkwa East Municipality.

i. Further studies should investigate the extensiveness of the aftermath of small-scale mining activities and conduct extra assessment of the effects of these activities on species composition and structure of vegetation.

ii. The threat to the local and conservational priority plant species in the study area calls for attention and protection of Red, Blue and Gold species. There is the need for stringent management approach for the control of small-scale mining activities in the area.

iii. Studies should investigate and enhance our ability to fully understand the effects of small-scale mining activities on plant nutrients, other soil properties and dynamics and how these influence quality of soils in mining communities.

iv. Strategies for reducing contamination by heavy metals especially Cd in Nyamebekyere area resulting from small-scale mining activities should be put in place and regularly monitored and also incorporated into the restoration processes for mined land in the area.

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APPENDICES

Appendix J: Plant species of the flora of the mined and unmined study areas

Species Name	Family	Life form	Star rating	Ecological guild
***Acroceras zizaniodes* (Kunth.) Dandy.**	Poaceae	Herb	Green	Pioneer
***Aframomum melegueta* (Hook. f.)**	Zingiberaceae	Herb	Blue	Pioneer
***Afzelia africana* Sm.**	Fabaceae	Tree	Red	NPLD
***Ageratum conyzoides* L.**	Asteraceae	Herb	NA	Pioneer
***Albizia ferruginea* (Guill & Perr.) Benth.**	Mimosaceae	Tree	Scarlet	NPLD
***Albizia zygia* (DC.) J.F Machr.**	Mimosaceae	Tree	Green	NPLD
***Alchornea cordifolia* (Schum. & Thonn) Muell.Arg**	Euphorbiaceae	Shrub	Green	Pioneer
***Allanblackia floridunda* A.Chev.**	Guttiferae	Tree	Green	SB
***Allophylus africanus* P. Beauv.**	Sapindaceae	Tree	Green	Pioneer
***Amphimas pterocarpoides* Harms.**	Papilionaceae	Tree	Red	NPLD
***Ananas sativa* Schult. f.**	Bromeliaceae	Herb	NA	Pioneer
Anchomanes *difformis* (Blume) Engl.	Araceae	Herb	Green	NA
***Andropogon gayanus* Kunth.**	Poaceae	Herb	NA	NA
***Aneilema beniniense* (P. Beauv.) Kunth.**	Commelinaceae	Herb	Green	Pioneer
***Aningeria altissima* (A. Chev) Aubrev. & Pellegr.**	Sapotaceae	Tree	Red	NPLD
***Anthocleista nobilis* (G..Don)**	Loganiaceae	Tree	Green	Pioneer
***Anthonatha macrophyla* P.Beauv.**	Caesalpinaceae	Tree	Green	SB
***Antiaris toxicaria* Leschen.**	Moraceae	Tree	Pink	NPLD
***Antrocaryon micraster* A. Chev. & Guillaum.**	Anacardiaceae	Tree	Red	NPLD
***Aspilia africana* (Pers.) C.D.Adams**	Asteraceae	Climber	NA	Pioneer
***Asystasia gigantica* (L.) T. Anders.**	Acanthaceae	Herb	Green	Pioneer
***Aulacocalx jasminiflora* Hook. f.**	Rubiaceae	Tree	Green	SB
***Bambusa vulgaris* Schrad. ex Mendel**	Gramineae	Tree	Green	Swamp
***Baphia nitida* Lodd.**	Papilionaceae	Tree	Green	SB
***Berlinia occidentalis* Keay**	Leguminosae	Tree	Gold	NA
***Bertiera racemosa* (G.Don) K. Schum.**	Rubiaceae	Tree	Green	Pioneer
***Bidens pilosa* L.**	Asteraceae	Herb	NA	Pioneer
***Blighia sapida* Konig.**	Sapindaceae	Tree	Green	NPLD

Boerhavia diffusa L.	Nyctaginaceae	Herb	NA	Pioneer
Bolbitis gemmifera (Hierm) C.Chr.	Lomariopsidaceae	Fern	Green	NA
Bombax buonopozense P. Beauv.	Bombacaceae	Tree	Pink	Pioneer
*Bracharia deflexa (Schumach.) Hubbard ex Robyns.	Poaceae	Herb	Green	Pioneer
Brillantaisia nitens Lindau	Acanthaceae	Herb	Green	Pioneer
Bryophylum pinnatum (Lam.) Kutz.	Crassulaceae	Herb	NA	NA
*Calopogonium mucunioides Desv.	Papilionaceae	Climber	NA	Pioneer
Calycobolus africanus (G.Don) Heine	Convolvulaceae	Liane	Green	NA
Capsicum frutescens L.	Solanaceae	Herb	NA	Pioneer
*Carapa procera DC.	Meliaceae	Tree	Green	SB
Cardiospermum grandiflorum Swartz.	Sapindaceae	Climber	Green	Pioneer
Cassia occidentalis L.	Caesalpiniaceae	Shrub	NA	Pioneer
Cassytha filiformis Linn.	Lauraceae	Climber	NA	NA
Castanola paradoxa (Gilg) Schellenb	Connaraceae	Liane	Green	NPLD
*Ceiba pentandra Gaertn.	Bombacaceae	Tree	Green	Pioneer
Celtis mildbraedii Engl.	Ulmaceae	Tree	Green	SB
*Centrosema pubescens Benth.	Papilionaceae	Climber	Green	Pioneer
Christiana africana DC	Tiliaceae	Tree	Green	NA
*Chromolaena odorata (L.) King & Robinson	Asteraceae	Shrub	Green	Pioneer
Chrysophyllum giganteum A. Chev	Sapotaceae	Tree	Pink	SB
*Cissus aralioides (Welw. ex Bak.) Planch.	Vitaceae	Climber	Green	NA
Cissus cymosa Schum.& Thonn.	Vitaceae	Climber	Green	NA
Citrus sinensis (l.) Osbeck	Rutaceae	Tree	NA	NA
Cleistopholis patens (Benth.) Engl. & Diels.	Annonaceae	Tree	Green	Pioneer
*Coffea abracteolata (Hiem) Brenan	Rubiaceae	Herb	Green	SB
Coix lacryma-jobi L	Poaceae	Herb	NA	Pioneer
*Cola chlamydantha K,Schum.	Sterculiaceae	Tree	Red	SB
Cola gigantea A. Chev.	Sterculiaceae	Tree	Green	NPLD
Colacassia esculenta (Linn.) Schott.	Araceae	Herb	NA	NA
*Combretum hispidium Laws	Combretaceae	Liane	Green	NA
*Combretum racemosum P. Beauv.	Combretaceae	Climber	Green	Pioneer
*Commelina benghalensis L.	Commelinaceae	Herb	Green	Pioneer
Cremaspora triflora (Thonn.) Schum.	Rubiaceae	Liane	Green	SB
Crotalaria retusa Linn.	Papilionaceae	Herb	NA	Pioneer
Cussonia bancoensis Aubrev. &	Araliaceae	Tree	Gold	Pioneer

Pellegr.				
*Cyathula achyranthoides (H.B.& K.) Moq.	Amaranthaceae	Herb	NA	Pioneer
Cyathula prostrata (L.) Blume	Amaranthaceae	Herb	NA	Pioneer
*Cyclosorus afer (Christ) Ching	Thelypteridaceae	Fern	NA	NA
Cyclosorus striatus (Schum.) Ching	Thelypteridaceae	Fern	NA	NA
Cylicodiscus gabuneensis Harms.	Mimosaceae	Tree	Pink	SB
Cynodon dactylon (L.) Pers.	Poaceae	Herb	NA	NA
Cyperus rotundus L.	Cyperaceae	Herb	NA	Pioneer
Dacryodes klaineana (Pierre). H.J. Lam	Burseraceae	Tree	Green	SB
Dactyladenia dinklagei (Engler) G.T.Prance & F.White	Chrysobalanaceae	Tree	Gold	SB
Dactyloctenium aegyptium (L.) P.Beauv.	Poaceae	Herb	NA	NA
*Daniellia ogea (Harms) Holland	Caesalpinaceae	Tree	Pink	Pioneer
*Desmodium adscendens (Sw.) DC.	Papilionaceae	Herb	NA	Pioneer
Desmodium scopiurus (SW.) Desv.	Fabaceae	Herb	NA	NA
Dialium aubrevillei Pellegr.	Caesalpinaceae	Tree	Green	SB
Dichapetalum jonstoni Engl.	Dichapetalaceae	Climber	Green	NPLD
Dieffenbachia seguire Schott.	Araceae	Herb	NA	NA
*Dienbollia pinnata (Poir) Schum. & Thonn.	Sapindaceae	Tree	Green	NPLD
*Digitaria horizontalis Willd.	Poaceae	Herb	NA	Pioneer
Dioscorea alata Linn.	Dioscoreaceae	Climber	Green	NA
*Diospyros viridicans Hiem	Ebenaceae	Tree	Green	SB
Diplazium sammatii (Kuhn.) C. Chr.	Athyriaceae	Fern	Green	NA
Diplazium welwitschii (Hook.) Diels	Athyriaceae	Fern	Gold	NA
Discoglypremna caloneura (Pax) Prain	Euphorbiaceae	Tree	Green	Pioneer
Dissotis rotundifolia (Sm.) Triana	Melastomataceae	Herb	Green	Pioneer
Distemonanthus benthamianus Baill	Caesalpinaceae	Tree	Pink	NPLD
Drypetes aubrevillei Leandri	Euphorbiaceae	Tree	Blue	SB
Drypetes floribunda (Muell. Arg) Hutch	Euphorbiaceae	Seedling	Green	NA
Echinochloa cruspavonis (Kunth) Schult.	Poaceae	Herb	NA	Pioneer
Eclipta prostrata (Linn.) Linn.	Asteraceae	Herb	NA	Pioneer
*Elaeis guineensis Jacq.	Palmaceae	Tree	Pink	Pioneer
Eleusine indica (L.) Gaertn.	Poaceae	Herb	NA	Pioneer
*Emilia coccinea (Sims) G.Don.	Asteraceae	Herb	NA	Pioneer

***Entandopgragma cylindricum* (Sprague) Sprague**	Meliaceae	Tree	Scarlet	NPLD
***Entandophragma angolense* (Welw.) DC.**	Meliaceae	Tree	Red	NPLD
***Eregeron floribundus* (H.B &K.) Sch. Bip**	Asteraceae	Herb	NA	NA
***Eremospatha marocarpa* (Man. & Wendl) Wendl.**	Palmaceae	Liane	Pink	NA
***Euclinia longiflora* Salisb.**	Rubiaceae	Herb	Green	NA
***Euphorbia heterophylla* L.**	Euphorbiaceae	Herb	NA	Pioneer
***Euphorbia hirta* L.**	Euphorbiaceae	Herb	Green	Pioneer
***Euphorbia prostrata* L.**	Euphorbiaceae	Herb	NA	Pioneer
***Ficus asperifolia* Miq.**	Moraceae	Herb	Green	Pioneer
***Ficus capensis* Thunb.**	Moraceae	Tree	NA	NA
***Ficus craterostoma* Mildbr. & Buretti**	Moraceae	Tree	Green	NA
Ficus exasperata Vahl.	Moraceae	Tree	Green	Pioneer
***Fleurya aestuans* Miq.**	Urticaceae	Herb	NA	NA
***Fluerya ovalifolia* (Schum. & Thonn.) Dandy**	Urticaceae	Herb	NA	NA
***Funtumia elastica* (Preuss) Stapf.**	Apocynaceae	Tree	Pink	NA
***Geophila obvallata* (Schum.) F. Didri**	Rubiaceae	Herb	Green	SB
***Geophila repens* (Linn.) I.M.Johnston**	Rubiaceae	Herb	Green	NA
***Gilbertiodendro limba* (Scott Elliot) J. Leonard**	Leguminosae	Tree	NA	NA
***Glyphaea brevis* (Spreng) Monach.**	Tiliaceae	Tree	Green	NA
***Gmelina arborea* Roxb.**	Verbanaceae	Tree	NA	NA
***Grandiflorum Cardiospermum* Sw.**	Sapindaceae	Climber	Green	Pioneer
***Grewia pubescens* P. Beauv.**	Tiliaceae	Herb	Green	Pioneer
***Griffornia simplicifolia* (Vahl. ex DC) Baill**	Caesalpinaceae	Tree	Green	NPLD
***Grossera vignei* Hoyle**	Euphorbiaceae	Seedling	Green	SB
***Guarea thompsoni* Sprague & Hutch**	Meliaceae	Tree	Pink	SB
***Gynura sarmentosa* (Blume.) DC.**	Asteraceae	Climber	NA	Pioneer
***Hallea ledermannii* (K. Krause) Verde**	Rubiaceae	Tree	Red	Swamp
***Hannoa klaineana* Pierre & Engl.**	Simaroubaceae	Tree	Green	Pioneer
***Harungana madagascariensis* Lam. Ex Poir.**	Hypericaceae	Tree	Green	Pioneer
***Herittiera utilis* (Sprague) Sprague**	Sterculiaceae	Tree	Red	NPLD
***Hewittia sublobata* L**	Convolvulaceae	Climber	NA	Pioneer
***Hexalobus crispiflorus* A. Rich**	Annonaceae	Tree	Green	SB

***Hibiscus esculentus* L.**	Malvaceae	Herb	NA	NA
***Hilleria latifolia* (Lam) H. Walt**	Phytolacaceae	Herb	NA	NA
***Holarrhena floribunda* (G.Don) Dur. & Schinz.**	Apocynaceae	Tree	Green	Pioneer
***Hoslunda opposita* Vahl./**	Lamiaceae	Herb	Green	Pioneer
***Hydrolea globra* Schum. & Thonn.**	Hydrophyllaceae	Herb	NA	NA
***Hyptis suaveolens* Poir**	Lamiaceae	Herb	NA	NA
***Imperata cylindrica* (L.) Beauv.**	Poaceae	Herb	NA	NA
***Indigofera macrophylla* Schum. & Thonn.**	Papilionaceae	Climber	**NA**	Pioneer
***Iodes africana* Welw. ex Oliv.**	Icacinaceae	Climber	Green	NA
***Ipomoea aquatica* Forsk.**	Convulvulaceae	Herb	NA	NA
***Ipomoea cairica* (L.) Sweet**	Convolvulaceae	Climber	NA	Pioneer
***Ipomoea herderifolia* Linn**	Convulvulaceae	Herb	NA	Pioneer
***Ipomoea involucrata* L.**	Convolvulaceae	Climber	NA	Pioneer
***Ipomoea mauritania* Jacq.**	Convulvulaceae	Climber	NA	Pioneer
***Ischaemum rugosum* Salisb.**	Poaceae	Herb	NA	Pioneer
***Jatropha gossypiifolia* Linn.**	Euphorbiaceae	Shrub	NA	NA
***Justicia flava* (Forsk) Vahl.**	Acanthaceae	Herb	NA	Pioneer
***Khaya ivoriensis* A.Chev.**	Meliaceae	Tree	Scarlet	NPLD
***Kigelia africana* (Lam.) Benth.**	Bignoniaceae	Tree	Green	NPLD
***Lantana camara* Linn.**	Verbenaceae	Herb	NA	Pioneer
***Leptochloa caerulescens* Steud.**	Poaceae	Herb	NA	Pioneer
***Ludwigia decurren* Walter**	Onagraceae	Herb	NA	NA
***Lycopersicum esculentum* Mill.**	Solanaceae	Herb	NA	NA
***Lycopodium cernum* Linn.**	Lycopodiaceae	Fern	Green	NA
***Lycopodium* sp.**	Lycopodiaceae	Fern	NA	NA
***Lygodium macrophylla* (Kuntz.) Sw.**	Lygodiaceae	Fern	NA	NA
***Macaranga barteri* Mull. Arg.**	Euphorbiaceae	Tree	Green	Pioneer
***Macaranga heterophylla* (Mull. Arg.) Mull. Arg.**	Euphorbiaceae	Tree	Green	Pioneer
***Macaranga hurifolia* Beille**	Euphorbiaceae	Tree	Green	Pioneer
***Mallotus oppositifolius* (Geisel.) Mull. Arg.**	Euphorbiaceae	Tree	Green	SB
***Mammea africana* Sabine**	Clusiaceae	Tree	Pink	SB
***Manihot esculenta* Crantz.**	Euphorbiaceae	Shrub	NA	NA
***Maniophyton fulvrum* Mull. Arg.**	Euphorbiaceae	Liane	Green	NPLD
***Mareya micrantha* (Benth.) Mull. Arg.**	Euphorbiaceae	Tree	Green	SB
***Margaritaria discoidea* (Baill.)**	Euphorbiaceae	Tree	Green	Pioneer

Webster				
Mariscus althernifolia Vahl.	Cyperaceae	Herb	NA	Pioneer
Melanthera scandens (Schum. & Thonn.) Roberty	Asteraceae	Climber	NA	Pioneer
*Melochia corchorifolia L.	Sterculiaceae	Herb	NA	Pioneer
Microglossa afzelii O. Hoffm.	Asteraceae	Herb	NA	NA
Mikania scandens (Burm.f.) Robinson	Asteraceae	Herb	NA	NA
Milicia excelsa (Welw.) Berg.	Moraceae	Tree	Green	Pioneer
Milletia zechiana Harms	Papilionaceae	Tree	Green	Pioneer
Mimosa nigra L.	Mimosaceae	Herb	NA	Pioneer
*Mimosa pudica L.	Mimosaceae	Herb	NA	NA
Mitragyna sp.	Rubiaceae	Tree	Red	NA
Mollugo verticillata L.	Molluginaceae	Herb	NA	Pioneer
Momordica charantia L.	Cucurbitaceae	Climber	NA	Pioneer
Momordica foetida Schum. &Thonn.	Cucurbitaceae	Herb	NA	Pioneer
*Morinda lucida Benth.	Rubiaceae	Tree	Green	Pioneer
Musa paradisiaca L.	Musaceae	Herb	NA	NA
*Musanga cecropioides R. Br.	Cecropiaceae	Tree	Green	Pioneer
*Mussaenda elegans Schum. & Thonn.	Rubiaceae	Climber	Green	Pioneer
Mussaenda tristigmatica Cummins	Rubiaceae	Climber	Blue	Pioneer
*Nephrolepis bisserata (Swartz.) Schott.	Nephrolepidaceae	Herb	Green	NPLD
Nesogordonia papaverifera (A. Chev.) R. Capuron	Sterculiaceae	Tree	Pink	SB
Newbouldia laevis (P.Beauv.) Seeman ex Bureau	Bignoniaceae	Tree	Green	Pioneer
Nuclea diderrichii (De Wild) Merr	Rubiaceae	Tree	Scarlet	NA
*Ochna staudtii Engl. & Gilg.	Ochnaceae	Tree	Green	SB
*Oldenlandia corymbosa L.	Rubiaceae	Herb	NA	Pioneer
Operculina macrocarpa (Linn.) Urban	Convolvulaceae	Climber	NA	NA
Pachypodanthium standtii Engl. & Diels.	Annonaceae	Tree	Green	NPLD
Pachystela brevipes Engl.	Sapotaceae	Tree	Green	NPLD
*Palisota hirsuta (Thunb.) K. Schum.	Commelinaceae	Herb	Green	Pioneer
*Panicum laxum Jacq.Sw. PR.Br.	Poaceae	Herb	NA	Pioneer
*Panicum maximum Jacq.	Poaceae	Herb	NA	Pioneer
Parinan excelsa Sabine	Chrysobalanaceae	Tree	Green	NPLD
Parkia bicolor A.Chev.	Mimosaceae	Tree	Green	NPLD

Paspalum conjugatum Berg.	Poaceae	Herb	NA	Pioneer
*Paspalum scrobiculatum L.	Poaceae	Herb	NA	Pioneer
Pauridiantha afzelii (Hiern.) Brem.	Rubiaceae	Shrub	Blue	Pioneer
Pauzolzia guineensis Benth	Urticaceae	Herb	NA	NA
Pavetta corymbosa (SC.) F.N.Williams	Rubiaceae	Tree	Green	NA
Pennisetum polystachion (L.) Schult.	Poaceae	Herb	NA	Pioneer
Pentaclethra macrophyla Benth.	Leguminosae	Tree	Green	NPLD
Pentadesma butyracea Sabine	Guttiferae	Tree	Blue	SB
Pergularia daemia (Forsk.) Chiov.	Asclepiadaceae	Herb	NA	Pioneer
Petersianthus macrocarpus (Beauv.) Liben	Lecythidaceae	Tree	Green	Pioneer
*Phyllantus amarus Schum. et Thonn.	Euphorbiaceae	Herb	NA	Pioneer
*Physalis angulata L.	Solanaceae	Herb	NA	Pioneer
Physalis micrantha Link	Solanaceae	Herb	NA	NA
Piper guineense Schumach. & Thonn.	Piperaceae	Climber	NA	NA
Piper umbellatum L.	Piperaceae	Shrub	Green	Pioneer
Piptadeniastrum africanum (Hook f.) Brenan	Leguminosae	Tree	Pink	NPLD
Pityrogramma calomelanos (Linn.) Link	Gymnogrammaceae	Fern	Green	NA
*Platostomi africanum P. Beauv.	Lamiaceae	Herb	NA	Pioneer
*Polygonium lanigerum R.Br.	Polygonaceae	Herb	NA	NA
Psydrax subcordata DC.Bridon	Rubiaceae	Tree	Green	Pioneer
Pteridium aquilinum (Linn.) Kuhn.	Dennstaedtiaceae	Fern	NA	Pioneer
*Pycnanthus angolense (Welw.) Warb	Myristicaceae	Tree	Pink	NPLD
Raphia hookeri Mann.& Wendi	Palmaceae	Tree	Green	Swamp
*Rauvolfia vomitoria Afzel.	Apocynaceae	Tree	Green	Pioneer
*Richardia brasiliensis Gomez	Rubiaceae	Herb	NA	NA
Ricinodendron heudolotii (Baill) Pierre ex Pax.	Euphorbiaceae	Tree	Green	Pioneer
Rinorea welwitschii (Oliv.) O.Ktze	Violaceae	Tree	Green	SB
Rottboellia cochinchinensis (Lour.) W.Clayton	Poaceae	Herb	NA	Pioneer
Sarcophrynium brachystachys (Benth.) K.Schum.	Maranthaceae	Herb	NA	NA
*Schrankia leptocarpus DC.	Mimosaceae	Herb	NA	Pioneer
*Schwenckia americana L.	Solanaceae	Herb	NA	Pioneer
*Sclerea verrucosa Wild	Cyperaceae	Herb	Green	Pioneer
*Scoparia dulcis Linn.	Scrophulariaceae	Herb	Green	Pioneer

***Secamone afzelii* (Shult) K. Schum**	Asclepiadaceae	Cimber	Green	SB
***Securinega virosa* (Roxb. Ex Wild) Benth.**	Euphorbiaceae	Shrub	NA	Pioneer
***Selaginella mysorus* (Sw.) Alston**	Selaginellaceae	Herb	Green	NA
***Setaria barbata* (Lam) Kunth.**	Poaceae	Herb	NA	Pioneer
***Sida acuta Burm*.f.**	Malvaceae	Herb	NA	Pioneer
***Sida cordifolia* L.**	Malvaceae	Shrub	NA	NA
***Sida rhombifolia* L.**	Malvaceae	Shrub	NA	Pioneer
***Smilax kraussiana* Meisn.**	Smilacaceae	Climber	Green	Pioneer
***Solanum erianthum* D. Don**	Solanaceae	Tree	Green	Pioneer
***Solanum nigrum* L.**	Solanaceae	Herb	NA	Pioneer
***Solanum torvum* Sw.**	Solanaceae	Herb	NA	Pioneer
***Sorghum arundinaceum* (Desv.) Stapf.**	Poaceae	Herb	NA	Pioneer
***Spigelia anthelmia* l.**	Loganiaceae	Shrub	NA	Pioneer
***Spilanthes filicaulis* (Schum. And Thunn.) C.D.Adams**	Asteraceae	Herb	NA	Pioneer
***Sporobolus pyramidalis* P.Beauv.**	Poaceae	Herb	NA	Pioneer
***Starchytarpheta indica* (L.) Vahl.**	Verbenaceae	Shrub	NA	Pioneer
***Synedrella nodiflora* Gaertn.**	Asteraceae	Herb	Green	Pioneer
***Tabernaemontana africana* DC.**	Apocynaceae	Tree	Green	SB
***Talinum triangulare* (Jacq.) Willd.**	Portulacaceae	Herb	NA	Pioneer
***Tectonia grandis* Linn.**	Verbanaceae	Tree	NA	NA
***Terminalia ivorensis* A. Chev.**	Combretaceae	Tree	Scarlet	Pioneer
***Terminalia superba* A. Chev.**	Combretaceae	Tree	Green	Pioneer
***Tetracera alnifolia* Willd.**	Dilleniaceae	Liane	Green	NA
***Tetrapleura tetraptera* (Schum & Thonn.)**	Mimosaceae	Tree	Green	Pioneer
***Thalia geniculata* L.**	Maranthaceae	Shrub	NA	NA
***Theobroma cacao* L.**	Sterculiaceae	Tree	NA	NA
Thespesia *populnea* (L.) Soland. ex Correa	Malvaceae	Tree	NA	NA
***Tragia benthamii* Bak.**	Euphorbiaceae	Herb	NA	NA
***Treculia africana* Decne.**	Moraceae	Tree	Green	NPLD
***Trema orientalis* (L.) Blume**	Ulmaceae	Tree	Green	Pioneer
***Tretrorchidium didymostemom* (Baill.) Pax & Hoffm**	Euphorbiaceae	Tree	Green	NA
***Trichilia monadelpha* (Thonn.) De Wild**	Meliaceae	Tree	Green	NPLD
***Trichilia prieuriana* A. Juss.**	Meliaceae	Tree	Green	NPLD
***Tridax procumbens* L.**	Asteraceae	Herb	NA	Pioneer

Triplochiton scleroxylon K.Schum.	Sterculiaceae	Tree	Scarlet	Pioneer
Turraenthus africanus (Weiw. ex C. DC.) Pellegr.	Meliaceae	Tree	Pink	SB
***_Tylophora sylvatica_ Decne.**	Asclepiadaceae	Climber	NA	Pioneer
Uapaca guineensis Muell. Arg.	Euphorbiaceae	Tree	Green	NPLD
***_Urena lobata_ L.**	Malvaceae	Herb	NA	Pioneer
***_Usteria guineensis_ Wild.**	Loganiaceae	Liane	Green	NPLD
Vernonia cinerrea (L.) Less.	Asteraceae	Herb	NA	Pioneer
Vernonia conferta Benth.	Asteraceae	Tree	Green	Pioneer
***_Voacanga africana_ Stapf.**	Apocynaceae	Tree	Green	Pioneer
Voacanga thouarsii Roem & Schult.	Apocynaceae	Tree	Green	Swamp
***_Waltheria indica_ L.**	Sterculiaceae	Herb	NA	Pioneer
Xanthosoma sagittifolium (L.) Schoott	Araceae	Herb	NA	NA
***_Xlyopia aethropica_ (Dunal.) A. Rich.**	Annonaceae	Climber	Blue	Swamp
Xylia evansii Hutch.	Mimosaceae	Tree	Blue	
Zanthoxylum gilletii (De Wild) Waterman	Rutaceae	Tree	Green	Pioneer
Zanthoxylum lemairei (De Willd.) Waterman	Rutaceae	Tree	Blue	Pioneer
Zea mays L.	Poaceae	Herb	NA	NA

* Plant species common to both the mined and unmined study areas. Source: Field study (2017).

Appendix K: Plant species in each plot of mined study area

Species name	**Life form**	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**
Aspilia africana (Pers.) C.D.Adams	Climber	185	280	164	167	210
Calopogonium mucunioides Desv.	Climber	73	149	88	115	92
Cardiospermum grandiflorum Swartz.	Climber	2	13	8	2	16
Centrosema pubescens Benth.	Climber	20	104	182	410	112
Cissus aralioides (Welw. ex Bak.) Planch.	Climber	114	210	98	188	175
Combretum racemosum P. Beauv.	Climber	90	92	63	106	190
Hewittia sublobata L	Climber	57	190	62	180	215
Indigofera macrophylla Schum. & Thonn.	Climber	40	263	128	24	34
Iodes africana Welw. ex Oliv.	Climber	188	121	32	83	19
Ipomoea cairica (L.) Sweet	Climber	288	85	78	248	112
Ipomoea involucrata L.	Climber	101	111	56	8	326
Melanthera scandens (Schum. & Thonn.) Roberty	Climber	480	101	86	128	138
Momordica charantia L.	Climber	41	17	37	26	345

***Mussaenda elegans* Schum. & Thonn.**	Climber	16	18	22	31	14
***Operculina macrocarpa* (Linn.) Urban**	Climber	9	35	48	44	8
***Secamone afzelli* (Schult) K. Schum.**	Climber	4	12	47	19	29
***Smilax kraussiana* Meisn.**	Climber	101	31	69	180	244
***Tylophora sylvatica* Decne.**	Climber	95	49	50	2	36
***Xlyopia aethropica* (Dunal.) A. Rich.**	Climber	52	42	116	78	13
***Cyclosorus afer* (Christ) Ching.**	Fern	1	2	0	0	0
***Lycopodium* sp.**	Fern	2	2	2	0	0
***Nephrolepis bisserata* (Swartz) Schott.**	Fern	100	72	59	119	87
. .*Pergularia daemia* (Forsk.) Chiov.	Herb	92	101	226	148	51
***Acroceras zizanoides* (Kunth.) Dandy**	Herb	173	80	49	13	12
***Ageratum conyzoides* L.**	Herb	158	93	58	16	42
***Anchomanes difformis* (BIume) Engl.**	Herb	19	162	62	110	8
***Andropogon gayanus* Kunth.**	Herb	41	46	260	8	43
***Aneilema beniniense* (P. Beauv.) Kunth.**	Herb	260	120	97	71	120
***Asystasia gigantica* (L.) T. Anders.**	Herb	85	152	162	120	88
***Bidens pilosa* L.**	Herb	45	220	129	310	87
***Boerhavia diffusa* L.**	Herb	59	14	16	28	70
***Bracharia deflexa* (Schumach.) Hubbard ex Robyns.**	Herb	350	220	126	90	362
***Brillantaisia nitens* Lindau**	Herb	310	290	162	79	189
***Bryophylum pinnatum* (Lam.) Kutz.**	Herb	24	187	125	90	0
***Capsicum frutescens* L.**	Herb	6	9	0	0	5
***Coffea abracteolata* (Hiem) Brenan**	Herb	192	86	230	710	130
***Coix lacryma-jobi* L**	Herb	121	288	126	67	320
Commelina benghalensis L.	Herb	107	314	126	460	343
***Crotalaria retusa* Linn.**	Herb	42	10	47	21	0
***Cyathula achyranthoides* (H.B.& K.) Moq.**	Herb	123	480	266	218	27
***Cynodon dactylon* (L.) Pers.**	Herb	261	266	270	192	148
***Cyperus rotundus* L.**	Herb	145	215	266	442	319
***Dactyloctenium aegyptium* (L.) P.Beauv.**	Herb	96	151	390	172	156
***Desmodium adscendens* (Sw.) DC.**	Herb	151	228	69	304	220
***Desmodium scopiurus* (SW.) Desv.**	Herb	180	490	151	82	413
***Dieffenbachia seguire* Schott.**	Herb	101	88	480	345	438
***Digitaria horizontalis* Willd.**	Herb	280	270	155	212	48
***Dissotis rotundifolia* (Sm.) Triana**	Herb	251	222	295	238	120
***Echinochloa cruspavonis* (Kunth) Schult.**	Herb	93	190	201	137	879
***Eleusine indica* (L.) Gaertn.**	Herb	32	25	88	37	36
***Emilia coccinea* (Sims) G.Don.**	Herb	350	58	92	416	134
***Eregeron floribundus* (H.B &K.) Sch. Bip**	Herb	91	78	204	155	77
***Euphorbia heterophylla* L.**	Herb	154	98	362	142	145
***Euphorbia hirta* L.**	Herb	15	38	663	351	762
***Euphorbia prostrata* L.**	Herb	162	141	31	29	58
***Ficus asperifolia* Miq.**	Herb	80	146	225	128	67

***Fleurya aestuans* Miq.**	Herb	14	41	27	20	40
***Fluerya ovalifolia* (Schum. & Thonn.) Dandy**	Herb	172	220	11	240	413
***Hibiscus esculentus* L.**	Herb	2	4	0	0	1
***Hilleria latifolia* (Lam) H. Walt**	Herb	48	57	113	327	126
***Hydrolea globra* Schum. & Thonn.**	Herb	17	8	214	54	474
***Hyptis suaveolens* Poir**	Herb	83	135	272	850	19
***Imperata cylindrica* (L.) Beauv.**	Herb	179	48	69	373	402
***Ischaemum rugosum* Salisb.**	Herb	313	154	64	73	187
***Leptochloa caerulescens* Steud.**	Herb	31	26	64	168	77
***Ludwigia decurren* Walter.**	Herb	88	122	101	420	109
***Lycopersicum esculentum* Mill.**	Herb	5	13	0	0	0
***Mariscus althernifolia* Vahl.**	Herb	28	410	76	280	163
***Melochia corchorifolia* L.**	Herb	150	100	38	560	165
***Microglossa afzelii* O. Hoffm.**	Herb	632	132	120	12	332
***Mimosa nigra* L.**	Herb	12	68	29	183	43
***Mimosa pudica* L.**	Herb	45	86	74	16	56
***Mollugo verticillata* L.**	Herb	375	159	38	45	192
***Momordica foetida* Schum. &Thonn.**	Herb	113	280	188	207	150
***Musa paradisiaca* L.**	Herb	4	0	3	0	5
***Oldenlandia corymbosa* L**	Herb	1	55	12	39	23
***Palisota hirsuta* (Thunb.) K. Schum.**	Herb	142	182	250	66	176
***Panicum laxum* Jacq.Sw. PR.Br.**	Herb	33	58	102	51	370
***Panicum maximum* Jacq.**	Herb	118	193	288	490	306
***Paspalum conjugatum* Berg.**	Herb	280	33	168	159	55
***Paspalum scrobiculatum* L.**	Herb	67	202	140	670	66
***Pauzolzia guineensis* Benth**	Herb	172	124	89	93	150
***Pennisetum polystachion* (L.) Schult.**	Herb	152	290	189	134	126
***Phyllantus amarus* Schum. et Thonn.**	Herb	35	48	64	136	138
***Physalis angulata* L.**	Herb	121	208	330	29	82
***Physalis micrantha* Link**	Herb	220	172	163	80	40
***Platostomi africanum* P. Beauv.**	Herb	174	244	219	140	186
***Polygonium lanigerum* R.Br.**	Herb	140	320	69	94	127
***Richardia brasiliensis* Gomez**	Herb	270	14	68	504	69
***Rottboellia cochinchinensis* (Lour.) W.Clayton**	Herb	125	56	48	103	23
***Schrankia leptocarpus* DC.**	Herb	75	59	230	55	48
***Schwenckia americana* L.**	Herb	81	60	160	310	98
***Sclerea verrucosa* Wild.**	Herb	220	160	36	151	33
***Scoparia dulcis* Linn.**	Herb	90	169	24	88	130
***Selaginella mysorus* (Sw.) Alston**	Herb	5	3	0	12	10
***Setaria barbata* (Lam) Kunth.**	Herb	42	159	158	96	165
***Sida acuta* Burn. F.**	Herb	53	62	90	142	63
***Solanum nigrum* L.**	Herb	55	37	16	22	108
***Solanum torvum* Sw.**	Herb	56	81	34	170	17
***Sorghum arundinaceum* (Desv.) Stapf.**	Herb	44	46	189	123	62
***Sporobolus pyramidalis* P. Beauv.**	Herb	412	285	367	268	804
***Synedrella nodiflora* Gaertn.**	Herb	69	41	115	170	25

Talinum triangulare (Jacq.) Willd.	Herb	37	15	29	27	62
Tragia benthmii Bak.	Herb	258	64	118	216	36
Tridax procumbens L.	Herb	52	102	111	53	49
Urena lobata L.	Herb	160	95	138	62	114
Vernonia cinerrea (L.) Less.	Herb	330	290	250	83	160
Walteria indica Linn.	Herb	28	370	150	58	120
Xanthosoma sagittifolium (L.) Schoott	Herb	125	203	410	115	30
Zea mays L.	Herb	0	15	13	3	15
Combretum hispidium Laws	Liana	154	216	48	580	102
Maniophyton fulvrum Mull. Arg.	Liana	114	270	144	214	38
Usteria guineensis Willd.	Liane	0	2	2	1	1
Allophylus africanus P. Beauv.	Sapling	4	0	5	2	1
Anthonatha macrophyla P.Beauv.	Sapling	5	0	2	1	0
Daniellia ogea (Harms) Holland	Sapling	0	0	2	1	5
Dienbollia pinnata (Poir) Schum. & Thonn.	Sapling	0	0	3	1	1
Diospyros viridicans Hiem	Sapling	1	0	0	2	1
Herittiera utilis (Sprague) Sprague	Sapling	2	1	2	1	0
Macaranga barteri Mull. Arg.	Sapling	0	0	1	5	2
Musanga cecropioides R. Br.	Sapling	1	1	0	0	3
Ochna staudtii Engl. & Gilg.	Sapling	0	2	0	5	3
Rauvolfia vomitoria Afzel.	Sapling	2	0	0	0	1
Terminalia ivorensis A. Chev.	Sapling	2	0	2	0	0
Treculia africana Decne.	Sapling	1	1	0	0	0
Trichilia prieuriana A. Juss.	Sapling	1	2	0	1	0
Voacanga africana Stapf.	Sapling	0	0	0	1	2
Drypetes floribunda (Muell. Arg) Hutch	Seedling	0	0	0	0	4
Ficus capensis Thunb.	Seedling	2	1	0	0	0
Grossera vignei Hoyle	Seedling	2	0	0	1	1
Macaranga heterophylla (Mull. Arg.) Mull. Arg.	Seedling	2	1	0	0	0
Macaranga hurifolia Beille	Seedling	0	5	1	0	4
Alchornea cordifolia (Schum. & Thonn) Muell.Arg	Shrub	6	15	8	11	10
Cassia occidentalis L.	Shrub	1	2	1	3	0
Chromolaena odorata (L.) King & Robinson	Shrub	469	605	919	1373	1002
Jatropha gossypiifolia Linn.	Shrub	138	211	150	17	11
Manihot esculenta Crantz.	Shrub	2	4	0	0	0
Securinega virosa (Roxb. Ex Wild) Benth.	Shrub	17	29	192	25	36
Sida cordifolia L.	Shrub	105	133	480	244	29
Sida rhombifolia L.	Shrub	140	120	83	94	43
Spigelia anthelmia l.	Shrub	45	191	228	460	152
Starchytarpheta indica (L.) Vahl.	Shrub	12	63	13	48	20
Antiaris toxicaria Leschen.	Tree	2	0	0	1	0
Baphia nitida Lodd.	Tree	1	0	1	2	2
Berlinia occidentalis Keay	Tree	0	2	1	0	0

***Carapa procera* DC.**	Tree	1	0	1	0	2
***Ceiba pentandra* Gaertn.**	Tree	1	2	2	1	1
***Cola chlamydantha* K,Schum.**	Tree	0	0	1	0	0
***Elaeis guineensis* Jacq.**	Tree	2	3	3	7	9
***Gmelina arborea* Roxb.**	Tree	0	0	1	2	2
***Hallea ledermannii* (K. Krause) Verde**	Tree	0	0	1	1	0
***Mallotus oppositifolius* (Geisel.) Mull. Arg.**	Tree	3	18	15	4	17
***Morinda lucida* Benth.**	Tree	1	0	2	5	5
***Pycnanthus angolense* (Welw.) Warb**	Tree	1	0	0	2	1
***Solanum erianthum* D. Don.**	Tree	1	4	0	1	0
***Tectonia grandis* Linn.**	Tree	0	3	2	0	0
***Tetrapleura tetraptera* (Schum & Thonn.)**	Tree	0	0	1	1	2

Appendix L: Plant species in each plot of unmined study area

Species Name	**Local name**	**Life form**	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**
***Acroceras zizanoides* (Kunth.) Dandy.**		Herb	18	28	35	12	0
***Aframomum melequeta* K. Schum**		Herb	0	2	0	0	1
***Afzelia africana* Sm.**	Papao	Tree	1	0	1	0	0
***Albizia ferruginea* (Guill & Perr.) Benth.**	Awiemfosemina	Tree	2	1	0	0	0
***Albizia zygia* (DC.) J.F Machr.**	Okoro	Tree	1	1	0	0	0
***Alchornea cordifolia* (Schum.&Thonn.) Muell.Arg**	Gyama	Tree	0	1	0	3	1
***Allanblackia floridunda* A.Chev.**	Sonkyi	Tree	2	0	1	1	0
***Allophylus africanus* P. Beauv.**	Dua-ahabanum	Tree	1	0	1	1	0
***Amphimas pterocarpoides* Harms.**	Yaya	Tree	0	1	0	0	1
***Ananas sativa* Schult. f.**		Herb	2	0	0	0	3
***Aningeria altissima* (A. Chev) Aubrev. & Pellegr.**	Samfena	Tree	1	0	0	0	0
***Anthocleista nobilis* (G..Don)**	Bontodea	Tree	1	0	0	0	0
***Anthonatha macrophyla* P.Beauv.**	Totoro	Tree	0	0	1	1	0
***Antiaris toxicaria* Leschen.**	Kyenkyen	Tree	2	1	0	0	0

***Antrocaryon micraster* A. Chev. & Guillaum.**	Aprokuma	Tree	1	1	0	0	0
***Aulacocalx jasminiflora* Hook. f.**	Ntweson	Tree	1	0	0	0	1
***Bambusa vulgaris* Schrad. ex Mendel**	Pampro	Tree	0	2	0	2	1
***Baphia nitida* Lodd.**	Adwene	Tree	0	0	1	2	1
***Berlinia occidentalis* Keay**	Okuo	Tree	1	1	0	0	0
***Bertiera racemosa* (G.Don) K. Schum.**	Kakadua	Tree	1	0	0	0	1
***Bidens pilosa* Linn.**		Herb	8	2	23	31	4
***Blighia sapida* Konig.**	Akye	Tree	2	0	1	0	0
***Bolbitis gemmifera* (Hierm) C.Chr.**		Fern	6	0	16	0	19
***Bombax buonopozense* P. Beauv.**	Kuntunkuni	Tree	1	1	0	0	0
***Brachiaria deflexa* (Schumach.) Hubbard ex Robyns**		Herb	16	15	12	26	28
***Calopogonium mucunoides* Desv.**		Herb	9	4	19	12	39
***Calycobolus africanus* (G.Don) Heine**		Liane	9	2	0	0	3
***Carapa procera* DC.**	Kwakuobese	Tree	2	0	0	0	2
***Cassytha filiformis* Linn.**		Climber	2	19	0	25	16
***Castanola paradoxa* (Gilg) Schellenb**		Liana	12	8	4	0	3
***Ceiba pentandra* Gaertn.**	Onyina	Tree	3	2	1	1	1
***Celtis mildbraedii* Engl.**	Esa	Tree	1	1	0	1	0
***Centrosema pubescens* Benth.**		Climber	26	35	36	2	19
***Christiana africana* DC**	Sesedua	Tree	1	1	0	1	0
***Chromolaena odorata* (L.) King & Robinson**		Shrub	29	37	35	28	24
***Chrysophyllum giganteum* A. Chev**	Kumfana	Tree	1	1	0	0	0
***Cissus aralioides* (Welw. ex Bak.) Planch.**		Climber	31	12	22	18	11
***Cissus cymosa* Schum.& Thonn.**		Climber	5	18	14	34	16
***Citrus sinensis* (l.) Osbeck**	Ekutu	Tree	0	0	0	0	2
***Cleistopholis patens* (Benth.) Engl. & Diels.**	Ngonenkyene	Tree	2	0	1	0	0
***Coffea abracteolata* (Hiem) Brenan**		Herb	16	9	0	40	4
Cola chlamydantha	Tana-nfre	Tree	1	0	0	1	0

K,Schum.							
***Cola gigantea* A. Chev.**	Watapuo	Tree	2	1	0	0	0
Colacassia esculenta		Herb	8	0	0	0	10
***Combretum hispidium* Laws**		Liana	13	2	0	0	12
***Combretum racemosum* P. Beauv.**		Climber	9	6	42	17	7
***Commelina benghalensis* Linn**		Herb	32	11	14	15	22
***Cremaspora triflora* (Thonn.) Schum.**		Liana	18	0	1	0	4
***Cussonia bancoensis* Aubrev. & Pellegr.**	Kwaebrofre	Tree	0	1	0	0	1
***Cyathula achyrantheides* (H.B & K) Moq.**		Herb	14	16	32	12	34
***Cyathula prostrata* (L.) Blume**		Herb	21	9	26	4	11
***Cyclosorus afer* (Christ) Ching**		Fern	23	16	35	18	18
***Cyclosorus striatus* (Schum.) Ching**		Fern	18	2	16	2	12
***Cylicodiscus gabuneensis* Harms.**	Denya	Tree	1	0	0	0	2
***Dacryodes klaineana* (Pierre). H.J. Lam**	Adwea	Tree	0	1	1	0	0
***Dactyladenia dinklagei* (Engler) G.T.Prance & F.White**	Atwere	Tree	1	0	1	0	1
***Daniellia ogea* (Harms) Holland**	Hyedua	Tree	2	0	0	1	0
***Desmodium adscendens* (Sw.) DC.**		Herb	9	13	12	11	28
***Dialium aubrevillei* Pellegr.**	Duabankye	Tree	1	0	1	1	0
***Dichapetalum jonstoni* Engl.**		Climber	12	5	18	6	6
***Dienbollia pinnata* (Poir.) Schum. & Thonn**	Woagye-akoa	Tree	1	0	0	0	1
***Digitaria horizontalis* Willd.**		Herb	10	16	14	19	8
***Dioscorea alata* Linn.**		Climber	0	0	1	0	1
***Diospyros viridicans* Hiem**	Atwea	Tree	0	1	0	1	1
***Diplazium sammatii* (Kuhn.) C. Chr.**		Fern	42	16	10	62	7
***Diplazium welwitschii* (Hook.) Diels**		Fern	27	19	3	21	5

***Discoglypremna caloneura* (Pax) Prain**	Fetefre	Tree	1	0	1	0	0
***Distemonanthus benthamianus* Baill**	Bonsamdua	Tree	1	0	0	1	0
***Drypetes aubrevillei* Leandri**	Duamoko	Tree	0	1	1	0	0
***Eclipta prostrata* (Linn.) Linn.**		Herb	16	26	23	6	8
***Elais guineensis* Jacq.**	Abe	Tree	0	1	1	0	2
***Emilia coccinea* (Sims.) G. Don**		Herb	14	10	2	0	12
***Entandophragma angolense* (Welw.) DC.**	Edinam	Tree	1	1	0	0	0
***Entandophragma cylindricum* (Sprague) Sprague**	Penkwa	Tree	1	0	0	0	0
***Eremospatha marocarpa* (Man. & Wendl) Wendl.**		Liane	11	0	8	0	6
***Euclinia longiflora* Salisb.**		Herb	9	0	0	12	11
***Euphorbia hirta* L.**		Herb	22	6	68	36	19
***Ficus asperifolia* Miq.**		Herb	16	15	5	25	16
***Ficus capensis* Thunb.**	Doma	Tree	1	0	0	0	11
***Ficus craterostoma* Mildbr. & Buretti**	Anomani	Tree	0	1	1	0	0
Ficus exasperata Vahl.	Nyankyeren	Tree	1	1	0	1	0
***Fleurya aestuans* Miq.**		Herb	2	0	0	0	2
***Funtumia elastica* (Preuss) Stapf.**	Funtum	Tree	1	2	1	0	0
***Geophila obvallata* (Schum.) F. Didri**		Herb	18	11	13	23	8
***Geophila repens* (Linn.) I.M.Johnston**		Herb	16	8	8	10	24
***Gilbertiodendro limba* (Scott Elliot) J. Leonard**	Tetekon	Tree	0	1	0	1	1
***Glyphaea brevis* (Spreng) Monach.**	Foto	Tree	0	1	1	0	0
***Grandiflorum cardiospermum* Sw.**		Climber	6	0	16	25	16
***Grewia pubescens* P. Beauv.**		Herb	48	18	22	23	27
***Griffornia simplicifolia* (Vahl. ex DC) Baill**	Kagya	Tree	1	0	0	1	0
***Guarea thompsoni* Sprague & Hutch**	Kwadwuma	Tree	0	0	1	1	0
***Gynura sarmentosa* (Blume.) DC.**		Climber	2	5	25	10	4
***Hannoa klaineana* Pierre & Engl.**	Hotrohotro/Fotie	Tree	0	1	0	1	0

***Harungana madagascariensis* Lam. Ex Poir.**	Kosoa	Tree	1	0	0	1	1
***Herittiera utilis* (Sprague) Sprague**	Nyankom	Tree	1	1	1	0	0
***Hexalobus crispiflorus* A. Rich**	Duabaha	Tree	0	1	1	0	0
***Holarrhena floribunda* (G.Don) Dur. & Schinz.**	Sese	Tree	1	0	1	1	0
***Hoslunda opposita* Vahl.**		Herb	11	4	6	14	2
***Iodes africana* Welw. ex Oliv.**		Climber	0	2	0	0	6
***Ipomoea aquatica* Forsk.**		Herb	12	8	0	3	10
***Ipomoea herderifolia* Linn**		Herb	9	14	8	12	13
***Ipomoea involucrata* P. Beauv.**		Climber	5	16	19	29	18
Ipomoea mauritania		Climber	4	4	12	11	11
***Jatropha gossypiifolia* Linn.**		Shrub	9	16	2	0	6
***Justicia flava* (Forsk) Vahl.**		Herb	8	12	6	17	12
***Khaya ivorensis* A.Chev.**	Dubini	Tree	2	0	0	0	0
***Kigelia africana* (Lam.) Benth.**	Nufuten	Tree	1	1	2	0	1
***Lantana camara* Linn.**		Herb	6	0	2	20	2
***Ludwigia decurren* Walter**		Herb	2	9	3	14	8
***Lycopodium cernum* Linn.**		Fern	14	10	32	17	12
***Lygodium macrophylla* (Kuntz.) Sw.**		Fern	26	8	11	10	16
***Macaranga barteri* Mull. Arg.**	Opam	Tree	2	4	1	2	1
***Macaranga heterophylla* (Mull. Arg.) Mull. Arg.**	Opam kokoo	Tree	1	2	3	2	3
***Macaranga hurifolia* Beille**	Opam fufuo	Tree	1	2	2	0	2
***Mallotus oppositifolius* (Geisel.) Mull.Arg.**	Satadua/Anyanyanforowa	Tree	0	0	0	1	2
***Mammea africana* Sabine**	Bompagya	Tree	1	1	0	1	0
***Manihot esculenta* Crantz.**		Shrub	6	0	0	3	2
***Maniophyton fulvrum* Mull.Arg.**		Liana	6	0	1	0	2
***Mareya micrantha* (Benth.) Mull. Arg.**	Dubrafo	Tree	0	1	1	0	0
Margaritaria discoidea	Pepea	Tree	1	0	1	0	0

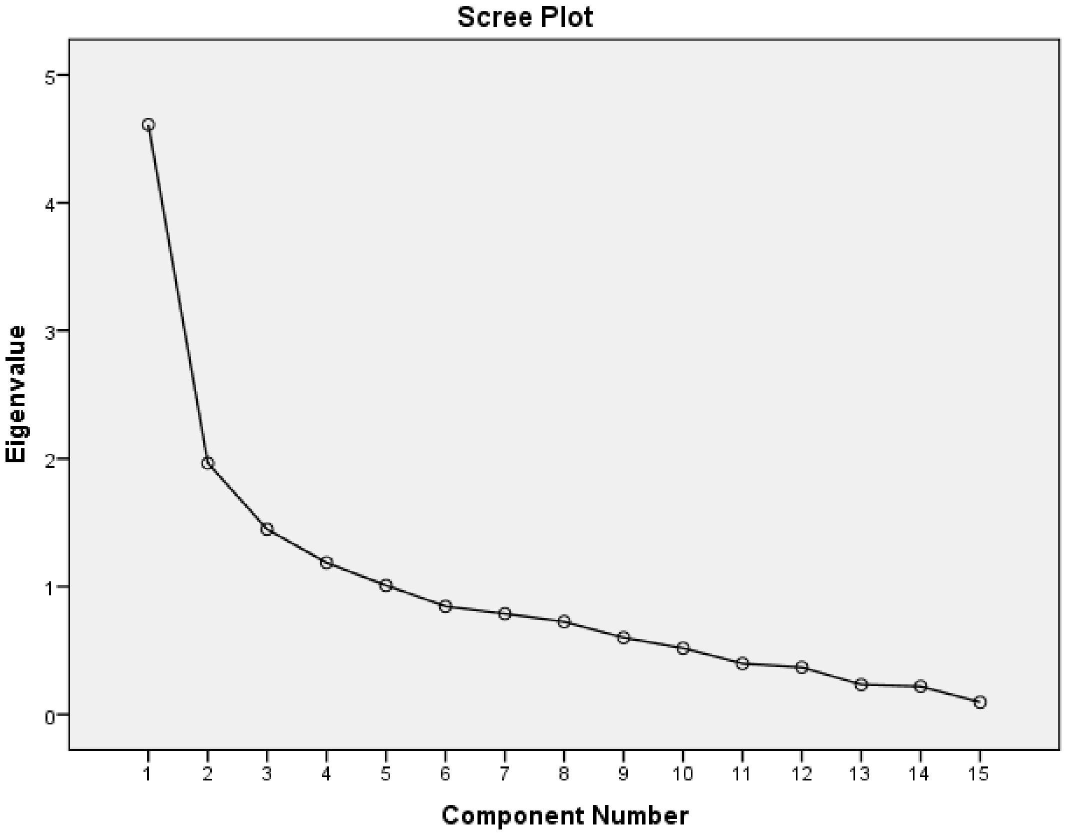
(Baill.) Webster							
***Melochia corchorifolia* L.**		Herb	13	15	41	8	7
***Mikania scandens* (Burm.f.) Robinson**		Herb	15	8	2	13	3
***Milicia excelsa* (Welw.) Berg.**	Odum	Tree	2	1	0	1	0
***Milletia zechiana* Harms**	Frafraha	Tree	0	1	1	1	0
***Mimosa pudica* L.**		Herb	19	38	38	17	7
***Mitragyna* sp.**	Subaha	Tree	0	1	0	1	1
***Morinda lucida* Benth.**	Konkroma	Tree	0	0	1	2	0
***Musanga cecropioides* R. Br.**	Odwuma	Tree	0	5	2	1	1
***Mussaenda elegans* Schumach & Thonn.**		Climber	2	0	11	13	11
***Mussaenda tristigmatica* Cummins**		Climber	1	0	14	25	5
***Nephrolepis bisserata* (Swartz.) Schott.**		Fern	48	26	13	24	16
***Nesogordonia papaverifera* (A. Chev.) R. Capuron**	Danta	Tree	1	0	1	0	0
***Newbouldia laevis* (P.Beauv.) Seeman ex Bureau**	Sesemasa	Tree	1	1	0	1	0
***Nuclea diderrichii* (De Wild) Merr**	Kusia	Tree	1	1	0	0	0
***Ochna staudtii* Engl. & Gilg.**	Kwaasiwa	Tree	0	1	0	0	0
***Oldenlandia corymbosa* Linn.**		Herb	12	23	2	15	21
***Pachypodanthium standtii* Engl. & Diels.**	Kumdwie	Tree	0	1	0	0	0
***Pachystela brevipes* Engl.**	Aframsua	Tree	1	2	1	0	0
***Palisota hirsuta* (Thunb.)**		Herb	22	10	14	0	4
***Panicum laxum* Sw. Pr.Br.**		Herb	10	18	2	23	18
***Panicum maximum* Jacq.**		Herb	11	22	21	42	17
***Parinari excelsa* Sabine**	Afam	Tree	0	1	1	0	0
***Parkia bicolor* A.Chev.**	Asoma	Tree	1	0	0	0	0
***Paspalum scrobiculatum* L.**		Herb	14	8	12	29	12
***Pauridiantha afzelii* (Hiern.) Brem.**		Shrub	9	12	4	9	8
***Pavetta corymbosa* (SC.) F.N.Williams**	Kronkoo	Tree	0	1	0	1	1
***Pentaclethra macrophyla* Benth.**	Ataa	Tree	1	2	1	0	1
Pentadesma butyracea	Abotoasebie	Tree	0	2	0	0	0

Sabine							
Petersianthus macrocarpus **(Beauv.) Liben**	Esia	Tree	2	1	1	1	0
Phyllantus amarus **Schum. et Thonn.**		Herb	9	16	18	7	5
Physalis angulata **Linn.**		Herb	13	11	7	18	25
Piper guineense **Schumach. & Thonn.**		Climber	0	4	24	10	7
Piper umbellatum **L.**		Shrub	4	0	13	16	13
Piptadeniastrum africanum **(Hook f.) Brenan**	Dahoma	Tree	2	0	1	1	0
Pityrogramma calomelanos **(Linn.) Link**		Fern	19	22	23	0	21
Platostomi africanum **P. Beauv.**		Herb	18	0	10	11	8
Polygonium lanigerum **R.Br.**		Herb	12	0	0	28	7
Psydrax subcordata **DC.Bridon**	Tetia-dupon	Tree	0	0	1	0	0
Pteridium aquilinum **(Linn.) Kuhn.**		Fern	72	18	56	58	11
Pycnanthus angolensis **(Welw.) Warb.**	Otie	Tree	1	1	0	0	1
Raphia hookeri Mann.& **Wendi**	Adobe	Tree	0	0	1	0	1
Rauvolfia vomitoria **Afzel.**	Kakapenpen	Tree	0	1	1	0	0
Richardia brasiliensis **Gomez**		Herb	14	22	11	7	5
Ricinodendron heudolotii **(Baill) Pierre ex Pax.**	Owama	Tree	0	1	0	0	1
Rinorea welwitschii **(Oliv.) O.Ktze**	Apose-nini	Tree	0	1	1	0	0
Sarcophrynium brachystachys **(Benth.) Schum.**		Herb	15	3	0	8	10
Schrankia leptocarpus **DC.**		Herb	6	8	12	11	14
Schwenkia americana **L.**		Herb	8	8	4	12	16
Sclerea verrucosa **Wild.**		Herb	12	8	24	7	11
Scoparia dulcis **Linn.**		Herb	17	28	5	31	4
Secamone afzelii **(Schult) K. Schum**		Climber	12	9	24	18	13
Setaria barbata **(Linn.)**		Herb	11	2	19	2	18
Sida acuta Burm**.f.**		Herb	12	0	0	14	7
Smilax kraussiana		Clim	0	4	18	0	14

Meisn.		ber					
***Solanum erianthum* D. Don**	Pepediawuo	Tree	1	1	1	1	0
***Sorghum arundinaceum* (Desv.) Stapf.**		Herb	8	7	13	16	9
***Spigelia anthelmia* L.**		Herb	22	12	12	10	42
***Spilanthes filicaulis* (Schum. And Thunn.) C.D.Adams**		Herb	18	9	7	14	19
***Sporobolus pyramidalis* P.Beauv.**		Herb	12	23	26	17	12
***Synedrella nodiflora* Gaertn.**		Herb	8	11	2	0	18
***Tabernaemontana africana* DC.**	Obonawa	Tree	0	1	1	2	0
***Terminalia ivorensis* A. Chev.**	Emire	Tree	2	0	0	1	1
***Terminalia superba* A. Chev.**	Ofram	Tree	1	0	1	1	0
***Tetracera alnifolia* Willd.**		Liane	8	0	12	0	5
***Tetrapleura tetraptera* (Schum & Thonn.)**	Prekese	Tree	0	1	1	0	0
***Thalia geniculata* L.**		Shrub	14	3	17	0	26
***Theobroma cacao* L.**		Tree	0	0	0	2	2
***Thespisia populnea* (L.) Soland. ex Correa**	Ayeduru	Tree	0	1	1	0	0
***Tragia benthamii* Bak**		Herb	18	13	24	8	19
***Treculia africana* Decne.**	Brebretim	Tree	1	0	1	0	0
***Trema orientalis* (L.) Blume**	Sesea	Tree	1	0	1	0	0
***Tretrorchidium didymostemom* (Baill.) Pax & Hoffm**	Anenedua	Tree	0	1	1	0	0
-*Trichilia monadelpha* (Thonn.) De Wild	Tandro	Tree	1	0	1	0	0
***Trichilia prieuriana* A. Juss.**	Kakadikro	Tree	0	1	1	0	0
***Tridax procumbens* L.**		Herb	17	56	63	39	16
***Triplochiton scleroxylon* K.Schum.**	Wawa	Tree	1	0	1	0	0
***Turraenthus africanus* (Weiw. ex C. DC.) Pellegr.**	Apapaye	Tree	0	0	1	1	0
***Tylophora sylvatica* Decne.**		Climber	8	12	4	8	3
***Uapaca guineensis* Muell. Arg.**	Kontan	Tree	1	1	1	0	0
***Urena lobata* Linn.**		Herb	12	5	0	13	20
***Usteria guineensis* Wild.**		Liane	10	7	0	0	5

***Vernonia conferta* Benth.**	Owudifokete	Tree	0	1	2	2	2
***Voacanga africana* Stapf.**	Ofuruma	Tree	0	1	1	0	1
***Voacanga thouarsii* Roem & Schult.**	Foba	Tree	2	1	1	0	0
***Waltheria indica* Linn.**		Herb	39	14	20	14	78
***Xylia evansii* Hutch.**	Samantawa	Tree	1	1	0	0	0
***Xylopia aethropica* (Dunal) A. Rich**		Climber	2	0	4	12	7
***Zanthoxylum gilletii* (De Wild) Waterman**	Okuo	Tree	1	0	1	0	1
***Zanthoxylum lemairei* (De Willd.) Waterman**	Okuonini	Tree	0	1	1	0	0

Appendix M: Scree plot showing variance associated with each PC and the commulative variance



Appendix N: Component transformation matrix after varimax rotation showing factor loadings

Component Transformation Matrix

Component	1	2	3	4	5
1	.903	.320	.158	.137	.195
2	-.175	.558	-.692	.381	.185
3	-.271	-.069	.501	.637	.514
4	-.132	.192	.028	-.644	.728
5	-.250	.738	.495	-.121	-.366

Rotation Method: Varimax with Kaiser Normalization.

Source: Field study (2016)

Appendix O: Field pictures from the study area

Researcher laying transect

Researcher identifying some plants

Reseacher interacting with some miners

Reclaimed mined pit with some vegetation (5 years)

Source: Field study (2016)

Reclaimed mined pit (2 years)

Abandoned mined pit

Oil palm on unreclaimed mined area

Cassava on unreclaimed mined area

Source: Field study (2016)