KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

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EFFECTS OF ARTISINAL MINING ON SELECTED FOREST RESOURCES IN TANO OFFIN EXTENSION FOREST RESERVE IN GHANA

A Thesis Submitted to the Department of Theoretical and Applied Biology
in partial fulfillment of the requirement for the award of
Master of Science Degree in Environmental Science

BY

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DECLARATION

I, Jones Agyei Kumi, hereby certify that this report is a true outcome of the research carried out in the Tano Offin Extension Forest Reserve in the Atwima District of Ashanti Region on Effects of artisanal mining on selected Forest resources. I hereby declare that, except for reference to other people's work which has been duly acknowledged, this research work consists of my own work produced from research undertaken under the supervision of Mr. Eric Agyapong (Department of Theoretical and Applied Biology – KNUST) and that no part has been presented for any degree elsewhere. This report is submitted in partial fulfillment for the award of MSc. in Environmental Science.

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ABSTRACT

This study assessed the effects of artisanal mining on selected forest resources in Tano Offin extension Forest Reserve. Sediment, water and soil samples from the Subin River and the catchment area were evaluated for the concentration of Pb, Zn, As and Fe using Atomic Absorption Spectrophotometer. Results showed that, upstream concentration levels for all trace metals were lower than their corresponding midstream and downstream levels. This phenomenon suggest anthropogenic sources for Pb, Zn, As and Fe. Pb concentrations in the water samples ranged between 0.059±0.001 and 0.097±0.001 mgL^{-1}, and were all above the WHO/FAO Drinking Water Quality Guideline value of 0.01mgL^{-1}. Arsenic concentrations in the sediment at all sampling stations which ranged between 89.10±0.26 and 117.40±0.47 $mgkg^{-1}$ were four times higher than the WHO/FAO Sediment Quality Guideline value of 20 $mgkg^{-1}$. Generally, heavy metal concentrations in soil samples from the controlled plot were lower than those from the mined area, indicating influence of the mining on the concentrations of the metals. Inspite of anthropogenic sources for trace metal concentrations at midstream and downstream, some metal levels were still below their respective WHO/FAO Quality Guideline values. Satellite images for 1990 – 2010 showed considerable changes in land cover in the Forest Reserve over the period. Closed canopy area dwindled from 3108 Ha to 1260 Ha over the period whiles that of open canopy increased from 2195Ha to 3444 Ha. The images for compartment 21 showed a considerable change in land cover as influenced by mining activities between 1990 – 2010. Kruskall-Wallis non-parametric one-way Analysis of Variance showed that significant differences existed among the mean concentrations of the metals in the sediments ($p<0.05$). However, no significant differences existed among the mean concentrations of the metals in the water samples ($p>0.05$) with the exception of Fe.

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MS3	-	Midstream sample 3
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DS3	-	Downstream sample 3
FP1	-	First plot sample 1
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FP3	-	First plot sample 3
SPI	-	Second plot sample 1
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As	-	Arsenic

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The total land area of Ghana is about 23.85 million hectares with forest areas confined to two vegetation zones, each with different forest types: the high forest zone (HFZ) constitutes 34% and the savannah zone forms the remaining 66%. Forests designated for the production of timber are mainly concentrated in the southwestern part of the country; forest types range from wet evergreen to semi-deciduous. Forest lands are owned by local communities and vested in stools (chiefs and families). However, forest resources, whether inside forest reserves or outside them, are managed by the Forestry Commission. Thus, even though traditional authorities are recognized as "land–owners" and receive benefits as such, they do not have any management rights over "their" forests (Marfo, 2010).

Approximately, 20% of the HFZ is occupied by forest reserves. These areas are gazetted to be managed for timber production, biodiversity or environmental conservation. About 0.39 million hectares of forest reserves have been categorized as degraded while 0.35 million hectares have protected status (including hill and swamp sanctuaries, areas of high biodiversity and fire protection sites) and the remainder is suitable for timber production (Marfo, 2010).

Forests provide numerous goods and services to support human life—timber and materials, firewood, food, medicines, fodder for livestock, and a variety of sources of income. Many forests are rich stores of valuable biodiversity stocks. They protect the fertility and stability of soils, play a key role in watershed management, are the habitats of countless species of wildlife, and the homes of many cultures and communities. Forests help to regulate the global climate and to mitigate climate change by absorbing carbon dioxide, which would otherwise enter the atmosphere as a greenhouse gas. In short, forests are natural assets of enormous importance (SCBD, 2009).

The Colonial government realized the importance of the forest to the citizens and ecology of the nation, and enacted an act in the late twenties to protect virgin forests in specified areas of the country. In a developing economy like Ghana, where over 50% of the population depends on the forest for shelter, feeding, drinking and medical purposes, the importance of the forest cannot be over-emphasized. (Appiah-Brenya & Antwi 2003)

Although it has been illegal for any activity in most of the forest reserves, it has been reported that the surface area of the forest dwindled from 8.2m hectares in 1957, to current 1.2m hectares within a period of about 50 years! Such a reduction has had a negative effect on the biosphere and its inhabitants, threatening the survival of man and animals. It then implies that the granting of mining leases will accelerate the rate of deforestation and compound the problems. Some of the forest reserves, which are mentioned, include Subri River, Supuma Shelter Belt, Opon Mansi, Tano Suraw, Suraw

Extension and Cape Three Points. The others are Ajenjua Bepo, and the Atiwa ranges. All these (and others) are so important to Ghana that the last thing any well-meaning citizen will want to do, is to reduce their size by a meter (Appiah-Brenya & Antwi, 2003).

Ghana seems to be fighting two 'natural' enemies from the north and south respectively. Extension of the Sahara from the North down, and erosion from the sea to the North. The extension of the grassland from the Northern Ghana through BrongAhafo to certain portions of the Ashanti region can be attributed to deforestation and lack of any commitment to keep it in check. A programme to plant trees could have prevented such degradation. Impact of mining for gold in the forest reserve will affect various sectors of the Ghanaian society (political, economic, social, technological, legal and environmental).

The government stands to gain some political inroads on the local scene, as jobs will be created. Unfortunately, however, she is bound to lose the confidence of the governments of the advanced countries who are more concerned with the impact of deforestation on life. It will not be surprising to have some governments withholding aid and/or grants to Ghana because of such environmentally unfriendly processes. Other well-meaning banking consortiums would not want to finance any such projects. The creation of jobs will bring in the much needed foreign exchange to mitigate the effects of the government's economic problems.

The rural areas will be developed, as small businesses (hotels, estates, recreational) are expected to spring up for the period that mining is undertaken. Royalties, paid to the local government, could lead to improvement in the economy, but the open-pit mining method will lead to vast areas of land being stripped of vegetation – to get to the depth at a safe, overall slope-angle. (Appiah-Brenya & Antwi, 2003)

The removal of overburden will increase erosion and the silt, carried along by surface run-off, will eventually be carried downstream, leading to flooding and blocking of waterways. A trip to the rural areas reveals trenches, tunnels, and pits which are abandoned by reputable mining companies and by small-scale operators. This will be a repetition of the small-scale mining law introduced by the government. The venture was to bring in some foreign exchange, but the implementation was poorly executed. Wildlife habitats are destroyed and the animals become exposed to poachers. Drinking water (stream) pollution in Ghana, by cyanide spill from mining operations, is a common occurrence.

The report of a fourth cyanide spill in Ghana is still fresh in our minds! It is believed that a lot of premature deaths occur as a result of cyanide poisoning in aqua life and humans. Some animals have been drowned or killed for game, and mosquitoes have had their breeding grounds enhanced. No wonder malaria cases are increasing every day, with resultant deaths especially in children and the aged (Appiah–Brenya & Antwi, 2003).

The forest reserves provide sources of herbal medicine used in the treatment of about 40% of the population who still depend on traditional medicine as their only source of health care. The same percentage of Ghanaians depends on streams for their domestic water requirements – for drinking and cooking. Such streams either start as aquifers from rocks in the forest reserves, or are protected by the shade of the forest as they meander towards the sea. They also serve as the natural habitat of thousands of endangered species, which would otherwise have been extinct. Due to erosion, land fertility is decreased, leading to reduced agricultural production (Antwi, 2002).

The impact of deforestation cuts across all spheres of the economy. The law enforcement agencies in mining have failed to assert their authority and this gross negligence has contributed to the current state of environmental degradation. The section of the mining regulation which charges mine owners to be responsible for the operation (including closure) seems to have been neglected (Antwi, 2002).

Beginning in 1986, as part of the Economic Recovery Program sponsored by the International Monetary Fund, there was a shift from state ownership to liberalization, deregulation, and privatization of the mining sector. Mining aspects of this Program were intended to help improve efficiency and raise much needed foreign exchange. A specific requirement of the National Mineral Policy of 1986 was to relax several mining policies. With the revision of the policies, government revenue from the extracted gold was restricted to 3-12% royalty tax, and corporate tax of 35%. In addition, the mining industry was not subject to environmental regulations until 1994, when the

Environmental Protection Agency (EPA) Act was passed by Parliament (EPA Act, 1994 (Act 490)). The EPA Act required Environmental Impact Assessments and Environmental Management Plans to be prepared by all new and 7 existing mining firms (Akabzaa and Darimani, 2001). In practice, lack of resources has limited the enforcement of these provisions.

This drive dramatically increased foreign direct investment (FDI) from $12.8 million in 1986 to $83 million in 1998 (Addy, 1998). Gold production eventually overtook the 1960 peak levels, and reached a record high of 2,481,635 ounces in 1998. By 1994, gold exports generated the highest export earnings (about 45% of total earnings), surpassing cocoa, which had been the leading commodity for export earnings (Akabzaa and Darimani, 2001).

However, this increased production had negative consequences on the environment. The surface mining technologies used to extract rainforest gold led to annual deforestation rates of about 2 million acres. By 2001 over 60% of the rainforest in Wassa West District (a typical gold mining district) was lost to gold mining activities (Tockman, 2001). It is estimated that only 12% of the country's rainforest remains, with surface gold mining the main cause of deforestation (Ismi, 2003).

Ghana's extremely heterogeneous tropical rainforest provides a range of benefits. For example, it is estimated that more than 75% of protein in West Africa come from bush meat (Asibey, 1974; Benhin and Barbier, 2004). The bush meat trade supports about

300,000 people in rural areas, out of which 270, 000 are self – employed hunters. Annual harvest is estimated at 385,000 tons, worth $350 million.

Traditional medicines are derived from roughly 2000 plants (Zhang, 2001) which are also exported to Europe for the production of medicine (Benhin and Barbier, 2004). Furthermore, many forest products are used as raw materials in household and local production of baskets, furniture, roofing materials, musical instruments, jewelry, hunting tools, traditional drums, and other items. Major rivers such as the Birim, Pra, Ankobra, Bonsa Offin, Densu, and Tano, which provide drinking water to many towns and cities, are fed by rivers and streams that run through all the forest reserves (Anane, 2003).

The Ghanaian forest is replete with several rare species of fauna and flora, the populations of which are declining due to rapid destruction of forest habitats. Some of the rare animal species include giant forest hogs, primates, bongo, small antelopes, small bats and rodents, and birds. In addition, forest elephants disperse seeds of important timber species and create tracks for white-breasted guinea fowls. The International Union for Conservation of Nature and Natural Resources (IUCN) database has recorded ten timber species in Ghana earmark for conservation concern (Benhin and Barbier, 2004). Unfortunately, these benefits are completely overlooked when concessions are granted to mining companies. The surface mining method used by the gold mining firms in Ghana removes the rainforest where the deposits are found, leaving open pits and valleys (Akabzaa and Darimani, 2001). After mining, the land is typically no longer usable for agriculture. As noted earlier, the nation's rainforest provides infinite non-timber forest products such as provision of wild fruits, tubers, and cereals for human consumption.

Although licenses have not been issued to mining companies in some of the forest reserves such as Asenanyo, Offin shelterbelt and others, there is visible evidence that illegal miners (Galamsey operators) have taken over portions of these forest reserves and prompt action is required to stop their activities. One serious problem facing the fringe communities is that the illegal miners wash their products in the Offin River without recourse to the use of ISO 14001 standards which guide legal mining companies internationally. This may pose a serious threat to the health and safety of the fringe communities. The recent flooding of some districts in Eastern Region such as Atiwa, Akim Oda, Kwaebibrem and West Akyem in July 2011 caused by excessive drainage of water into the Birim River has been partly attributed to the "galamsey" mining operations in the area. This was collaborated by the Okyehene Nana Amoatia Ofori Panin when the President of the Republic, John Evans Atta Mills visited the area on the 25th of July 2011(www.myjoyonline, 25thjuly 2011).This phenomenon raises a lot of concern about the activities of galamsey operators. Concerted efforts by all stakeholders are needed in finding a lasting solution to the menace. This situation calls for a review of the policy on mining and also call on the government to increase budgetary allocation for the implementation of the policy. In spite of the environmental concerns raised by United States of America and other multinational Donor Agencies, on the issuance of mining permit to Colorado based Newmont Mining Company to carry out mining operations in the Ajenjua Bepo Forest Reserve, the government of Ghana still went ahead to do so. This destructive mine project would create an open-pit in a Forest Reserve, threaten water sources, and displace around nine thousand people from their homes, lands, or livelihoods (Ghana news agency, 2010).

Communities in Ghana have expressed great concern about the Akyem project, and their concerns have already stalled the mine project several times. Wassa Association of communities Affected by Mining (WACAM) and other community groups have protested over the company's plan to mine in a Forest Reserve, potential impacts on water supply, loss of access to land, and inadequate compensation plans for displaced communities. Newmont has already displaced some community members. In total, over a thousand people would lose their lands and homes, and thousands more would lose their agricultural lands. The mine would destroy approximately 340 acres (140 ha) of tropical forest and a quarter of the forest left in the Ajenjua Bepo Forest Reserve. In 2009, the project gained notoriety when it caused Newmont to receive the Public Eye Award for irresponsible practices (Ghana news agency, 2010).

Newmont has yet to adequately assess the impacts of the project and never accounted for serious technical and biodiversity concerns expressed by civil society groups (Ghana news agency, 2010). ~~In 2008,~~ independent reviews of the draft mine plans by the Center for Science participation and Earth Works revealed that the project had failed to plan to adequately line the waste storage areas or to reduce the threat of cyanide and other toxic acid mine drainage contamination. The company also neglected to thoroughly survey and accurately assesses impacts on biodiversity. The project's impact statements also neglected to consider a smaller surface or underground mine for the project in order to destroy less land. Mining has already destroyed most of Ghana's forest cover and only 12% of this remains. At independence in 1957, Ghana had a forest estate of about 8.3 million hectares of which only 1.2 million is left today. Ten to twelve thousand people depend on the forest reserves directly for their food and livelihood. Rivers and streams in the reserves feed into major rivers that supply water to many villages, towns and cities. Mining requiring use of toxic Chemicals will destroy the water bodies that provide drinking water for millions of people. The forest reserves are also considered globally significant for their biological diversity; they Contain over 700 types of tropical trees and many endangered species including 34 species of plants, 13 mammals, 23 butterflies and 8 birds. Trees do not only provide food for man, but also medicine to treat all kinds of diseases. Trees have gone a long way in helping to save the existing problem of climate change. One percent of African Forest is cleared each year. From 2000 to 2005, Africa lost 10 million acres of forest land a year, up from 9 million a decade earlier. The forest contributes to over 6% of the nation's Gross Domestic Products (GDP) annually. It also provides employment to about 100,000 in Ghana (Marfo, 2010). If the current rate of forest degradation is not checked, some researchers have predicted that many Ghanaians in the forestry sub sector including artisans will lose their jobs (Marfo, 2010). Mining in forest reserves will aggravate the already alarming rate of forest degradation in the country and destroy on freshwater systems and watersheds, which are already targets for conservation, as well as the entire ecosystem and biodiversity. The forest is not only a source of timber for commercial exploitation but also a collection of biodiversity required for human existence in the tropics like Ghana.

1.2 General Objectives

- To evaluate the effects of artisanal mining on changes in land cover, water quality and soil fertility in the Tano Offin extension forest reserve.

1.3 Specific Objectives

- To determine the levels of As, Cd, Pb, Fe and Zn in soils from the affected mining area and unmined area within the catchment area.
- To assess the levels of As, Cd, Pb, Fe and Zn in water samples from the Subin River within the catchment area.
- To determine the levels of As, Cd, Pb, Fe and Zn in sediment from the Subin River within the catchment area.
- To determine the changes in land cover / vegetation cover using GIS and remote sensing.

1.4 Justification

Mining activities have been in existence in the country since years, but has never posed any threat to our forest reserves. Nevertheless the emergence of more mining companies seems to pose a threat, not only to a section of the economy, but also, to Agriculture and biodiversity conservation. The activities of mining companies do not only reduce the number of trees in the country, but as well, increase the poverty level of affected people, create unemployment, and reduce the Gross Domestic Product (GDP). It is pathetic to note that the government is giving up the contribution of the forestry sector to the economy and the environmental benefits derived from the forest, for the 5% contribution of mining. The government seems to forget that deforestation, which causes desertification, does not only affect the climate, but also leads to drought, famine, and starvation, like what is being experienced in some African countries such as Niger.

The recent increase in illegal mining in forest reserves such as Atiwa in the Eastern region, Asenanyo, Offin shelterbelt and Desiri in the Ashanti region and that of the legal open cast mining in Ajenjua Bepo also in the Kade forest district in the Eastern region and others poses a great threat not only to biodiversity but also water quality and soil fertility. The irony is that, some of the forest reserves like Atiwa are globally significant biodiversity areas (GSBA) but most people including some professional foresters do not even know that it is among 36 important bird areas globally with 460 species of butterflies and 130 species of birds. Others who even know have little information on its ecosystem uniqueness.

If more research is not done on the dangers associated with mining in these forest reserves, the damage to biodiversity in future could be irreparable. The Tano Offin Extension Forest Reserve was chosen as the study area because of its richness with respect to biodiversity and also the Subin River within the forest reserve where the miners wash their gold contains a lot of fish species which is consumed as delicacy by the fringe communities. Heavy metals contamination of this river through mining must be of great concern because of its health implications. Scientific researchers must be encouraged to undertake research in the area of problems associated with mining in forest reserves so that their findings could be employed as a spring board data base for use at educational platform to sensitize people about the dangers mining poses to forest resources. This new forms part of the motivation for the project reported in this thesis.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mining and water quality

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. There is growing public concern about the condition of fresh water in Canada. Mining affects fresh water through heavy use of water in processing ore, and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which we all depend. Water has been called "mining's most common casualty" (British Columbia, 1993).

There is growing awareness of the environmental legacy of mining activities that have been undertaken with little concern for the environment. The price we have paid for our everyday use of minerals has sometimes been very high. Mining by its nature consumes, diverts and can seriously pollute water resources. Mining can deplete surface and groundwater supplies. Groundwater withdrawals may damage or destroy streamside habitat many miles from the actual mine site (British Columbia, 1993).

In Nevada, the driest state in the United States of America, the Humboldt River is being drained to benefit gold mining operations along the Carlin Trend. Mines in the northeastern Nevada desert pumped out more than 580 billion gallons of water between

1986 and 2001 – enough to feed New York City's taps for more than a year. Groundwater withdrawn from the Santa Cruz River Basin in Southern Arizona for use at a nearby copper mine is lowering the water table and drying up the river (British Columbia, 1993).

A study by Armah *et al.* (2010) in Tarkwa Ghana on water bodies revealed that most of the water bodies in the study area have elevated mean levels of As, Zn, Pb and Fe which were above WHO and Ghana EPA guideline values.

High concentrations coupled with high coefficients of variation suggest anthropogenic sources for arsenic, iron, mercury, zinc and lead. Some of the water bodies sampled including the alternate source of water have low pH values. The turbidity values were higher than the WHO and Ghana Environmental Protection Agency (GEPA) permissible limits.

To extract minerals for use by industries, the Earth's crust must be disturbed (Howard and Ramson, 1998). On this crust are living things whose life patterns are disturbed when mining is undertaken, resulting in a loss of biodiversity. Mines, both active and inactive, are potential water contamination sources (Davis, 1966). The Mining excavations create direct connection between ground water and the land surface. Oxidation of exposed minerals can lead to acid mine drainage (Domenico and Schwartz, 1990). Leaching of heavy metals is also a threat. Drainage of materials from abandoned mines can act as ground water contamination source for years after mining operations have stopped (Freeze and Cherry, 1979).

Both anthropogenic pressures and natural processes account for degradation in surface water and groundwater quality (Carpenter *et al.,* 1998). In Ghana, contaminations of surface and ground water bodies have particularly been experienced in gold mining communities (Davies- colley *et al*., 1994; Kuma, 2007; Manu *et al.,* 2004; Kuma and Younger, 2004; Obiri, 2007). Gold mining has played a significant role in the socioeconomic life of Ghana for the past hundred years (Akabzaa *et al,*. 2005).

Heavy metal pollution within mining communities of Ghana has been extensively studied (Adimado and Amegbey, 2003; Akabzaa *et al.,* 2005; Carbo and Serfor-Armah, 1997; Essumang *et al*., 2007; Hilson, 2002; Manu *et al.,* 2004; Obiri, 2007; Yidana *et al.,* 2008). The application of multivariable statistical methods offers a better understanding of water quality for interpreting complicated data sets (Zhang *et al*., 2009). However, wide-ranging applications of different multivariable statistical methods and sources apportionment have not been fully explored in surface and ground water studies in Ghana (Yidana *et al.,* 2008). Multivariate statistical techniques have become widely accepted in water quality assessment and sources apportionment of water bodies over the last ten years (Vega *et al*. 1998; Wunderlin *et al*., 2001; Grande *et al*., 2003; Simeonov *et al.,* 2003; Pekey *et al*., 2004; Singh *et al*., 2004; Astel *et al*., 2006; Kowalkowski *et al*., 2006; Shrestha and Kazama, 2007).

On March 21, 2011 a research commissioned by Wacam, human rights and mining advocacy Non-Governmental Organization (NGO), on water quality in mining communities around Obuasi and Tarkwa revealed that 250 rivers had been polluted by cyanide and heavy metals. The mining operations of Golden Star Resources (Bogoso/Prestea) Mine has polluted and destroyed six rivers around Dumase namely Aprepre; Wurawura; Akyesua; Pram; Nana Nyabaa and Nsu Abena and two rivers in Twigyaa.

The research further revealed that the operations of AngloGold Ashanti Obuasi Mine has polluted about 12 rivers in Sanso and many communities in Obuasi and areas such as Odumase and Fenaso did not have access to clean water. The report stated that mining activities of AngloGold Ashanti Iduapriem Limited has completely dried up and buried rivers Awura, Atibri and Betihini with mine rock waste while cyanide seepage from the Tailings Storage Facilities of the Company has polluted rivers such as Achofoe, Angonaben and Bromenasu.

According to Wacam, seepage from the tailings storage facility of Anglogold Ashanti Iduapriem Limited for example necessitated the closure of two such facilities by Ghana Environmental Protection Agency (EPA) in February 2010. The activities of "Galamsey" operators also led to the pollution of rivers and water bodies. Wacam said mining was depriving mining communities of access to clean water and this had implication for the health status of the people since the ingestion of cyanide and heavy metals in rivers for long periods could lead to many serious health problems for the people living in mining communities.

"The then Environmental Protection Council (EPC, 1991) (now Environmental Protection Agency (EPA) of Ghana) estimated that freshwater resource in Ghana amounted to 40 million acre from rainfall, rivers, streams, spring and creeks, natural lakes impoundments and ground water from various aquifers (Wacam, 2010). Availability of potable water to the population is an indicator of social and economic well – being. "The rate at which mining operations are polluting water bodies in Ghana is a source of serious concern. The practice where Ghana Manganese Company used to discharge manganese waste into river Bonsa which was distributed by Ghana Water Company to consumers in Tarkwa and its environs became a source of conflict between communities around Bonsa and the Company. There were Newspaper reports in 2005 that Newmont Ghana Gold Limited, Ahafo mine, had a facility that discharged fecal matter into river Asuopre which served the needs of communities in the area. "Sometimes, effluents which contain cyanide and heavy metals from the Tailings Storage Facilities of mining companies which seep into surface and ground water occur unnoticed for a long time (Wacam, 2010) Again, the activities of "Galamsey" operators also pollute rivers and water bodies. (EPA, 2011)

A study conducted by Byambaa and Todo (2011) in Mongolia revealed that though the mining industry was growing at a faster pace as predicted by the International Monetary Fund (IMF), leading to double digit economic growth, its direct impacts on the environment and in particular on the health of the country's river systems were negative.

The research further revealed that, a study on Surface Water Census conducted by the Ministry of Nature and Environment of Mongolia in 2007, showed that 900 streams and small rivers have gone dry or have completely disappeared between 1992 and 2007 due to outdated gold extraction methods such as dredging and river diversion.

It was also shown that there is 13% loss in river and streams, 15% in springs, and 19% in lake to compare with the previously conducted Census in 2003. Erosion from waste rock piles or runoff after heavy rainfall often increases the sediment load of nearby water bodies. In addition, mining may modify stream morphology by disrupting a channel, diverting stream flows, and changing the slope or bank stability of a stream channel. These disturbances can significantly change the characteristics of stream sediments, reducing water quality (Johnson, 1997)

Higher sediment concentrations increase the turbidity of natural waters, reducing the light available to aquatic plants for photosynthesis (Ripley, 1996). In addition, increased sediment loads can smother benthic organisms in streams and oceans, eliminating important food sources for predators and decreasing available habitat for fish to migrate and spawn (Johnson *et al* 1997). Higher sediment loads can also decrease the depth of streams, resulting in greater risk of flooding during times of high stream flow (Mason, 1997).

Mercury used in gold mining in the Amazon Basin in Brazil contaminated vast areas of Amazon river with about 200 tons being deposited per year in the Basin(Malm *et al.*1990). (Grosser *et al.*, 1994) also reported of similar mercury contamination in gold mining area in Southern Colombia. Contamination of water bodies has degraded aquatic ecosystems especially in most of the industrialized world, resulting in altered fish populations and in some cases, complete loss of fish (Down & Stocks, 1978; Welcomme, 1992).

Chemicals used in mining operations may consequently affect man through the food chain such as occurred in Minamata Bay in Southern Kyushu, Japan, due to discharge of mercury-laden effluents (Fujiki, 1980). Apart from chemicals, large quantities of solids are suspended in the water column due to mining operation, especially in alluvial dredging. Suspended solids affect biological resources in various ways (Chansang, 1988).

A study by Biney and Degraft –Johnson in (2005) revealed that, alluvial dredging practiced in certain parts of River Offin has resulted in the release of residual chemicals not only in the dredging area but also further downstream. It also showed that high amounts of heavy metals, especially Pb and Fe have been released in to the Offin River.

2.1.1 Types of water pollution from mining

There are four main types of mining impacts on water quality

1. Acid Mine Drainage

Acid drainage is one of the most serious environmental impacts associated with mining. It occurs when sulphide-bearing minerals, such as pyrite or pyrrhotite, are exposed to oxygen or water, producing sulphuric acid. The presence of acid-ingesting bacteria often speeds up the process. Acidic water may subsequently leach to other metals in the rock, resulting in the contamination of surface and groundwater. Waste rock piles, other exposed waste, mine openings, and pit walls are often the source of acidic effluents from a mine site. The process may occur rapidly and will continue until there is no remaining sulphide. This can take centuries, given the large quantities of exposed rock at some mine sites. Although the process is chemically complex and poorly understood, certain conditions can reduce likelihood of its occurrence. For example, if neutralizing minerals are present (e.g., carbonates), the prevailing pH environment is basic, or if preventative measures are taken, then acid drainage is less likely to occur (Schmiermund and Drozd, 1997)

Acid drainage impacts aquatic life when acidic waters are discharged into nearby streams and surface waters. Many fish are highly sensitive to even mildly acidic waters and cannot breed at pH levels below 5. Some may die if the pH level is less than 6 (Ripley, 1996). Predicting the potential for acid drainage can help determine where problems may occur. Methods vary from simple calculations involving the balance of acid generating minerals (e.g., pyrite) against the existence of neutralizing minerals (e.g., calcium carbonate) to complex laboratory tests (i.e., kinetic testing). However, even laboratory-based tests cannot be relied upon to accurately predict the amount of metals that will be leached if acid drainage occurs, because of the differences in scale and composition that occur when samples are analyzed ex situ (De Rosa and Lyon, 1997).

2. Heavy Metal Contamination and Leaching

Heavy metal pollution is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come into contact with water. These metals are leached out b water run-off and carried downstream over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is particularly accelerated in the low pH conditions such as are created by Acid Mine Drainage. (De Rosa and Lyon, 1997)

3. Processing Chemicals Pollution

This kind of pollution occurs when chemical agents (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to humans and wildlife. (De Rosa and Lyon, 1997)

4. Erosion and Sedimentation

Mineral development disturbs soil and rock in the course of constructing and maintaining roads, open pits, and waste impoundments. In the absence of adequate prevention and control strategies, erosion of the exposed earth may carry substantial amounts of sediment into streams, rivers and lakes. Excessive sediment can clog riverbeds and smother watershed vegetation, wildlife habitat and aquatic organisms (De Rosa and Lyon, 1997).

2.2 Mining and soil fertility

Ecosystems are affected by the physical perturbations of mining operations, as well as the chemical alterations in soil and water. Mining activities vary, but can include soil compaction and conversely, removal of the topsoil. These alterations disrupt nutrient dynamics by minimizing the availability of nitrogen and phosphorus, lower the pH through the acidification of the soil and can introduce toxic metals and acids(Elkins *et al*, 1984) Depending on the scale and nature of the mining operation, these effects can be localized to the location of the mining or, through local hydrology, can extend to nearby aquatic systems, such as stream, wetlands and lakes (Elkins *et al.*, 1984).

Soil compaction is one of the most severe effects mining has on ecosystems. Compaction is often the result of bulldozers and other pieces of large machinery moving across the landscape, often for many years while the mining is still in operation. As the soil is compacted, there are fewer pore spaces for oxygen and water to move through the soil profile, minimizing the potential for plant establishment. Also, as water is unable to percolate down through the soil, it inevitably will move across the surface of the landscape and increase the possibility of contaminating nearby aquatic systems, such as wetlands, streams and lakes. Conversely, the topsoil, which is typically the top

30 cm of soil, can be mined. This lowers the overall fertility of the soil and increases water movement through the soil and landscape. (Elkins *et al.*, 1984).

Mining operations often contaminate the soil with toxic heavy metals and acids. Acids can lower the pH of the soil, preventing plants and soil microorganisms from thriving, and can also react with various minerals in the soil that are required by plants, such as calcium and magnesium. The hydrogen ions from the acid absorb the soil particles, preventing other nutrients required by plants to remain in the soil. These chemical alterations can interact with soil compaction. Because water isn't moving through the soil profile, some of the metals and acids can be carried away by the water, extending the mining effects throughout greater portions of the landscape. Elkins *et al.* (1984), reported that the addition of organic matter to mined lands can increase water retention in the soil, as well as the microbial process of nutrient accumulation and processing, potentially offsetting and minimizing the ecosystem effects from mining operations.

Ecosystems function because of the continuing interaction between the biotic (living) and abiotic (nonliving) components. Because each component affects how all others function, the depletion of soil nutrients and the acidification and compaction of the soil profile can limit the amount of plant life that can colonize a location. With reduced plant biomass, less carbon is being processed via photosynthesis, which leads to less oxygen production, less standing biomass and reduced transfer and cycling of nutrients. Also, plants are key regulators in an ecosystem's water cycling as they utilize moisture in photosynthesis and transpire water vapor back into the atmosphere. As such, the absence of plants in an ecosystem can inhibit the multiple functions and services commonly provided. (Roberts *et al.*, 1988).

Nutrient mining across Africa ranges from 9 kg NPK/ha per year in Egypt to 88 kg in Somalia in East Africa. Nitrogen (N) Losses range from 4.1 kg/ha yearly in South Africa to 52.3 kg in Somalia in the Sudano-Sahelian of East Africa. Losses of phosphorus range from none or minor losses in the Mediterranean and arid North Africa to 9.2 kg/ha per year in Burundi and Somalia in East Africa. Potassium losses range from 6.5 kg/ha per year in Algeria to 30.4 kg in Equatorial Guinea and Gabon in humid Central Africa. (Henao and Baanante, 2006).

The main factors contributing to nutrient depletion are loss of nitrogen and phosphorus through soil erosion by wind and water, and leaching of nitrogen and potassium. Nutrient losses due only to erosion in African soils range from of 10 to 45 kg of NPK/ha per year. If erosion continues unabated, yield reductions by 2020 could be from 17% to 30%, with an expected decrease of about 10 million tons of cereals, 15 million tons of roots and tubers, and 1 million tons of pulse (Henao and Baanante, 2006).

Based on nutrient mining estimated by country, total annual mining of nutrients (NPK) is about 800,000 t for humid Central Africa; 3.0 million t for the humid and sub-humid West Africa; 600,000 t for the Mediterranean and arid North Africa; 1.5 million t for the sub humid and Mountain East Africa; 1.7 million t in the Sudan Sahel; and 1.4 million t in sub humid and semi- arid Southern Africa. Total nutrient mining in the sub-Saharan region may be about 8 million tons of NPK per year (Henao and Baanante, 2006).

The declining fertility of African soils because of soil nutrient mining is a major cause of decreased crop yields and per capita food production in Africa and, in the mid to long term, a key source of land degradation and environmental damage. (Henao and Baanante, 2006).

Soil organic matter dynamics is recognised as a key ecosystem process regulating ecosystem sustainability (Hart *et al.,* 1990). At Weipa (North Queensland, Australia), routine soil stripping and replacement operations for bauxite mine rehabilitation markedly reduce the storage and activity of soil organic matter in the replaced soil surface compared with the undisturbed areas from whence it came (Grundy, 1980; Jehne and Thompson, 1983; Foster, 1986). Concerns over possible links between this organic matter loss and the long-term sustainability of rehabilitated ecosystems at Weipa led to detailed investigations of the effects of routine soil stripping and replacement operations on the short-term dynamics of soil organic matter (Schwenke *et al.*, 2000).

Measurements of the whole replaced soil profile showed that the difference between undisturbed areas and immediately (not stockpiled) replaced soils was principally caused by dilution of topsoil rich in organic matter with subsoil, low-grade bauxite, and ironstone (Schwenke *et al.*, 2000). However, despite retention of the original organic matter within the profile, the imbalance between accelerated organic matter decomposition and reduced organic inputs during vegetation establishment did lead to significant losses of soil organic matter storage and activity in the first few years after rehabilitation (Schwenke *et al.,* 2000). This imbalance in the organic matter cycle should reverse with increasing age of rehabilitation as post-mining soil and vegetation development are interdependent processes (Schafer and Nielsen, 1979).

Assessment of the sustainability of post-mining ecosystems requires investigation of both vegetation development, (Roberts, 1994), and soil organic matter development, the latter in terms of quantity, quality, and activity. Qualitative assessments of soil organic matter may be made through physical fractionations (particle density or particle-size separations) which separate organic matter into biologically and chemically distinct fractions based on their level of association with soil minerals (Christensen, 1992). Organic matter quality can also be assessed in terms for nutrient supply, particularly nitrogen, through biological indices which integrate chemical, physical, and biological aspects of soil quality (Sparling, 1997).

Mineral extraction process must ensure the return in productivity of the affected land. A study by Ghose (2004) showed that in India, every tone of coal extracted by surface mining methods damages a surface area of 4ha. When results of soil samples were compared with samples collected from stockpiles and using component size analysis, the study further revealed that sand particles increased, silt and clay particles decreased in the unmined soil.

This trend may be because of increased erosion. Dominance of sand particles indicated low stability of aggregates and consequently a high rate of infiltration. The average infiltration rate was found to be intermediate in nature.

The infiltration rate or water intake rate is initially high, but decreased with time. Infiltration also decreased, approaching to a steady infiltration rate with time. The high bulk density of dumps was evidently influenced by the use of machinery. This has serious implication for subsequent change of soil properties because gaseous diffusion is made more difficult. Such high bulk density would pose restrictions on the growth of deep rooted plants and may be one of the reasons of cessation of plant growth at the shrub stage.

The porosity was found to be less than that found in unmined soil due to compaction during excavation and as a result, plants cannot grow smoothly. For good plant growth, bulk density should be below 1.4g/cm^3 for clays and 1.6 g/cm^3 for sand. The most useful water parameters of the soil relating to plant growth, are moisture content, field capacity, WHC and the wilting coefficient that were found to be lower in the soil dump samples than those of unmined soil and decrease slightly with age due to the decrease in OC. A decrease in soil WHC as a result of storage is also reported.

Greater value of wilting coefficient indicates the deficiencies of plant growth materials. The pH of soil dumps was acidic due to leaching of basic cations. Under such acidic conditions, ion toxicity, high availability of Al and Mn and availability of Mo are the principal deterrents of plant growth.

For plant nutrient availability, optimum pH is 6.5 to 7.5. Electrical conductivity decreased with increasing age of soil dump but was higher than the surrounding unmined soils. A mixing of lower surface horizon may cause this. The cations exchange capacity of soil dumps was lower than unmined soils and decrease with increasing age of the soil dumps. Again, the mixing of the lower soil horizon may cause this. Similar trends were also observed for exchangeable Ca, Mg, Na and K (Ghose, 2004).

2.3 Mining and sedimentation

2.3.1 Sediment Contamination

Mining processes can result in the contamination of associated sediments in receiving streams when dissolved pollutants discharged to surface waters partition to sediments in the stream. In addition, fine grained waste materials eroded from mine sites can become sediments. Specifically, some toxic constituents (e.g., lead and mercury) associated with discharges from mining operations may be found at elevated levels in sediments, while not being detected in the water column or being detected at much lower concentrations. Sediment contamination may affect human health through the consumption of fish and other biota that bio-accumulate toxic pollutants. Elevated levels of toxic pollutants in sediments also can have direct acute and chronic impacts on macro invertebrates and other benthic organisms. Finally, sediment contamination provides a long-term source of pollutants through potential re-dissolution in the water column. This can lead to chronic contamination of water and aquatic organisms. Currently, no national sediment standards/criteria have been established for toxic pollutants associated with mining operations. An ecological risk assessment may be an appropriate tool to evaluate sediment impacts (US EPA, 2000).

Exposed materials from mining operations, such as mine workings, wastes, and contaminated soils, may contribute sediments with chemical pollutants, including heavy metals. Contaminated sediments in surface water may pose risks to human health and the environment as a persistent source of chemicals to human and aquatic life and those non-aquatic life that consume aquatic life. Human exposure occurs through experiencing direct contact, eating fish/shellfish that have bio-accumulated toxic chemicals, or drinking water exposed to contaminated sediments. Continued bioaccumulation of toxic pollutants in aquatic species may limit their use for human consumption. Accumulation in aquatic organisms, particularly benthic species, can also cause acute and chronic toxicity to aquatic life. Finally, organic-laden solids have the effect of reducing dissolved oxygen concentration, thus creating toxic conditions. (US EPA, 2000).

2.3.2 Sedimentation of surface water

Because of the large land area disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion is a primary concern at mine sites. Erosion may cause significant loading of sediments and any entrained chemical pollutants to nearby streams, especially during severe storm events and high snowmelt periods.

Historic mining and mineral processing sites may have discharged wastes directly into surface waters. This has been particularly the case with tailings that historically in many areas were deposited directly into surface waters or placed at the edge of surface waters where erosions would transport the tailings to the surface waters. (US EPA, 1976).

Many experiments have quantified the increase in sediment caused erosion on both active and abandoned surface mines. For instance, in studies of mined and unmined watershed in Kentucky(leatherwood Creek and Bear Branch), the impact of surface mining on both the suspended sediments and the bed loads sediments in the streams was investigated. The study revealed that there is continuous sediment generation in areas affected by surface mining after abandonment.(US EPA, 1976).

Another study in Beaver Creek Basin in Kentucky found that the annual sediment production from land affected by surface mining was 42 tons/acre, 1000 times higher than the yield of sediment from an unmined watershed (US EPA, 1973). Reductions in water clarity caused by suspended sediment severely reduce the amount of light available for photosynthesis thereby affecting the growth of benthic algae (Davies-Colley *et al.*, 1992).

Sediments iron-floc can ~~reduce~~ invertebrate habitat within stream beds by clogging interstitial spaces and consolidating bed materials (Letterman & Mitsch, 1978; Ryan, 1991). Acidification of mineralized deposits may result in precipitates of iron-floc forming on the streambeds on receiving water. (Letterman& Mitsch, 1978; Ryan, 1991).

2.4 Mining and biodiversity conservation

Biodiversity can be defined as "The variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecological systems" (UNEP, 1994). Troubles are mounting in one of Earth's most beautiful landscapes. Deep in the Venezuelan Amazon, among ancient forested tabletop mountains known as tepuis, crystalline rivers, and breathtaking waterfalls, illegal gold miners are threatening one of world's largest remaining blocks of wilderness, one that is home to indigenous people and strikingly high levels of biological diversity (Butler, 2006).

In the southern Venezuelan state of Bolivar, near the border of Brazil and Guyana in the Caroni and Caura river basins, illegal gold miners are threatening the existence of the Tropical rainforest in the Caura basin which is the second largest river draining the Guiana shield, highlands that separate the Orinoco and Amazon river basins.

Characterized by lowland Tropical rainforest, the Caura basin has impressive levels of biological diversity—2600 vascular plant species, 168 mammal species, 475 bird species, 34 amphibian species, 53 reptile species and 441 species of fish and stores some 700 million metric tons of carbon, or about the amount released by 162 million cars a year (Butler, 2006).

Miners rely heavily on hydraulic mining techniques, blasting away at river banks with high-powered water cannons and clearing forest to expose potential gold-yielding gravel deposits. Gold is usually extracted from this gravel using a sluice box to separate heavier sediment and mercury used to amalgamate the precious metal. While most of the mercury is removed for reuse or burned off, some invariably ends up in rivers. A number of threats to biodiversity in Australia have been identified, namely, habitat modification and fragmentation, overexploitation of species, the impact of introduced species or genes, and pollution of soil, water and the atmosphere (BDAC, 1992).

All recognise the value of mineral wealth, but the concept of biological wealth has been slower to be accepted (Beattie, 1992). The activities of the minerals industry could potentially pose some major threats to biodiversity. Mining removes all of the biota within the active area and therefore halts the associated ecosystem functions and processes. The industry, however, has come a long way since its historical activities, and systems are now in place to ensure that steps are taken to restore biodiversity wherever possible. For example, prior to mining in Western Australia, the Departments of Minerals and Energy, and Conservation and Land Management review the resource potential and biodiversity values of pastoral leases including those where exploration and mining leases are taken out (Smurthwaite *et al.*, 2000).

Diamond mining has had a very heavy impact on the Namaqualand coastline and alluvial terraces of the lower Orange River Valley. Approximately two-thirds of the South African coastline, and almost all the Namibian coastline in this hotspot, have been mined for diamonds. This mining is now supplemented by the large-scale extraction of heavy minerals, including gypsum, marble, monazite, kaolin, ilmenite, and titanium, which threatens to vastly increase the impact of mining on the region's biodiversity (Conservation International, 2007).

Long term effects of mining in priority biodiversity areas or water catchments include devastating impacts on the future water security of South Africa, large scale loss of threatened vegetation types and potentially severe cultural and economic impacts on high-yield agricultural areas and tourism nodes. All of this ultimately impacts on the sustainable development of our country and the well-being of our people.

"While mining is an important component of the South African economy, it cannot override longer term, viable economic, social and environmental land uses. Restriction of rights is required in areas of biodiversity, hydrological and cultural/heritage priority, and these areas need to be communicated widely. Public consultation is also an important aspect of establishing locally important areas.

"Protecting areas of such critical value through voluntary avoidance of prospecting and mining is in the national interest and in line with a wide range of good governance and environmental guidelines. Therefore we call upon all mining companies and banks in South Africa were to consider the WWF(2011) list, avoid these key areas and promote the sustainable development of the nation's mineral resources (WWF, 2011).

The exploitation of coltan created a well-publicized late 20th century conservation crisis throughout eastern Democratic Republic of Congo, including the range of globally important and endangered species, such as Graueri's gorilla, the eastern chimpanzee, and the forest elephant. A boom and bust cycle of pricing lured thousands of people away from agriculture (reducing food security) into mining camps where anarchy was common (banditry, prostitution, disease, deaths from pit collapse, etc.) and has been identified as an important factor in fueling the civil war in Congo. This "coltan rush" therefore created conditions in which thousands of farmers abandoned their fields and become miners, selling their ore most often to Ugandan and Rwandan commercial interests, who moved the ore out of Congo and delivered it via flights from the Kigali and Entebbe to large multinational companies based in North America, Europe and Russia.

Coltan mining creates direct environmental damage related to the destruction of streambeds, pole cutting, and firewood collecting. However, more significant environmental damage results from the large camps of men (and armed guards) who poach local wildlife to maintain their mining camps. In 2001, it was estimated that over 10,000 people moved into Kahuzi-Biega National Park and 4000 into Okapi Wildlife Reserve in order to follow this coltan rush, effectively eradicating much native fauna near their mining camps (IUCN Web-based report, 2001).

The Tantalum-Niobium International Study Center (T.I.C.), the industry organization representing producers, processors and consumers of tantalum and niobium around the world, stated that it deplored the reported activities of illegal miners in the Kahuzi-Biega National Park and the Okapi Wildlife Reserve in DRC. A more realistic view of this, however, is that neither they nor at present, is it actually possible to physically determine coltan sources (despite some work with niobium/tantalum percentages as signatures for particular sources), thus analogous to the ivory trade, suppliers can mix many different sources together, masking "tainted" coltan.

Inevitably, market forces were probably the most important factor that heralded the "end" of the coltan rush, and its most devastating consequences for the environment in eastern DRC. With the crash of technology-related stocks, the reduced production of electronic materials, and finally, cheaper sources (and politically less problematic) of production-mined coltan from Australia, coltan prices eventually collapsed in late 2002 and 2003 dropping in price from as high as $600/kg in 2001 to the 2004 price of <$50/kg). This resulting in the majority of coltan miners turning to other mining activities or bush meat and animal trafficking, and abandoning the "coltan rush" ((IUCN Web-based report, 2001).

The island of Palawan in the Philippines is endowed with beautiful hills and mountains, lush forest vegetation, rivers/creeks with crystal clear water, rich biodiversity and fertile lowland providing bountiful harvest. The major sources of livelihood of the local communities including indigenous people are agriculture and forest products. Ecotourism has become a potential livelihood in the entire island because of the experiences in Puerto Princesa City where its Mayor banned mining and developed instead, several ecotourism sites which brought millions of pesos in gross domestic products and increased the earning capacity of its constituents (Emelina, 2011).

The mining act of 1995 however allowed mining to be conducted even in key biodiversity sites such as in Southern Palawan. The mining company operating in this area boasts of having planted and grown 800,000 trees in their 238 hectares of mined-out land. However, these species of trees could grow in toxic land because they are capable of absorbing heavy metals. If the miners think this is good, on the contrary, this is even worse because the toxic heavy metals are transferred from the layers of soil into the surface through the bodies of these colonizer trees. These plants will eventually contain toxic heavy metals that could affect herbivorous animals and instead of restoring biodiversity, will cause death to other living organisms that are connected through the food chain. When branches and leaves of these plants die and fall to the ground, their heavy metal contents will be release and scattered onto the surface soil. This is not the way to store the toxic metals (Emelina, 2011).

Naturally growing trees in mineralized areas are not necessarily the aggressive metal absorbers, but could tolerate a small amount of metals. When mining disturbs the layers of soil and rocks, the process scatters toxic heavy metals contained in these layers and become mixed with loosened soil and tailings. Through mining, these metals become concentrated in surface soil and brought downslope by heavy rains and typhoons in tropical environments. In island ecosystem with steep slopes, these toxics reach the sea and kill marine organisms in marine habitats such as the coral reefs, seaweed and sea grass beds that provide nursery grounds and food for various fishery resources.

Metals provide the rocks and soil strength so that trees, through their roots could get a strong foothold on the ground. Thus, when metals are intact, the trees do not easily topple down in places regularly visited by typhoons. Trees replenish groundwater through the watershed effect. They provide an effective shield to smaller trees and plants that need only small amount of sunlight. In this way, moisture is conserved; temperature is controlled to an ideal condition creating comfortable habitats of biodiverse animals and plants. This is how biodiversity could be sustained.

Biodiversity cannot be sustained when trees carry toxic heavy metals that kill living organisms because such poison can transfers through the food chain when living organisms eat and are eaten. It is really naïve of miners to think that by just planting trees that could absorb and survive in highly toxic and artificially metal-enriched soil, the solution to pollution resulting from mining activities, is solved (Emelina, 2011).

Where acid is not produced naturally, mining activities necessitate the addition of acid such as sulfuric acid and/or cyanide to extract the metals such as what the current mining in Southern Palawan is doing. These metals/minerals normally found in these areas that are associated with laterite soil are highly toxic to living organisms such as nickel (Ni), Aluminum (Al), cobalt (Co), chromium (Cr), manganese (Mn), copper (Cu), cadmium (Cd), and Zinc (Zn). Mining activities caused the downward movement of silt and tailings laced with toxic metals onto the croplands, into rivers/creeks and marine ecosystems through run-off, erosion, and landslides.

Laterite is a residual ore deposit resulting from the weathering of rocks and soil. Its parent rock is aluminum- and iron-rich igneous rock. Aside from this, nickel and cobalt deposits are also found in laterite soil developed from ferromagnesian-rich igneous rocks (Keller, 2000). Other metals such as iron, aluminum and chromium can also be found in association with nickel in laterite soil (Trolard *et al.,* 2000). In some places such as New Caledonia (Southeast Asia), nickeliferous goethite when heated, shows other metals associated with iron during subsequent dissolution. These are: Ni, Cr, Al, Co, and Mn (Landers and Gilkes, 2007). The impacts of some of these metals to plants and animals including humans based on several studies are as follows:

Nickel, above the natural tolerable level in soil caused reduction in yield of shoots of rye grass (Khalid and Tinsley, 1980). The species of Rice belongs to the family of grasses which is supposed to compose of sturdy plants. Nickel also reduced the growth of corn (Huillier *et al.*, 1996) and higher concentration of Nickel in the germinating seeds of cabbage, lettuce, millet, radish, turnips and wheat cause reductions in root elongation (Carlson *et al.,* 1991). Similarly, elevated levels of nickel in higher forms of flowering plants such as ~~rice for~~ instance, blocks cell division in the pericycle of roots, resulting in the inhibition of root branching (Seregin and Kozhevnikova, 2005). Likewise, the toxic effects of Cr on plant growth and development are in the germination and growth of roots, stems and leaves, hence; its yield. In addition, Cr causes harmful effects on photosynthesis, water relations and mineral nutrition by direct effects on enzymes and anti-oxidants (Shanker *et al.*, 2005). Hence, the abovementioned effects would definitely impact on plant growth and productivity.

The study of Hamoutene *et al.* (2000) observed that even iron ore leachate is also potentially toxic to fish such as salmon. In another study, manganese toxicity in plants include those observed for rice plant such as chlorosis (whitening) of young leaves, stunted plant, drying of leaf tips, reduced grain yield among other effects (Dobermann and Fairhurst, 2000). Iron also reduced root elongation (Ward *et al.,* 2008). In animals, chromium is a carcinogen and can alter their genes and high levels of Cr in aquatic ecosystem can damage the gills fishes. In an experiment by Hale *et al.* (1985). Heavy metals Cd, Cu, Zn, Mn, Co and Ni, when found together, also caused decreased in plant growth. Among the metals involved, this study observed that the most damaging was nickel.

Mining may result in additional indirect impacts that emanate far from the mine site. In order to provide charcoal for pig-iron smelters, Fearnside estimated that the Carajás project in the Brazilian Amazon would result in the deforestation of 72,000 hectares of forest per year over the 250-year life of the project (Fearnside, 1989).

The most obvious impact to biodiversity from mining is the removal of vegetation, which in turn alters the availability of food and shelter for wildlife. At a broader scale, mining may impact biodiversity by changing species composition and structure. For example, acid drainage and high metal concentrations in rivers generally result in an impoverished aquatic environment. Some species of algae and invertebrates are more tolerant of high metals and acid exposure and may, in fact, thrive in less competitive environments (Kelly, 1998). Exotic species (e.g., weedy plants and insect pests) may thrive while native species decline (Ripley, 1997). Some wildlife species benefit from the modified habitat provided by mines, such as bighorn sheep that use coal mine walls as shelter (MacCallum, 1989).

2.5 Mining and Heavy metal contamination

The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration (Lenntech, 2004). "Heavy metals" is a general collective term, which applies to the group of metals and metalloids with atomic density greater than 4 g/cm3, or 5 times or more, greater than water (Huton and Symon, 1986; Battarbee *et al.*, 1988; Nriaguand Pacyna, 1988; Nriagu, 1989; Garbarino *et al.,* 1995, Hawkes, 1997).

However, being a heavy metal has little to do with density but concerns chemical properties. Heavy metals include lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), and arsenic (As), silver (Ag) chromium (Cr), copper (Cu) iron (Fe), and the platinum group elements. Heavy metals occur as natural constituents of the earth crust, and are persistent environmental contaminants since they cannot be degraded or destroyed. To a small extent, they enter the body system through food, air, and water and bio-accumulate over a period of time. (Lenntech, 2004; UNEP/GPA, 2004). In rocks, they exist as their ores in different chemical forms, from which they are recovered as minerals. Heavy metal ores include sulphides, such as iron, arsenic, lead, lead-zinc, cobalt, gold, silver and nickel sulphides; oxides such as aluminum, manganese, gold, selenium and antimony. Some exist and can be recovered as both sulphide and oxide ores such as iron, copper and cobalt.

Environmental pollution by heavy metals is very prominent in areas of mining and old mine sites and pollution reduces with increasing distance away from mining sites (Peplow, 1999). These metals are leached out and in sloppy areas, are carried by acid water downstream or run-off to the sea. Through mining activities, water bodies are most emphatically polluted (Garbarino *et al.*, 1995; INECAR, 2000). The potential for contamination is increased when mining exposes metal-bearing ores rather than natural exposure of ore bodies through erosion (Garbarino *et al.*, 1995), and when mined ores are dumped on the earth surfaces in manual dressing processes.

Wells located near mining sites have been reported to contain heavy metals at levels that exceed drinking water criteria (Garbarino *et al.*, 1995; Peplow, 1999). Heavy metals can be emitted into the environment by both natural and anthropogenic causes. The major causes of emission are the anthropogenic sources specifically mining operations (Hutton and Symon, 1986; Battarbee *et al.*, 1988; Nriagu, 1989). In some cases, even long after mining activities have ceased, the emitted metals continue to persist in the environment. Peplow (1999) reported that hard rock mines operate from 5-15 years until the minerals are depleted, but metal contamination that occurs as a consequence of hard rock mining persist for hundreds of years after the cessation of mining operations.

Apart from mining operations, mercury is introduced into the environment through cosmetic products as well as manufacturing processes like making of sodium hydroxide. Heavy metals are emitted both in elemental and compound (organic and inorganic) forms. The metal content of the rivers is a consequence of: geochemistry of the rocks in the catchments area (metals released into the water by weathering); anthropogenic pollution (by waste inputs and atmospheric deposition); river chemistry (adsorption of metals ions to particles and other surfaces and particle deposition into the sediments) (Stumm, 1992).

A study by Senila *et al.* (2006) to investigate the influence of mining on heavy metal contamination in Crisul Alb River in Romania showed that part of metal content in Crisul Alb River is due to natural background (geochemistry of the rocks).The influence of geochemistry was determine by analyzing a sampling point unaffected by mining upstream from the mining activities. The sampling points directly affected by mining showed high content of metals and low pH values. This area showed an increase in concentration of Cu, Cd, Zn, Pb, Fe and Mn compared with the upstream.

Chon *et al.* (2001), assessed the heavy metal contamination and seasonal variations of heavy metals in soils, plants and waters in the vicinity of Daduk mine in Korea with aqua regia and 0.1 N HCL. The range and mean concentrations of Cd, Cu, Pb and Zn in surface soils extracted by aqua regia and 0.1 N HCl showed that, elevated levels of those metals extracted by aqua regia were found in samples of tailings, with average values of 8.57 Cd, 481 mg/kg Cu, 4,450 mg/kg Pb and 753 mg/kg Zn. These levels in the tailings are significantly higher than those in uncontaminated soils reported by Bowen (1979). In addition, some tailings samples contain high levels of those heavy metals extracted by a 0.1 N HCl solution, which is the standard method for the Korean Soil Environmental Conservation Act established in 1996. The relationship of heavy metal concentrations in soil samples using both the methods revealed that, although there were variations from metal to metal, the concentrations of Cd, Cu, Pb and Zn in soils extracted by both methods are statistically highly correlated ($P<0.001$). Jung and Chon (1997) also found these relationships in the paddy soils contaminated by an abandoned metal mine in Korea.

According to the Korean Soil Environmental Conservation Act, soils containing over 12 g/kg of Cd, 200 mg/kg of Cu and 400 mg/kg of Pb extracted by 0.1N HCl solution need to be continuously monitored and not used for agricultural purposes such as crop planting. The study showed that some of the tailings exceeded these guidelines. Elevated levels of Cd, Cu, Pb and Zn were also found in soils sampled in paddy fields and a forest area due to dispersion of the metals from the tailings by clastic movement through wind and water. Therefore, these contaminated soils can influence the metal uptake by plants grown on the soils. In comparison with the contaminated area, relatively low contents of heavy metals which are similar to those in background levels reported by Bowen (1979) are found in soils sampled at a nearby control area with similar geology. Results from a t-test indicated that there is a statistical difference between the average concentrations in the contaminated area and the control site ($P<0.05$).

A study by Armah *et al.* (2010) about the assessment of mining and heavy metal pollution in Tarkwa in Ghana revealed that, most of the water bodies in the study area have elevated mean levels of arsenic, iron, mercury, zinc and lead which are above WHO and Ghana EPA guideline values. High concentrations coupled with high coefficients of variation suggest anthropogenic sources for arsenic, iron, mercury, zinc and lead. Some of the water bodies sampled including the alternate source of water have low pH values. The turbidity values were higher than the WHO and Ghana Environmental Protection Agency (GEPA) permissible limits.

2.6 Land cover change detection

Land cover change is a common phenomenon in all parts of the world. The changes can be pervasive, and can have adverse impacts and implications at local, regional and global scales. Changes may be rapid (e.g. Clearing of forest for Agriculture) or relatively slow (e.g. tree damage and death due to acid rain) (Skidmore, 2002).

The recently developed spatial technologies, remote sensing and GIS have paramount roles in the understanding of our environment and management of resources. Remote sensing technology allows us to survey the whole Earth with unprecedented regularity, which can have many inventories of natural resources while GIS provides the tools to accurately map and analyze such information in both global and local terms (Foresman, 2002).

Land use affects land cover and changes in land cover affect land use. A change in either however is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply degradation of the land. However, many shifting land use patterns driven by a variety of social causes, result in land cover changes that affects biodiversity, water and radiation budgets, trace gas emissions and other processes that come together to affect climate and biosphere (Riebsame, Meyer, and Turner, 1994).

A study conducted by Mengistu and Salami in 2007 in part of south western Nigeria with the application of remote sensing and GIS, in land use / land cover mapping and change detection with the use of Landsat imageries of 1986 and 2002 revealed that, forest land which was 30.6% of the total study area in 1986 reduced to 28.1% in 2002. On the contrary, shrub land/ farm land increased from 12.6% to 14.0% during the same period.

Bhagawat (2005) conducted a study which revealed a dramatic decrease of the forest area in the years between 1976 and 2009. It seems13.90% in1976, 8.80 in 1989, 2.93 in 2001 and 2.32 in 2009. But the decrease of the forest area seems constant in 2001 and 2009. Also a survey by Kiranmay (2005) about the impact of coal mining on vegetation in Jaintia Hills District revealed that vegetation in the mined area reduced drastically to about 3-11 tree species per demarcated plot compared to 27 tree species in the unmined area.

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Change detection is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of the population of interest.

Macleod and Congalton (1998) list four aspects of change detection which are important when monitoring natural resources:

i. Detecting the changes that have occurred
ii. Identifying the nature of the change
iii. Measuring the area extent of the change
iv. Assessing the spatial pattern of the change

The basis of using remote sensing data for change detection is that changes in land cover result in changes in radiance values which can be remotely sensed. Techniques to perform change detection with satellite imagery have become numerous as a result of increasing versatility in manipulating digital data and increasing computer power. A wide variety of digital change detection techniques have been developed over the last two decades. Singh (1989 summarize eleven different change detection algorithms that were found to be documented in the literature by 1995. These include:

1. Mono-temporal change delineation.

2. Delta or post classification comparisons.

3. Multidimensional temporal feature space analysis.

4. Composite analysis.

5. Image differencing.

6. Multi temporal linear data transformation.

7. Change vector analysis.

8. Image regression.

9. Multi temporal biomass index

10. Background subtraction.

11. Image rationing

In some instances, land use land cover change may result in environmental, social and economic impacts of greater damage than benefit to the area (Mohsen 1999). Therefore data on land use change are of great importance to planners in monitoring the consequences of land use change on the area. Such data are of value to resources management and agencies that plan and assess land use patterns and in modeling and predicting future changes.

Shosheng and Kutiel (1994) investigated the advantages of remote sensing techniques in relation to field surveys in providing a regional description of vegetation cover. The results of their research were used to produce four vegetation cover maps that provided new information on spatial and temporal distributions of vegetation in this area and allowed regional quantitative assessment of the vegetation cover.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

The Tano Offin Extension Forest Reserve has been chosen as my study area because of ongoing mining activities in portions of the reserve. It is located in the Atwima District Assembly of the Ashanti Region, under the jurisdiction of the Nkawie Forest District.

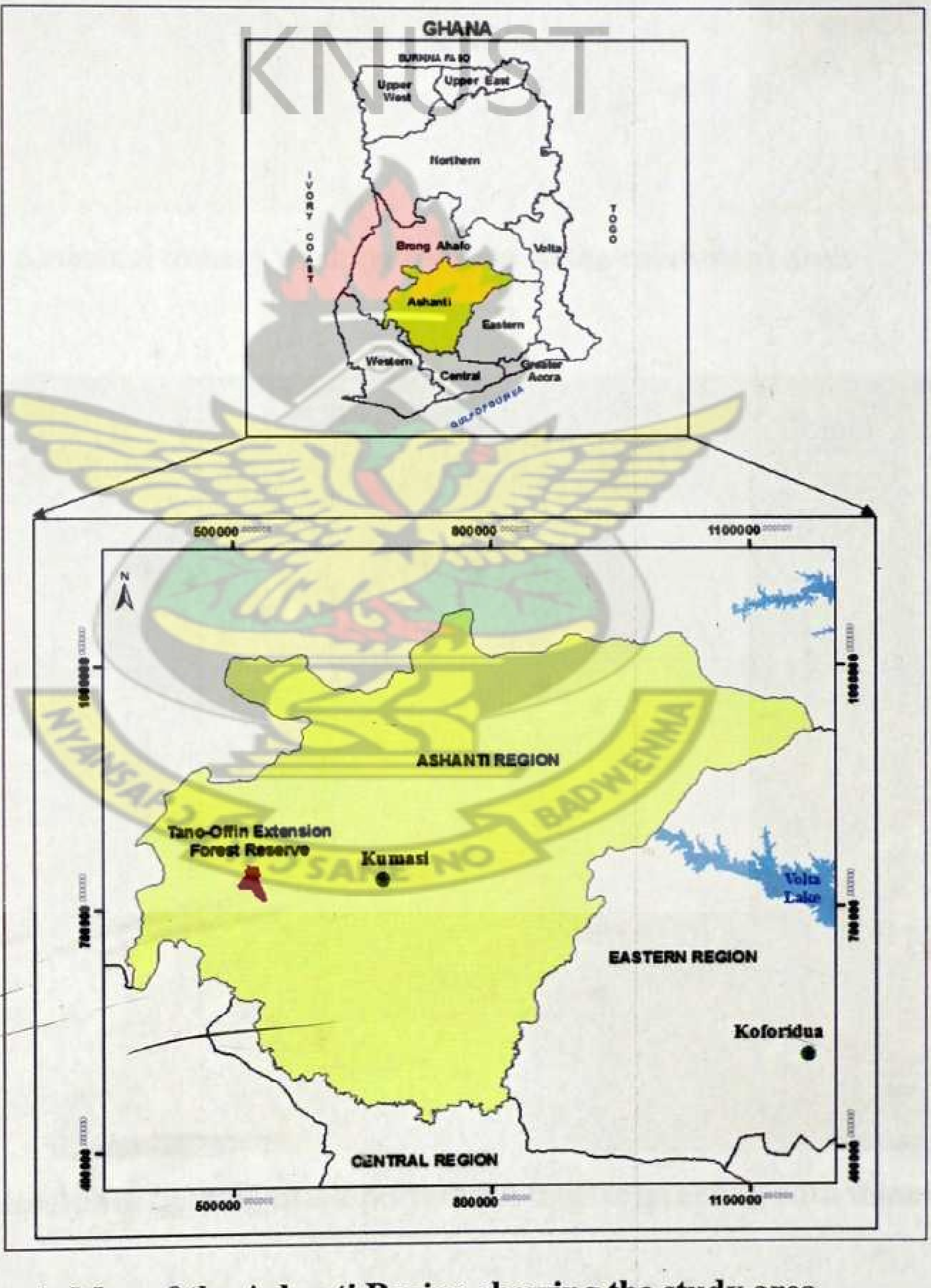


Figure 1: Map of the Ashanti Region showing the study area

Plate 1: Artisanal miners washing for gold in the catchment area

Plate 2: The researcher holding black polyethene bags interacting with miners

3.1.1 Ecology of the area

The area used to be very rich in tropical timber species in the 1980's and 1990's but it can no longer boast of its uniqueness in terms of ecology any more as a result of anthropogenic activities such as mining and logging (Djagbletey, 2007). The upsurge of illegal mining activities in the Forest Reserve recently is very dangerous to the existence of the reserve.

3.2 Data collection

3.2.1 Reconnaissance survey

An initial visit was made to the study area to assess first-hand information of the area. Identification of the sampling site was carried out during the visit

3.2.2 Sampling Techniques

3.2.2.1 Collection of water sample

Nine (9) Water samples each were collected at three (3) reference points (upstream, midstream and downstream) that were 400 m apart along the Subin River within the catchment area over a period of two months. Nine samples were picked during each visit. The twenty seven (27) bottles (500 ml) used were washed with dilute acid (HCl) before the collection of samples. The reference points were taken at up-stream, mid-stream and down-stream according to the direction of flow of water. The sample bottles were held firmly with the necks plunged to the depth of 0.5m before samples were taken. Nitric acid measuring 1% of the total volume of water in each sample was added to the sampled water as preservatives. The samples were then taken to the laboratory for digestion and AAS analysis.

Global positioning system (GPS) was used to measure the distances between the reference points.

3.2.2.2 Collection of soil samples

Four (4) plots measuring 3 m x 3 m (9 m sq) each were demarcated with GPS and coded to avoid duplication. Three (3) points were picked in each plot diagonally from the western to the eastern corner per visit on three occasions during a period of two months. 10 cm of top soil was removed from each picked point before one soil sample each was taken from the designated points with the aid of soil auger. One of the plots was laid outside the mine area and was used as a control. A total of thirty six (36) soil samples were collected from the four (4) plots and were kept in thirty six (36) different paper bags, and transported to the laboratory for analysis. Three plots laid in the mine area were 200 m apart whiles the control plot was laid 500 m from the mine area.

3.2.2.3 Collection of sediment samples

Nine (9) sediment samples each were collected from the sediment bottom of each of the three (3) reference points where the water samples were collected over a period of two (2) month. Nine (9) samples were collected per each visit over the two month period on three occasions. These were to enable me check the correlation between water and sediment samples at each reference point. This was done with minimum disturbance of the topmost sediment by the pressure wave with the aid of the Ekman Grab. A total of twenty seven (27) samples obtained were taken to the lab for drying, grinding, digestion and ASS. The closing mechanism of the Ekman Grab enables it to hold the sample as well as prevent wash-out during retrieval.

3.2.2.4 Detection of land cover changes with GIS and remote sensing

This was done through series of steps as described below:

Step 1: Acquisition of raw satellite image with Landsat EMT Image followed by Rectification or Georeferencing the raw image to Ghana Projection System.

This process assigned Ghana Coordinates to the image using ERDAS IMAGINE image processing software (fig 2). Rectification is the process of projecting the data onto a plane and making it conform to a map projection system.

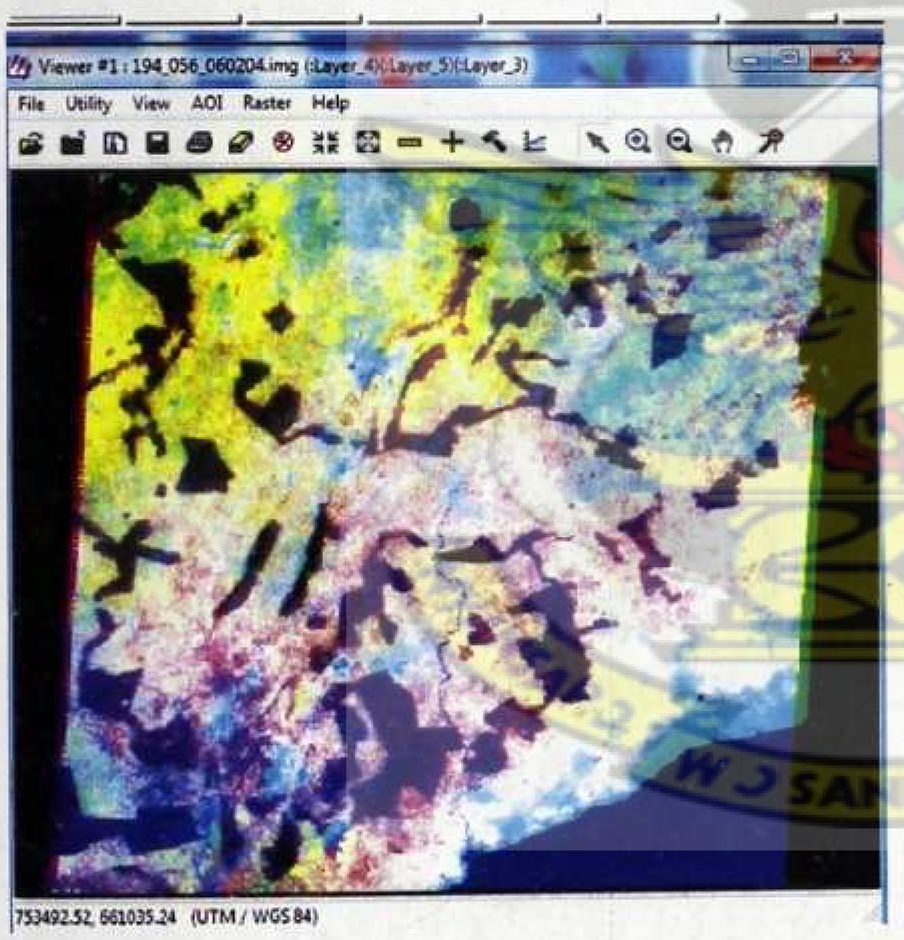


Figure 2: Acquired satellite image

Assigning map coordinates to the image data is called Georeferencing. Since all map Projection systems are associated with map coordinates, rectification involves Georeferencing.

Step 2: This involves sub setting the area of interest. Sub setting is a process of breaking up a portion of a larger image into a smaller one. Here the Tano Offin Extension Forest Reserve which forms part of the larger acquired satellite image was projected out of the larger map and enlarged to make it more visible showing its boundaries as in fig 4.

Figure 3: Sub setting the area of interest

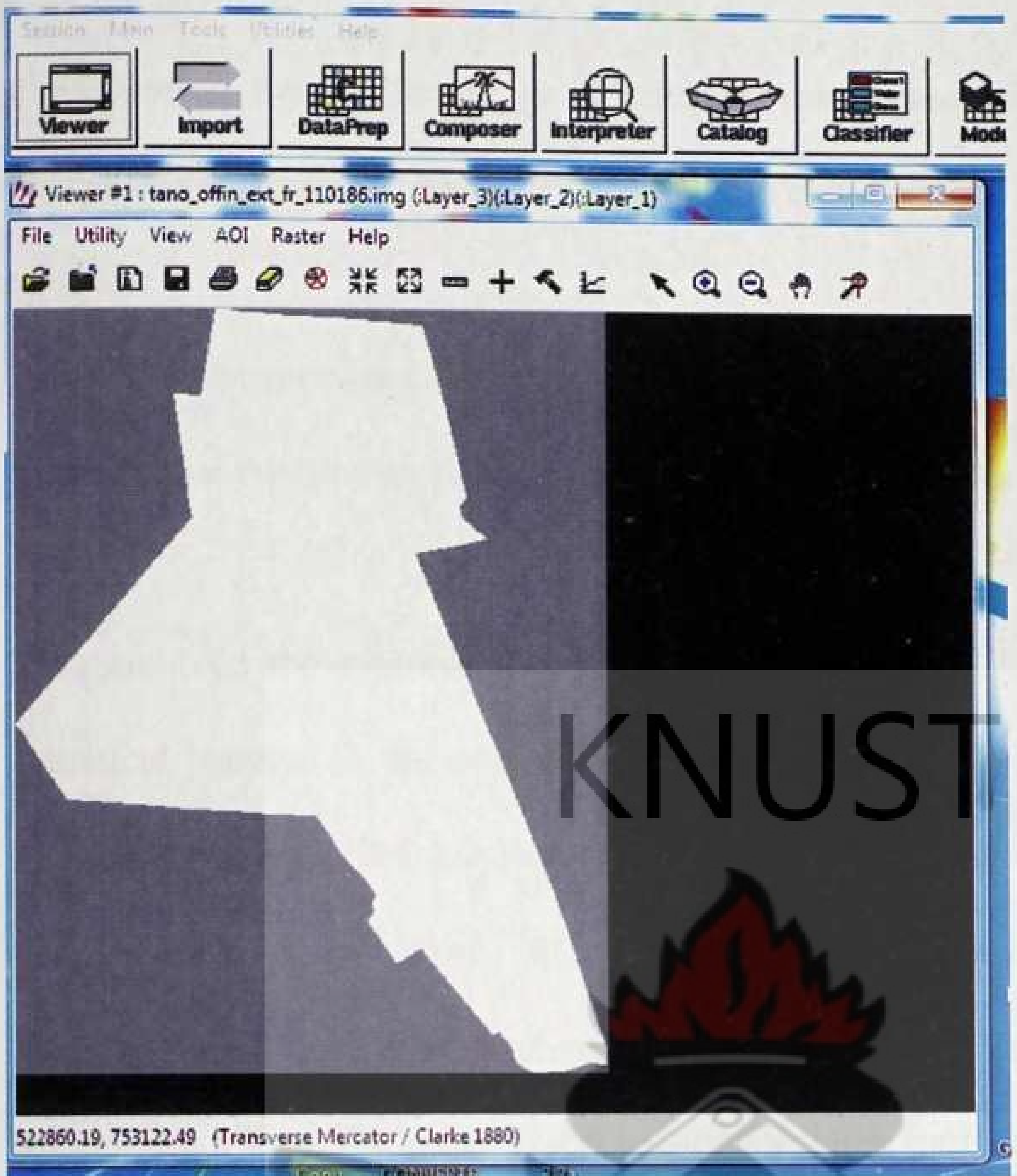


Figure 4: Image of Tano Offin Extension Forest Reserve after sub setting.

Step 3: This involved classification. It is the process of sorting pixels into a finite number of individual classes, or categories of data based on their data file values. If a pixel satisfies a certain set of criteria, then the pixel is assigned to the class that corresponds to that criterion.

There are two ways to classify pixels into different categories: Supervised and Unsupervised. The supervised classification involves acquiring the satellite image and taking it to the field to observe the condition of the area physically and to understand what each colour of the image represents. Based on this, one can assign classes to the image on the field before any laboratory work but in the case of unsupervised classification, the satellite image is first input into a computer and using Erdas Imagine Processing software the image is grouped into classes based on the set of criteria a pixel satisfies.

I used the unsupervised classification option, and then validated the classified images using Global Positioning System (GPS) for the purpose of orientation in the field.

This involved the creation of a thematic raster layer by letting the software identify statistical patterns in the data without using any ground truth data using the ERDAS IMAGE software. ERDAS IMAGINE uses the ISODATA algorithm to perform an unsupervised classification. ISODATA stands for "Iterative Self-Organizing Data Analysis Technique." It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. "Self-Organizing" refers to the way in which it locates the clusters that are inherent in the data.

The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. The ISODATA utility repeats the clustering of the image until either a maximum number of iterations have been performed, or a maximum percentage of unchanged pixels have been reached between two iterations. The output file has a grayscale color scheme if the initial cluster means are arbitrary. If the initial cluster means are from an existing signature set, then the output file uses the colors of this signature set. You can use the raster attribute editor to change the color scheme

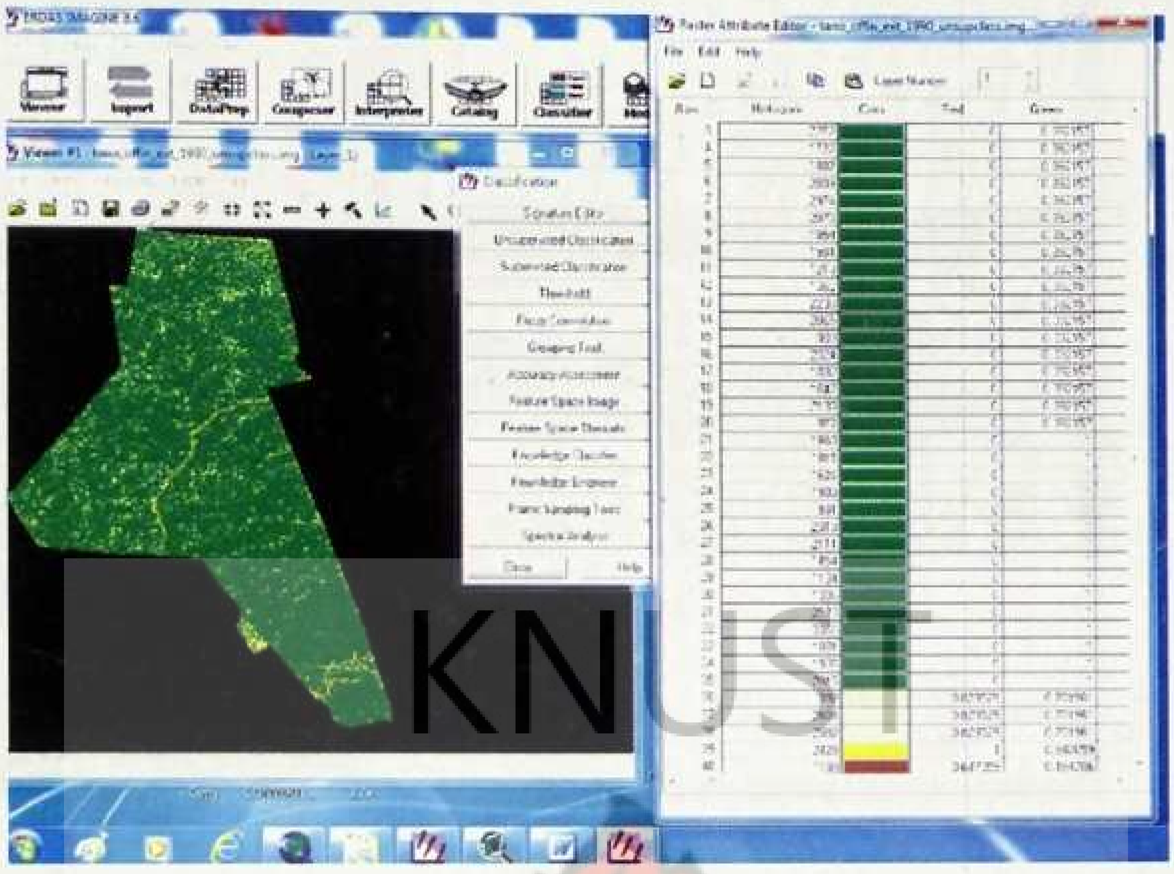


Figure 5: Validated image of Tano Offin Extension Forest Reserve

Step 4: This involves recoding, that is assigning a new class value number to all classes, creating a new thematic raster layer using the new class numbers. Some of the classes were combined through this process using Erdas Image software. Figure 6 shows what is involved in recoding.

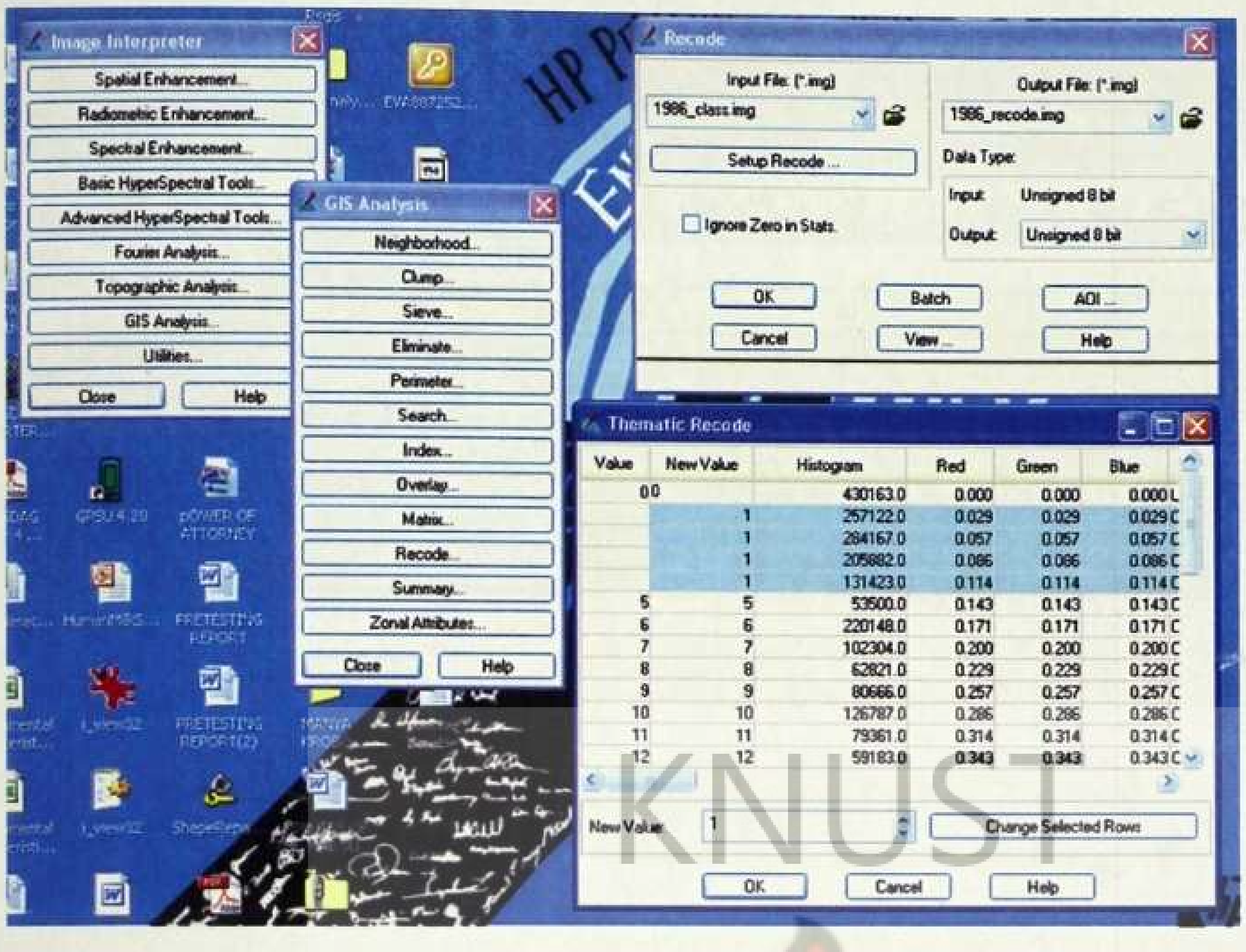


Figure 6: Recoding

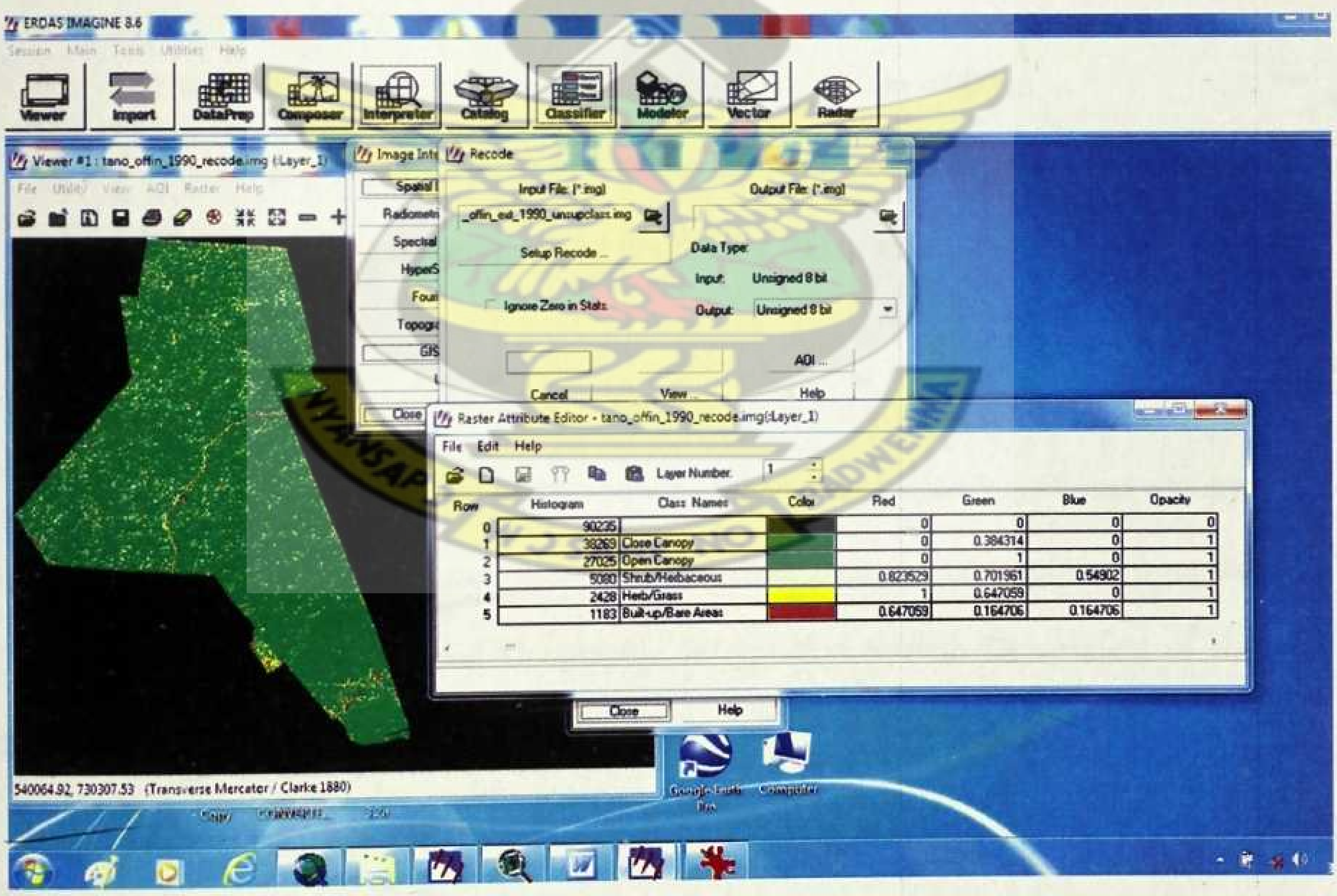


Figure 7: Data obtained after recoding

CLASS	PIXEL	SQ_METRE	HA	SQ_KM
Closed Canopy	38269	31083995	3108.3995	31.0840
Open Canopy	27025	21951056	2195.1056	21.9511
Shrub/Herbaceous	5080	4126230	412.6230	4.1262
Herb/Grass	2428	1972143	197.2143	1.9721
Built-up/Bare Areas	1183	960892	96.0892	0.9609

Figure 8: Data obtained for Tano Offin Extension in 1990 showing the various canopy classes and the corresponding area occupied by each class.

Once you know the size of a pixel (eg, the Landsat 30 m x 30 m = 900 m

You multiply the pixels per class by 900 to get the total area in meters per class, this was divided by 10000 to get hectares, then divided by 100 to get sq. km

Map Composition

ArcGIS was used to compose the maps, showing the various classes eg. Closed canopy, Open canopy, Shrub / herbaceous, etc. All the satellite images were acquired from the Center for Remote Sensing and Geographic Information System Department of the University of Ghana, Legon.

CHAPTER FOUR

4.0 RESULTS

4.1 Land Cover Change Detection for Tano Offin Extension Forest Reserve

The satellite images as shown in Figures 9, 10 and 11 depict the state of the Tano Offin Extension Forest Reserve in the years 1990, 2000, 2010, respectively.

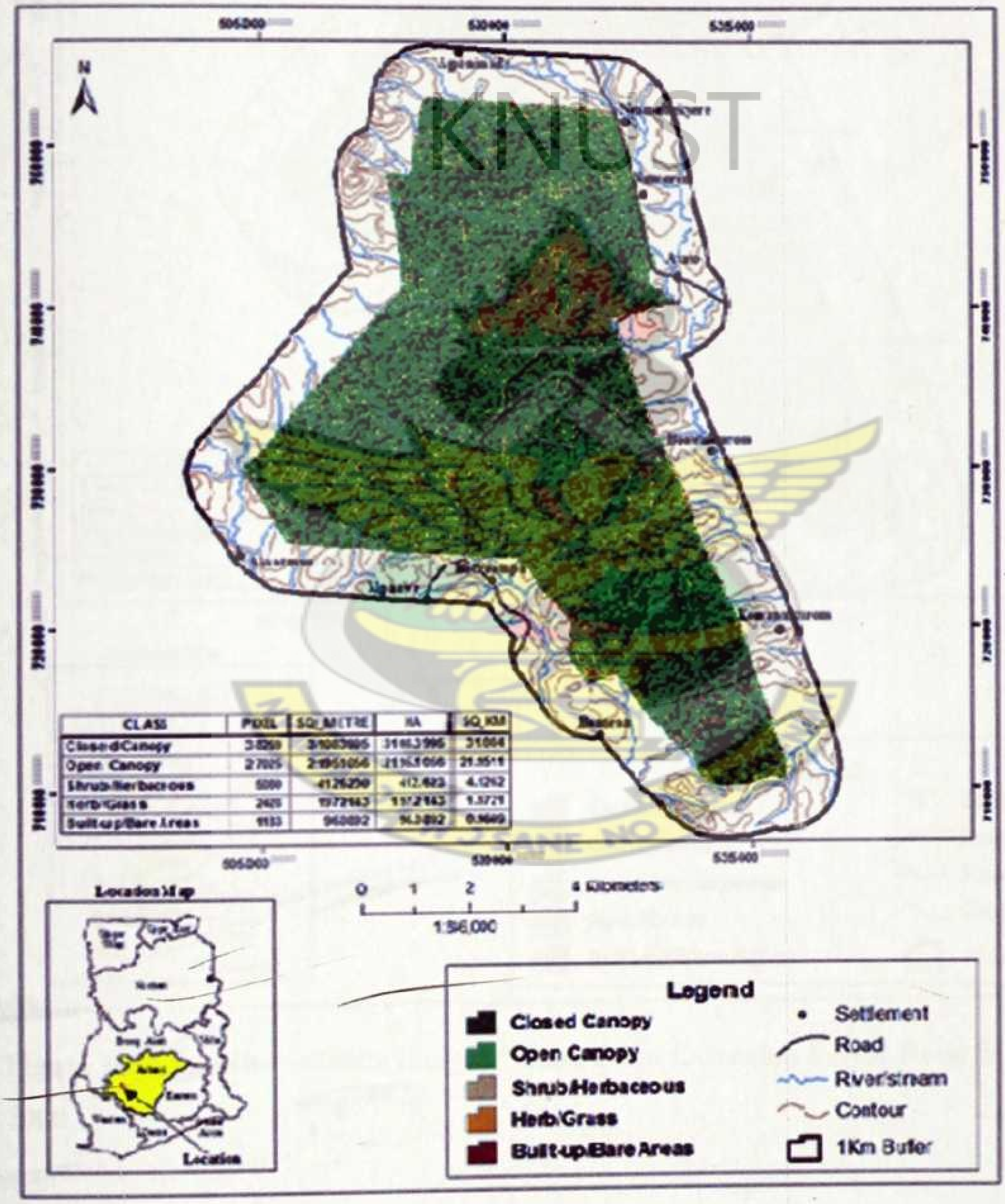
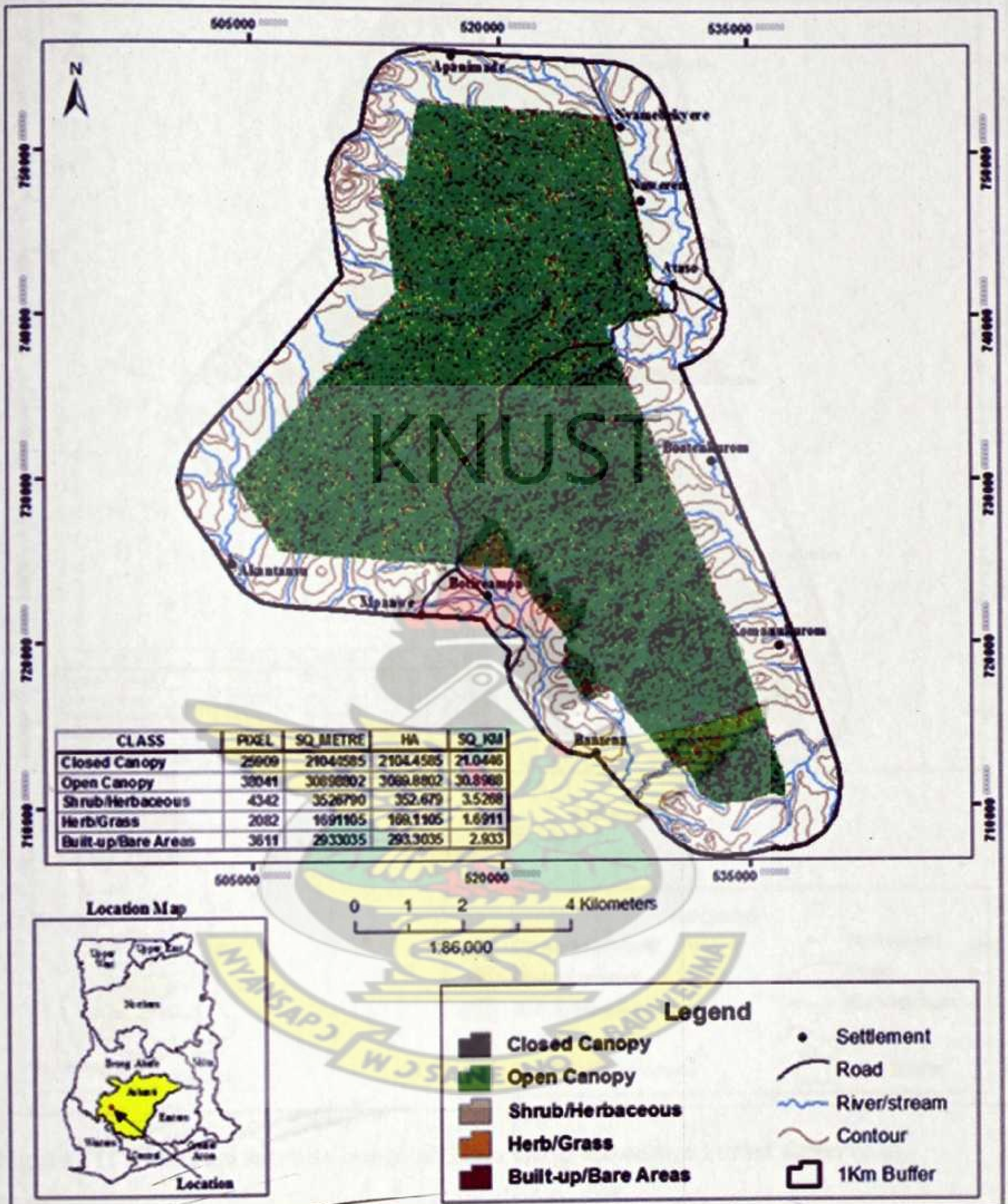
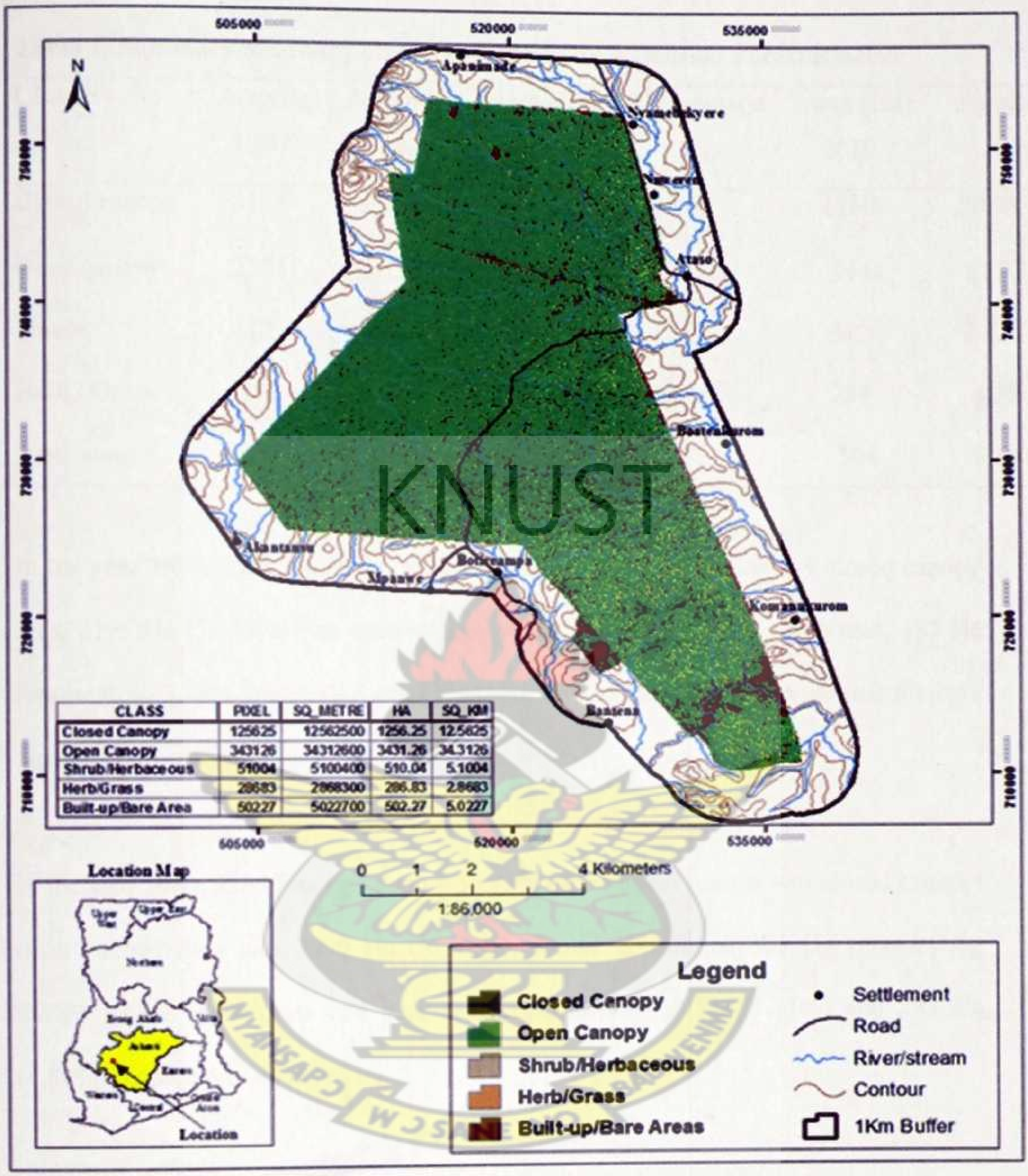


Figure 9: Classified satellite image of Tano Offin Ext Forest Reserve in 1990



CLASS	PIXEL	SQ_METRE	HA	SQ_KM
Closed Canopy	25909	21044585	2104.4585	21.0446
Open Canopy	38041	30898802	3089.8802	30.8988
Shrub/Herbaceous	4342	3526790	352.679	3.5268
Herb/Grass	2082	1691105	169.1105	1.6911
Built-up/Bare Areas	3611	2933035	293.3035	2.933

Figure 10: Classified satellite image of Tano Offin Extension Forest Reserve in 2000



CLASS	PIXEL	SQ_METRE	HA	SQ_KM
Closed Canopy	125625	12562500	1256.25	12.5625
Open Canopy	343126	34312600	3431.26	34.3126
Shrub/Herbaceous	51004	5100400	510.04	5.1004
Herb/Grass	28683	2868300	286.83	2.8683
Built-up/Bare Area	50227	5022700	502.27	5.0227

Figure 11: Classified satellite image of Tano Offin Extension Forest Reserve in 2010

Table 1: Summary of canopy classes in Tano Offin Extension Forest Reserve

CLASS	Area(Ha) 1990	Percentage %	Area (Ha) 2000	Percentage %	Area (Ha) 2010	Percentage %
Closed canopy	3108	51.72	2104	35.02	1260	20.98
Open canopy	2195	36.53	3090	51.42	3444	57.32
Shrubs	412	6.87	353	5.87	512	8.52
Herb / Grass	197	3.28	169	2.81	288	4.79
Bare area	96	1.6	293	4.88	504	8.39

In the year 1990, 3108 Ha of the total area representing 51.72% was a closed canopy area, 2195 Ha (36.53%) was open canopy, 412 Ha (6.87%) was a shrub area, 197 Ha representing 3.28% was herb / grass area and 96 hectares (1.6%) represented the bare area in the Forest Reserve. (Table 1)

In the year 2000, 2104 Ha representing 35.02% of the forest reserve was closed canopy, open canopy area was 3090 Ha (51.42%), shrubs constituted 353 Ha representing 5.87% whiles herb /grass and bare areas constituted 169 Ha (2.81%) and 293 Ha (4.88%) respectively. (Table 1)

Also in 2010, 1260 Ha representing 20.98% was closed canopy, 3444 Ha (57.32%) was constituted by open canopy area, 512 Ha representing 8.52% represented the shrub land, herb / grass was 288 Ha (4.79%) while the bare area was 504 Ha (8.39%) (Table 1).

4.1.1 Land cover change detection as influenced by mining in compartment 21 of the Tano offin extension Forest Reserve

The satellite images as shown in Figures 12, 13, 14 depict the state of compartment 21 of the Tano Offin Forest Reserve in the year 1990, 2000 and 2010, respectively.

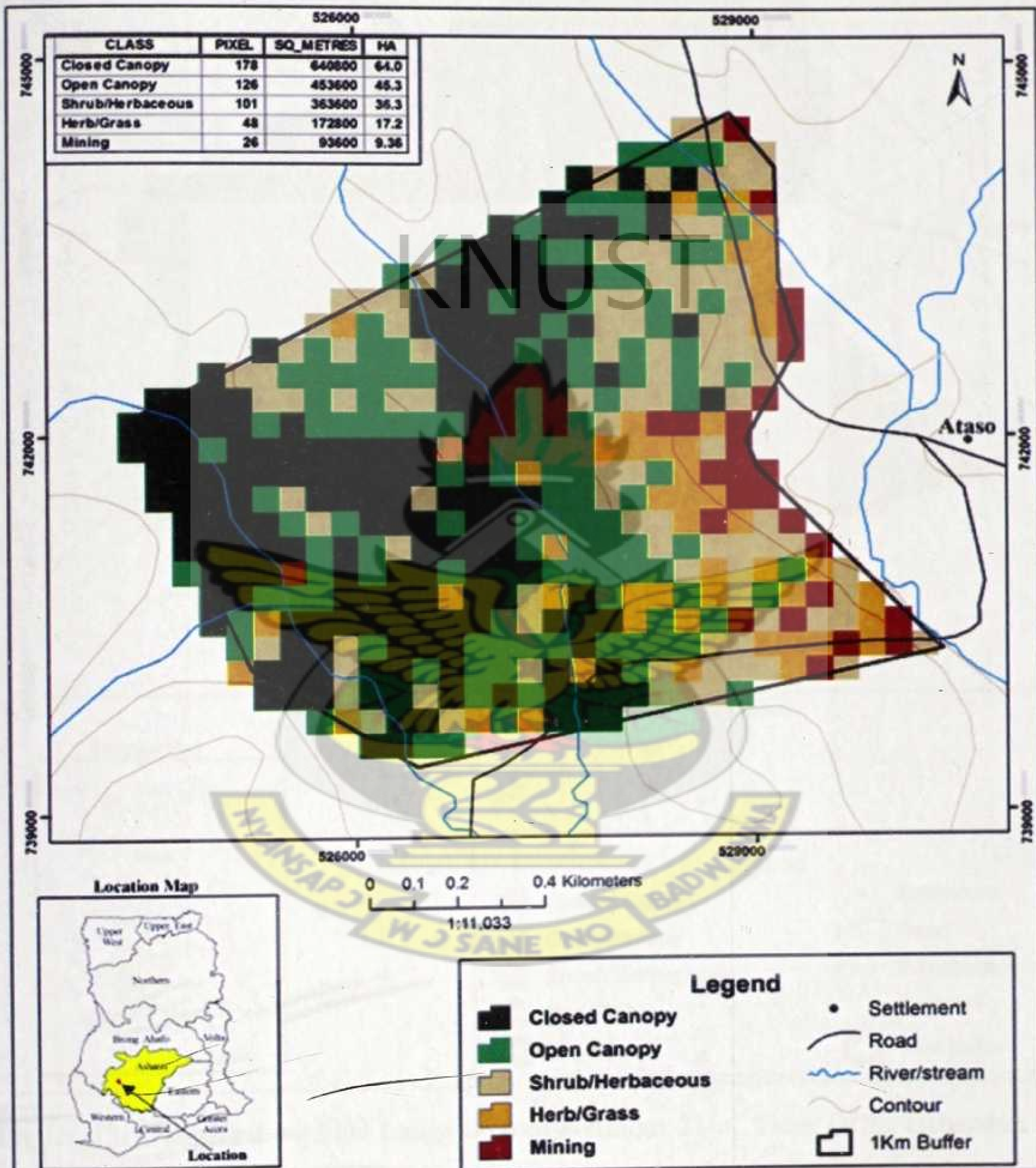


Figure 12: Classified satellite image of compartment 21 of Tano Offin Extension Forest Reserve in 1990

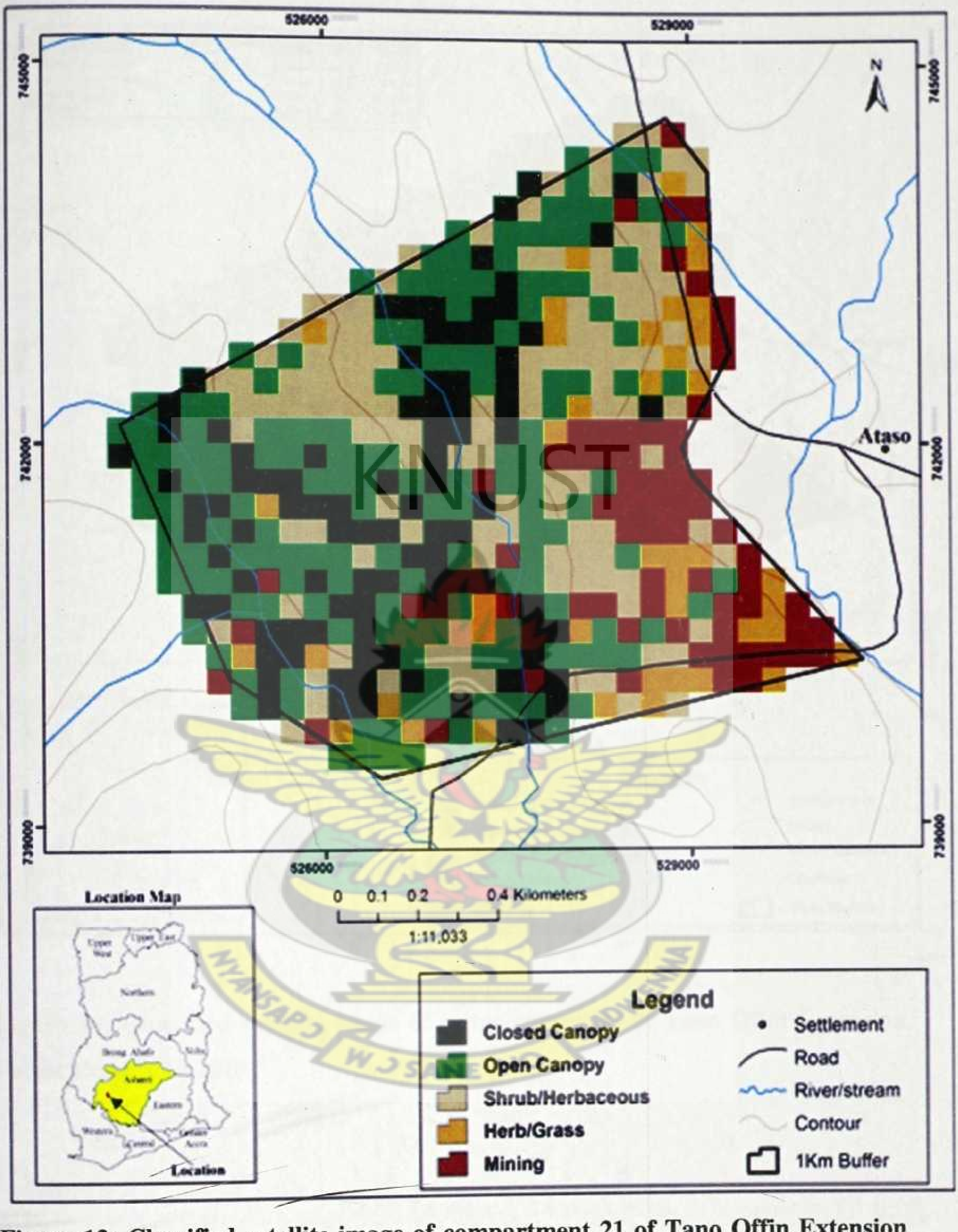


Figure 13: Classified satellite image of compartment 21 of Tano Offin Extension Forest Reserve in 2000.

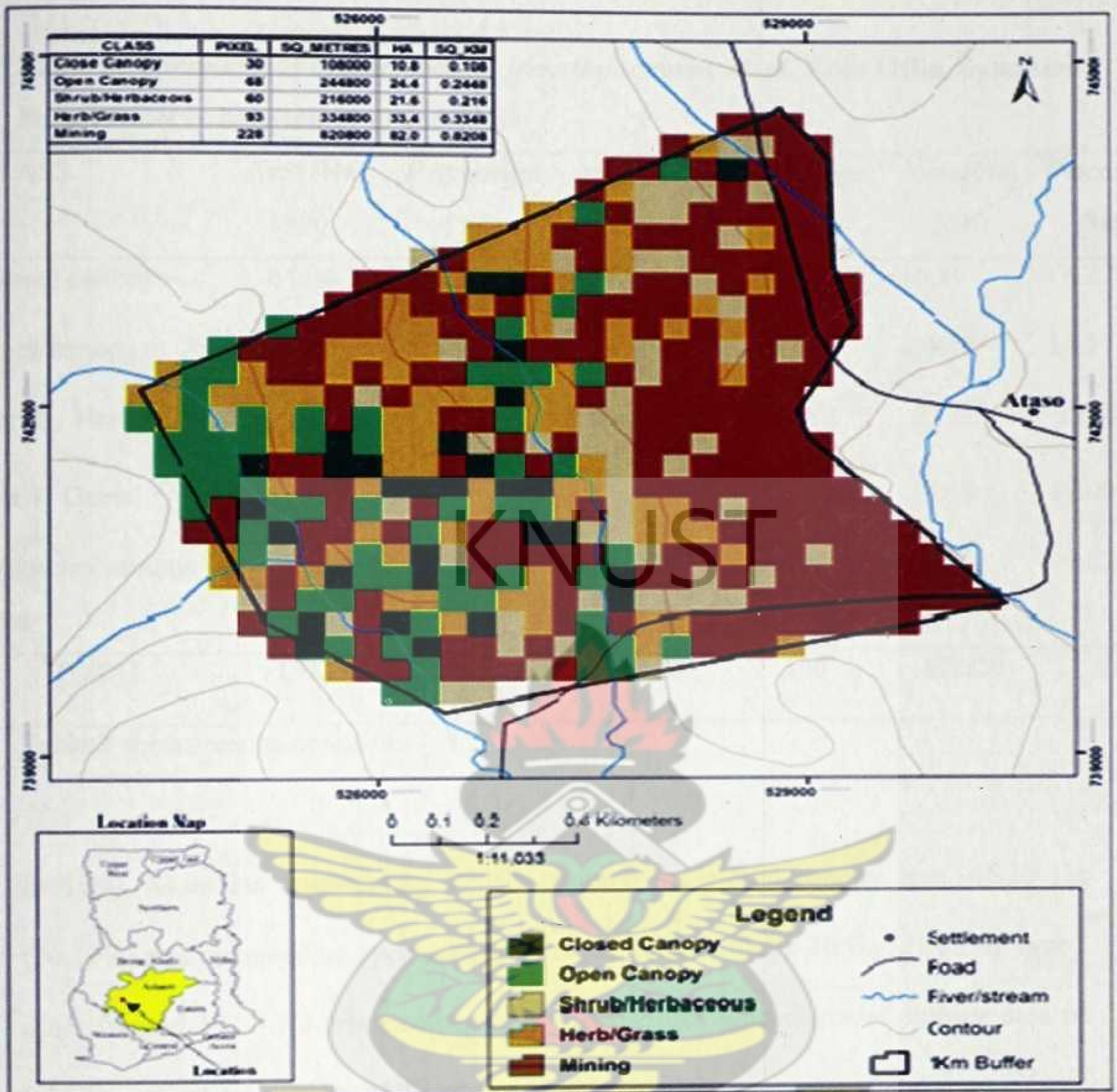


Figure 14: Classified satellite image of compartment 21 0f Tano Offin Extension Forest Reserve in 2010

Table 2: Summary of canopy classes in compartment 21 of Tano Offin Extension Forest Reserve between 1990 and 2010

CLASS	Area (Ha) 1990	Percentage (%)	Area (Ha) 2000	Percentage (%)	Area (Ha) 2010	Percentage (%)
Closed canopy	64.04	37.19	34.50	20.03	10.80	6.27
Open canopy	45.30	26.31	55.70	32.35	24.40	14.17
Shrub / Herbaceous	36.30	21.08	42.8	24.85	21.60	12.54
Herb / Grass	17.2	9.98	15.10	8.77	33.40	19.40
Degraded mining area	9.36	5.44	24.10	14.00	82.0	47.62
TOTAL	**172.20**	**100**	**172.20**	**100**	**172.20**	**100**

Table 2 shows results obtained:

In 1990, 64.04 Ha representing 37.19% formed the closed canopy area, 45.30 Ha (26.31%) was occupied by open canopy; shrubs / herbaceous 36.30 Ha (21.08%); herb / grass formed 17.20 Ha representing 9.98% of the area with degraded mining area of 9.36 Ha constituting 5.44% of the compartment (Table 2).

From Table 2 it is clear that in the year 2000, 34.50 Ha represented by 20.03% was closed canopy area; 55.70 Ha (32.35%) constituted the open canopy area; 42.80 Ha (24.85%) represented the shrub / herbaceous area with the herb / grass area of 15.10 Ha representing 8.77%, degraded mining area occupied 24.10 Ha formed 14.00% of the area.

According to Table 2 in the year 2010, 10.80 Ha representing 6.27% was the closed canopy area in the compartment, open canopy area formed 24.40 Ha (14.17%); shrub grass constituted 21.60 Ha (12.54%); herb / grass was 33.40 Ha (19.40%) whiles degraded mining area formed 82.0 Ha representing 47.62% of the area.

4.2 Heavy metal concentrations in water from the Subin River

Kruskall-Wallis non-parametric one-way Analysis of Variance was used to determine the variability in metal levels recorded at the various sampling stations over the sampling period. The Dunn's Multiple Comparison Test was used to further test for significant differences among the three sampling stations. In the case of the soil samples, the metal concentrations of the soils of the catchment area were compared to the concentrations in the control plot using the Dunnett's Test.

Table 3: heavy metal levels in water from the Subin River

	As (mgL^{-1})	Fe (mgL^{-1})	Zn (mgL^{-1})	Pb (mgL^{-1})
Sampling Stations				
US1	ND	2.47±0.04	0.030±0.001	0.062±0.002
US2	ND	2.33±0.03	0.032±0.001	0.068±0.001
US3	ND	2.38±0.03	0.027±0.001	0.059±0.001
MS1	0.005±0.00	2.51±0.01	0.046±0.001	0.086±0.002
MS2	0.006±0.00	2.52±0.03	0.041±0.001	0.081±0.001
MS3	0.005±0.00	2.40±0.03	0.049±0.001	0.075±0.002
DS1	0.005±0.00	2.96±0.04	0.036±0.000	0.093±0.004
DS2	0.005±0.00	2.86±0.03	0.031±0.000	0.091±0.001
DS3	0.006±0.00	2.89±0.02	0.038±0.001	0.097±0.001

USI, US2, US3 are upstream samples, MS1, MS2, MS3 are midstream samples and DSI, DS2, DS3 downstream samples.

The WHO (2011) Drinking Water Quality Guideline values which were used as standards are Arsenic (As) 0.01mgL^{-1}. Lead (Pb) 0.01mgL^{-1}, No WHO values has been proposed for Zinc (Zn) and Iron (Fe) for Drinking Water Quality. The concentrations of As, Fe, Zn and Pb in water samples from the Subin River are shown in Table 3. All the trace metals recorded lower mean concentration values upstream than midstream and downstream. Arsenic levels in upstream was below detection limit with levels in midstream and downstream recording mean concentrations between 0.005±0.00 and 0.006±0.00 mgL^{-1}. Zn recorded upstream mean concentrations between 0.027±0.001 and 0.032±0.001 mgL^{-1} with midstream and downstream concentrations between 0.041±0.001 and 0.049±0.001 mgL^{-1}, and 0.031±0.000 and 0.038±0.001 mgL^{-1} respectively.

Fe also recorded upstream mean concentrations between 2.33±0.03 and 2.47±0.04 mgL^{-1} while the midstream and downstream mean concentrations were between 2.40±0.03 and 2.52±0.03 mgL^{-1}, 2.86±0.03 and 2.96±0.04 mgL^{-1} respectively.

The mean concentrations of Pb in upstream water samples were between 0.059±0.001 and 0.068±0.001 mgL^{-1} with the midstream also recorded mean concentrations between 0.075±0.002 and 0.086±0.002 mgL^{-1} while that of the downstream was between 0.091±0.001 and 0.097±0.001 mgL^{-1}.

Results from Kruskall Wallis non-parametric one way Analysis of variance and Dunn's Multiple Comparism Test indicated that There were no significant variations ($p>0.05$)

in the Arsenic concentrations recorded in the water samples of the three sampling stations. Iron concentrations in the water samples showed significant spatial variations ($p<0.05$) over the sampling period with mean Iron concentration of the upstream portion varying significantly from the mean concentration recorded at downstream portion. No significant difference ($p>0.05$) was recorded between the mean Iron concentrations at the upstream and midstream stations and between the midstream and downstream stations. The mean Lead concentration of the upstream portion varied significantly from the mean concentration recorded at downstream portion. No significant differences ($p>0.05$) were, however, found between the mean Lead concentrations recorded at the upstream and midstream stations and between the midstream and downstream stations. Zinc concentrations in the water of the three sampling locations exhibited similar spatial trends to the zinc concentrations in the sediment samples. Mean Zinc concentration of the upstream portion differed significantly from the mean concentration recorded at midstream portion. There were, however, no significant difference ($p>0.05$) recorded between the mean Zinc concentrations at the upstream and downstream stations and between the midstream and downstream stations.

4.3 Heavy metal levels in sediment from the Subin River

Table: 4 Heavy metal levels in sediment from the Subin River

	As ($mgkg^{-1}$)	Fe ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)	Pb ($mgkg^{-1}$)
Sampling Stations				
US1	90.27±0.23	1377.00±9.94	10.33±0.05	11.83±0.12
US2	89.10±0.26	1307.00±6.08	9.90±0.10	12.07±0.12
US3	89.43±0.21	1310.00±4.52	10.90±0.10	10.63±0.15
MS1	109.10±0.80	1955.00±38.70	11.27±0.15	13.20±0.20
MS2	111.10±0.10	2002.00±12.75	12.90±0 .10	12.90±0.10
MS3	100.80±0.20	2060.00±32.12	11.80±0.10	12.40±0.10
DS1	113.30±0.24	2222.00±27.24	11.20±0.20	9.30±0.30
DS2	117.40±0.47	2142.00±17.51	10.50±0.26	10.13±0.05
DS3	114.60±0.15	2137.00±15.16	11.03±0.12	10.37±0.15

USI, US2, US3 are upstream samples, MS1, MS2, MS3 are midstream samples and DSI, DS2, DS3 downstream samples.

The WHO/FAO (2011) Sediment Quality Guideline values which were used are Arsenic (As) 20 $mgkg^{-1}$, Lead (Pb) 40 $mgkg^{-1}$, Iron (Fe) 1500 $mgkg^{-1}$, Zinc (Zn) 90 $mgkg^{-1}$. The mean concentrations level of As, Fe, Zn and Pb in sediment from Subin River are shown in Table 4. All heavy trace metals recorded lower mean concentration values upstream as compared with midstream and downstream values. Arsenic concentrations at upstream were between 89.10±0.26 and 90.27±0.23 $mgkg^{-1}$

The measured As concentrations for midstream and downstream were between 100.80±0.20 and 111.10±0.10 $mgkg^{-1}$, and 113.30±0.24 and 117.40±0.47 $mgkg^{-1}$ respectively. Pb recorded upstream concentrations between 10.63±0.15 and 12.07±0.12 $mgkg^{-1}$ with midstream and downstream recording mean concentrations between

12.40±0.10 and 13.20±0.20 $mgkg^{-1}$, and 9.30±0.30 and 10.37±0.15 $mgkg^{-1}$ respectively.

The measured Zn concentrations at upstream sampling stations of US1, US2 and US3 were 10.33±0.05, 9.90±0.10 and 10.90±0.10 $mgkg^{-1}$, respectively whiles their midstream counterparts of MS1, MS2 and MS3 also recorded concentrations of 11.27±0.15, 11.80±0.10 and 11.80±0.10 $mgkg^{-1}$ respectively with the downstream sampling stations of DS1, DS2 and DS3 recording mean concentrations of 11.20±0.20, 10.50±0.26 and 11.03±0.12 $mgkg^{-1}$ respectively.

The upstream mean concentrations for Fe were between 1310.00±4.52 and 1377.00±9.94 $mgkg^{-1}$ with midstream samples recording means between 1955.00±38.70 and 2060.00±32.12 $mgkg^{-1}$ whiles the downstream were between 2137.00±15.16 and 2222.00±27.24 $mgkg^{-1}$. The measured Pb concentrations for upstream were between 10.63±0.15 and 12.07±0.12 $mgkg^{-1}$. Midstream and downstream recorded mean concentrations between 12.40±0.10 and 13.20±0.20 $mgkg^{-1}$, and 9.30±0.30 and10.37±0.15 $mgkg^{-1}$ respectively.

Results from Kruskall Wallis non-parametric one way Analysis of variance and Dunn's Multiple Comparism Test showed that, Arsenic concentrations in the sediments samples showed significant spatial variations ($p<0.05$) over the sampling period. Mean Arsenic concentration of the upstream portion differed significantly from the mean concentration recorded at downstream portion. No significant difference ($p>0.05$) was recorded between the mean Arsenic concentrations recorded at the upstream and midstream stations and between the midstream and downstream stations. Similar to the trends observed for Arsenic, Iron concentrations in the sediments samples showed significant spatial variations ($p<0.05$) over the sampling period. Mean Iron concentration of the upstream portion differed significantly from the mean concentration recorded at downstream portion. No significant difference ($p>0.05$) was found between the mean Iron concentrations recorded at the upstream and midstream stations and between the midstream and downstream stations.

Overall, there were significant spatial variations ($p<0.05$) in the mean Lead concentrations in the sediments of the study area. The mean Lead concentration of the midstream portion differed significantly from the mean concentration recorded at downstream portion. No significant difference ($p>0.05$) was recorded between the mean Lead concentrations at the upstream and midstream stations and between the Upstream and downstream stations. There were significant variations ($p<0.05$) in the mean Zinc concentrations in the sediments samples of the three sampling stations. Mean Zinc concentration of the upstream portion differed significantly from the mean concentration recorded at midstream portion. There were, however, no significant difference ($p>0.05$) between the mean Zinc concentrations recorded at the upstream and downstream stations and between the midstream and downstream stations.

4.4 Heavy metal concentrations in soil within the catchment area.

Table 5: Heavy metal levels in soils within the catchment area

	As ($mgkg^{-1}$)	Fe ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)	Pb ($mgkg^{-1}$)
Sampling Stations				
FP1	89.37±0.55	1233.00±0.98	131.33±1.52	116.00± 2.00
FP2	90.37±0.25	1357.00±12.08	123.30±2.51	119.70±1.53
FP3	88.63±0.35	1372.00±2.75	121.70±0.58	117.70±3.51
SP1	107.10±1.00	2740.00±40.65	117.70±0.57	101.30±1.16
SP2	101.70±0.122	2841.00±0.75	121.30±1.16	115.30±1.16
SP3	100.70±0.49	2804.00±8.48	115.00±1.00	110.30±1.53
TP1	122.10±0.25	1837.00±15.86	101.30±1.16	94.33±1.53
TP2	112.20±1.16	1804.00±4.77	115.30±0.16	93.33±1.16
TP3	116.60±0.55	1848.00±16.41	105.30±1.53	88.33±1.53
CP1	9.60±0.30	194.50±4.60	8.30±0.20	7.90±0.06
CP2	7.40±0.10	258.60±7.10	9.70±0.20	8.60±0.06
CP3	6.40±0.10	250.10±1.30	8.70±0.20	7.60±0.02

FP1, FP2 and FP3 are samples from the first plot, SP1, SP2 and SP3 are samples from the second plot, TP1, TP2 and TP3 are samples from the third plot and CP1, CP2 AND CP3 are samples from the controlled plot.

The WHO/FAO (2011) Sediment Quality Guideline values used as standards were Arsernic (As) 20 $mgkg^{-1}$, Iron (Fe) 1500 $mgkg^{-1}$. Zinc (Zn) 300 $mgkg^{-1}$, Lead (Pb) 35 $mgkg^{-1}$.

The mean concentration levels of As, Fe, Zn and Pb levels in soils are shown in Table 5. The measured As mean concentrations levels in samples from the first plot were between 88.63±0.35 and 90.37±0.25 $mgkg^{-1}$ with samples from the second plot recording means between 100.70±0.49 and 107.10±1.00 $mgkg^{-1}$. Samples from the third plot also recorded levels ranging between 112.20±1.16 and 122.10±0.25 $mgkg^{-1}$ whiles samples from the control plot were between 6.40±0.10 and 9.60±0.30 $mgkg^{-1}$.

The estimated Zn mean levels in samples from the first plot were between121.70±0.58 and 131.33±1.52 $mgkg^{-1}$ with samples from the second plot recording mean levels ranging between 115.00±1.00 and 121.30±1.16 $mgkg^{-1}$. Samples from the third plot also recorded mean levels between 101.30±1.16 and 115.30±0.16 $mgkg^{-1}$ whiles that of samples from the controlled plot were between 8.30±0.20 and 9.70±0.20 $mgkg^{-1}$. The measured Fe mean concentrations in samples from the first plot were between 1233.00±0.98 and 1372.00±2.75 $mgkg^{-1}$ with that of samples from the second plot recording mean levels between 2740.00±40.65 and 2841.00±0.75 $mgkg^{-1}$. The third plot samples recorded mean levels ranging between 1804.00±4.77 and 1848.00±16.41 $mgkg^{-1}$ whiles the controlled plot recorded mean levels between 194.50±4.60 and 258.60±7.10 $mgkg^{-1}$.

Pb mean concentrations in samples from the first plot were between116.00± 2.00 and 119.70±1.53 $mgkg^{-1}$. The mean concentration in samples from the second plot ranged between 101.30±1.16 and 115.30±1.16 $mgkg^{-1}$. Samples from third plot also recorded mean levels between 88.33±1.53 and 94.33±1.53 $mgkg^{-1}$ whiles samples from the controlled plot recorded mean levels between7.60±0.02 and 8.60±0.06 $mgkg^{-1}$.

Results from Kruskall Wallis non-parametric one-way Analysis of variance, followed by Dunnett's Test to further test for significant differences among the soil samples indicated that, for all the four metals, there were highly significant differences ($p<0.05$) between the heavy metal concentrations of the three sampling areas in the catchment area and the control samples.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Land cover change detection for Tano Offin Ext. Forest Reserve

The satellite image obtained for 1990 shows that closed canopy area in the Tano Offin extension Forest Reserve was 51.72% of the total area with open canopy occupying an area of 36.53%. Shrubs, herbaceous/grass and bare areas also occupied 6.87%, 3.28% and 1.60% respectively during the same period (Table 1).

When we visited the area to validate the satellite image, some of the inhabitants of the fringe communities told us that the change in vegetation was caused by logging of timber, artisanal mining and illegal farming. This assertion was collaborated by an ongoing logging activity in compartment 10 of the Forest Reserve, as well as ongoing galamsey mining in compartment 21 coupled with illegal farms in adjacent compartments. These activities caused considerable change in the land cover within a spate of 10 years. The satellite image obtained for the year 2000 showed that whiles the closed canopy area decreased from 51.72% to 35.02%, the open canopy area on the other hand increased from 36.53% to 51.42% over the same period with the bare area also increasing from 1.60% to 4.88 % (Table 1).

This trend of degradation was not different from that of the satellite image obtained for the year 2010. This pattern continued and the closed canopy area of 35.02% in 2000 reduced further to 20.98% in 2010 with the open canopy area increasing from 51.42%

to 57.32% with the bare area increasing again from 4.88% to 8.39%. These changes as depicted by the satellite images agrees with a study conducted by Bhagawat (2005) and Mengistu and Salami (2007) which also revealed changes in land cover with the use of remote sensing and GIS elsewhere. The consequences of these developments will be a reduction in biodiversity conservation, destruction of wildlife habitats, reduction in carbon stocks of the area and drying up of rivers and streams within the catchment area.

5.1.1 Land cover change detection as influenced by mining in compartment 21

The satellite image for compartment 21 in 1990 shows that the closed canopy area in the compartment was 37.19%, open canopy area 26.31%, shrubs/ herbaceous 21.8%, herb/grass 9.98 and degraded mining area 5.44%. Ten years later, the closed canopy area in the year 2000 dwindled to 20.03% while the open canopy area increased from 26.31% to 32.35% with degraded mining area tripling from 5.44% to 14.00% during the same period. The increase in the open canopy and degraded mining areas was as a result of clearing of the vegetation by the artisanal miners before digging for gold alongside the creation of open pits which reduces the ability of the forest to regenerate naturally.

This trend continued further to 2010 but the changes in land cover as influenced by mining as detected by the satellite image in 2010 was too phenomenal. The closed canopy area reduced from 20.03% in 2000 to 6.27% with the open canopy following the same trend reducing from 32.35% to 14.17%. The worse of the land cover change was that, the degraded mining area which was 14.00% in 2000 increased dramatically to 47.62% of the total size of compartment 21 (Table 2). This also agrees with a study by

Kiranmay (2005). The consequences of these developments could be colonization of the area by non native light demanding species because of the increase in light to the forest floor as a result of a decrease in closed canopy area. This could also lead to a reduction in wildlife stocks in the area because of destruction of their habitats alongside decrease in tree population in the compartment.

5.2 Heavy Metal Concentration in water from the Subin River

Analyses of the water samples and comparing sampling stations influenced directly by mining activities showed that part of the metal content in the river was due to natural (geochemistry of the rocks). However, water samples showed high mean levels of arsenic, iron, zinc and lead at midstream and downstream compared to mean levels at upstream suggests anthropogenic sources for arsenic, iron, lead and zinc. This phenomenon could be attributed to the presence of the two main types of gold ore found in the Ashanti belt, namely quartz veins and sulphide ore in the soil and rocks been mined. (Anglogold Ashanti, 2006).

Quartz veins consist mainly of quartz with free gold in association with lesser amounts of various metal sulphides such as Fe, Zn, Pb and Cu. The gold particles are generally fine- grained and are occasionally visible with the naked eye. This type of ore is generally non- refractory, the sulphide ore is that characterized by the inclusion of gold in the crystal structure of a sulphide material. The gold in these ore is fine – grained and often locked in arsenopyrite (FeAsS). Higher gold grades tend to be associated with finer grained arsenopyrite crystals. When deposits of arsenopyrite become exposed to the atmosphere, usually due to mining, the mineral will slowly oxidize, converting the arsenic into oxides that are more soluble in water. Sulphide ore is generally refractory (Anglogold Ashanti, 2004).

Increased mean concentrations of heavy metals at midstream and downstream is as a results of the gold been mined coming from quartz veins and sulphide ore (Pyrite / arsenopyrite). Because the afore-mentioned gold bearing ores are associated with heavy metals (Fe, Zn, Pb and As) as described above. The miners in their quest to mine for the gold ended up breaking down the rocks which serve as stores for these ores associated with the metals. This resulted in the introduction of these heavy metals into the environment and they got into the Subin river through surface round-off and leaching.

The As concentration recorded at all sampling stations which were between 0.005±0.00 and 0.006±0.00 mgL^{-1} were below WHO (2011) guideline value of 0.01mgL^{-1}. Though Fe and Zn recorded increases at both midstream and downstream, no WHO guideline has been proposed for them but this was not the case for Pb which recorded mean levels at all sampling stations ranging between 0.059±0.001 and 0.097±0.001 mgL^{-1} were above WHO (2011) Drinking Water Quality guideline value of 0.01 mgL^{-1}.

Results from Kruskall Wallis non-parametric one way Analysis of variance and Dunn's Multiple Comparism Test indicated that there were no significant variations ($p>0.05$) in the Arsenic concentrations recorded in the water samples of the three sampling stations. This suggests that, though there were increases in Arsenic concentration at midstream and downstream compared with concentrations in upstream samples, the impact of anthropogenic activities on Arsenic concentration in water is low. Though No significant differences ($p>0.05$) were found between the mean Lead concentrations recorded at the upstream and midstream stations and between the midstream and downstream stations, the concentration of Lead (Pb) in water samples at all sampling stations were four times higher above the WHO (2011) guidelines.

The health implications of excess Lead (Pb) in drinking water could result in dullness, headaches, muscle tremor, abdominal cramps, kidney damage, poor attention span, loss of memory and encephalopathy, sleeplessness, tiredness and joint pain. WHO (2011). This data agrees with the report of Senila *et al*. (2006) and Armah *et al*. (2010).

5.3 Heavy metal levels in sediment from the Subin River

Comparing the mean concentration levels of Zn, Fe, Pb and As in upstream sediment with its corresponding midstream and downstream data it showed that, part of the metal content in the sediment in the River was due to the geochemistry of the rocks but increase in concentration at midstream and downstream section of the river suggest anthropogenic sources for Zn, Fe, Pb and As.

The ore bearing gold which is mainly from a quartz and arsenopyrite (FeAsS) are associated with the afore-mentioned trace metals. The miners in their attempt to mine for gold also introduced these metals into the environment in the form of waste rock and soil particles. Through surface run-off, emission and wind erosion some of these materials settled in the River bed thus leading to the increases at midstream and downstream. Though No significant difference ($p>0.05$) was recorded between the mean Arsenic concentrations recorded at the upstream and midstream stations and between the midstream and downstream stations, the As concentrations at all sampling stations which ranged between 89.10±0.26 and 117.40±0.47 $mgkg^{-1}$ were found to be more than four times higher than the FAO/WHO Sediment Quality Guideline value of 20 $mgkg^{-1}$. The measured Pb mean concentrations at all sampling stations which ranged between 9.30±0.30 to 13.20±0.20 $mgkg^{-1}$ were far below the FAO/WHO Sediment Quality Guideline value of 40 $mgkg^{-1}$. Similar to the trends observed for Arsenic, Iron concentrations in the sediments samples showed significant spatial variations ($p<0.05$) over the sampling period. Mean Iron concentration of the upstream portion differed significantly from the mean concentration recorded at downstream portion. This suggests anthropogenic sources for Fe. Though the upstream mean concentration of Fe was high ranging between1307.00±6.08 and 1377.00±9.94 $mgkg^{-1}$, it was still below the FAO/WHO Sediment Quality Guideline value of 1500 $mgkg^{-1}$. However mean concentration levels at midstream and downstream which ranged between 1955.00±38.70 and 2222.00±27.24 $mgkg^{-1}$ were all above the prescribed standards.

Zn mean concentrations varied over a narrow range among all sampling stations. Measured mean levels at all sampling stations ranged between 9.90±0.10 and12.90±0.10 $mgkg^{-1}$ far below the FAO/WHO Sediment Quality Guideline value of 90 $mgkg^{-1}$.This agrees with the report of chon *et al.* (2001).

The implication of excess Arsenic on humans are damage to DNA, infertility and miscarriages with women, skin disturbance, decline resistance to infections, heart disruptions and brain damage with both men and women. The consequences of excess iron can cause premature aging, cancer, osteoporosis, arthritis, diabetes, liver damage and heart and brain disorder. WHO (2011)

5.4 Heavy metal levels in soils within the catchment area

The influence of soil geochemistry was determined by analyzing samples from the controlled plot (CP1, CP2 and CP3) and results show that part of the metal content in the catchment area was due to the natural background (geochemistry of rocks). However, increases in concentrations of As, Fe, Zn and Pb at all the sampling stations affected by the mining activities suggest anthropogenic sources for As, Fe, Zn and Pb. This phenomenon was due to the fact that the ore bearing gold is part of the Ashanti belt which is from a quartz vein (quartz with free gold associated with trace metals such as Fe, Pb and Zn with gold occasionally visible with the naked eye) and sulphide ore (Arsenopyrite and pyrite). This view point was confirmed when I visited the catchment area and saw pure gold particles with my naked eyes after two artisans had finished washing their four (4) head loads of soil particles with ordinary water without any chemical. The artisans during the process of mining for gold also introduced these trace metals into the environment through the activity of breaking down the rocks in which these ores and metals are stored resulting in the increase in mean concentrations at uncontrolled sampling stations.

The concentrations for As, Fe, Zn and Pb in samples from the controlled plot were however below the FAO/WHO Soil Quality Guideline values. The mean concentration levels for As in all the nine (9) samples from the uncontrolled area which ranged from 88.63±0.35 to 122.10±0.25 $mgkg^{-1}$ were far above the FAO/WHO Soil Quality Guideline value of 20 $mgkg^{-1}$ (Table 5).

Fe concentration in the first plot samples (FP1, FP2 and FP3) which ranged between 1233.00±0.98 and1372.00±2.75 $mgkg^{-1}$ were still below the FAO/WHO Soil Quality Guideline value of 1500 $mgkg^{-1}$. However mean levels for samples SP1, SP2, SP3 and TP1, TP2 and TP3 from the second and third plots respectively in the same area showed a different trend and recorded mean levels which were between1804.00±4.77 and 2841.00±0.75 $mgkg^{-1}$ were above the prescribed standards.

The Zn concentrations in soils at all sampling stations within the uncontrolled area which ranged between 101.30±1.16 and 131.33±1.52 were below the FAO/WHO Soil Quality Guideline Value of 300 $mgkg^{-1}$. On the contrary, the measured Pb concentrations in the soils at all sampling stations in the uncontrolled area which were between 88.33±1.53 and 119.70±1.53 $mgkg^{-1}$ were above the FAO/WHO Soil Quality Guideline value of 35 $mgkg^{-1}$. Results from Kruskall-Wallis non-parametric one-way Analysis of Variance and Dunnett's Test indicated that, for all the four metals, there were highly significant differences ($p<0.05$) between the heavy concentrations of the three sampling areas in the catchment area and the control samples. This suggest the impact of mining on the concentrations of As, Zn, Pb and Fe is high.

Lead, Iron and Arsenic were found to have recorded concentrations in soil above the prescribed standards and their implications on human health are as follows. The implication of excess Arsenic on humans are damage to DNA, infertility and miscarriages with women, skin disturbance, decline resistance to infections, heart disruptions and brain damage with both men and women WHO (2011). The consequences of excess iron can cause premature aging, cancer, osteoporosis, arthritis, diabetes, liver damage and heart and brain disorder. WHO (2011). The health implications of excess Lead (Pb) in drinking water could result in dullness, headaches, muscle tremor, abdominal cramps, kidney damage, poor attention span, loss of memory and encephalopathy, sleeplessness, tiredness and joint pain WHO (2011).

CHAPTER SIX

6.0 CONCLUSSIONS AND RECOMMENDATIONS

6.1 Conclusions

Analyses of satellite images show obvious rapid changes in land cover in the Tano Offin extension Forest Reserve as a result of anthropogenic activities. Fringe communities attributed these changes to mainly logging, chain sawing, artisanal (galamsey) mining and illegal farming. This was confirmed when the sites were inspected during the project. There was an ongoing logging in compartment 10 of the Forest Reserve, artisanal mining in compartment 21, numerous illegally sawn trees and illegal farms in adjacent compartments. It has also been established that, the changes in land cover in compartment 21 is related to the increased mining activities.

Evidence in compartment 21 shows that, natural regeneration in the mining area was very poor as a result of mining pits coupled with the introduction of non-native species in the area. These non-native species may have emerge naturally as a result of changes in ecosystem characteristics and soil quality. To compound the problem Chromolena odorata, (Acheampong) a highly invasive plant has taken over portions of the mining area. This unsustainable mining activity has reduced the ability of the forest to perform some of its ecosystem functions such as protection of water shed, habitat for wildlife, maintenance of soil fertility and carbon sequestration. If care is not taken to control these anthropogenic activities, the once unique forest reserve could lose its integrity and the purpose of its establishment could be compromised.

Secondly, it was obvious that part of the mineral elemental content in the water, soil and sediment samples were as a result of the geochemistry of the underlying rocks. However increases in concentrations of heavy metals in the mining area compared with the unmined areas suggest anthropogenic sources of these heavy metals. Also, it was clear that gold in the area is part of the Ashanti belt which is available in an ore form and is mainly from a quartz vein(quartz with free gold associated with lesser amounts of trace metals such as As, Fe, Pb and Zn and sulphide ore(Arsenopyrite and pyrite).

In spite of obvious anthropogenic impacts, concentrations of some metal such as Arsenic in water samples, Zinc and Lead in sediment samples remained within the limits of international standards. The high level of As concentrations in sediment and soil and that of Pb in soil were above permissible international standards and could pose a threat to human health and aquatic life forms in the Subin River including flora and fauna in the Tano Offin Extension Forest Reserve. The direct impact of high concentration of Pb in water from the Subin River will be on the health of the people of Ataso and other fringe communities who depend largely on the river as a source of drinking water.

Lastly, the study has shown that artisanal miners in the catchment area do not use mercury to recover the gold from the ore in the field but rather uses ordinary water as confirmed by over eighteen miners interviewed within the catchment area.

6.2 Recommendations

Artisanal mining in the forest reserve is illegal and unsustainable due to its destructive approach towards biodiversity conservation, the very purpose for which the forest reserve was established. It requires a multi-institutional approach to the problem. Bringing together all stakeholders involved such as the Minerals Commission, Forestry Commission, Police, Military and the Judiciary would be a good starting point. This should involve the formation of a joint Taskforce constituted by the afore-mentioned institutions, which should be tasked to use existing regulations to evict and arrest the perpetrators of the illegal mining activities in the forest and also their subsequent prosecution to serve as a deterrent to others.

An intensive educational campaign aimed at sensitizing the artisans on the benefits derived from the forest and also the threat posed by their activities on the environment should be pursued vigorously as a matter of urgency. Again, a restoration plan should be drawn and executed so as to bring back the forest to its original state.

Furthermore, since the illegal mining is mainly as a result of poverty and financial constraints, funds should be procured by the government to train the artisans in alternative livelihood ventures (Bee-keeping, Grass cutter –rearing etc.) so as to reduce their dependence on galamsey in the forest reserve for survival. In addition, fringe communities which depend on the Subin River downstream as a source of drinking water should be advised to look for other sources of water because of the health implications associated with contaminated trace metals whose concentrations were above the WHO recommended standards. Prospecting for water in boreholes where the water table is not affected by their anthropogenic activities should be considered.

Lastly, this study can serve as a baseline data for a more comprehensive study that will consider a wider range of heavy metals including the levels of heavy metals accumulating in the tissues of fish and other aquatic organisms in the Subin River. Also, the species characteristics in the mined area after natural regeneration in the forest including species dominance can also be looked at in future.

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APPENDICES

Table 1: Results of the Kruskall-Wallis non-parametric test for sediment Arsenic

Table Analyzed	Sed As Mean		
Kruskal-Wallis test			
P value	0.0273		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	7.200		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstreamvs Midstream	-3.000	No	ns
Upstreamvs Downstream	-6.000	Yes	*
Midstreamvs Downstream	-3.000	No	ns

Table 2: Results of the Kruskall-Wallis non-parametric test for sediment Iron

Table Analyzed	Sed Fe Mean		
Kruskal-Wallis test			
P value	0.0273		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	7.200		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstreamvs Midstream	-3.000	No	ns
Upstreamvs Downstream	-6.000	Yes	*
Midstreamvs Downstream	-3.000	No	ns

Table 3: Results of the Kruskall-Wallis non-parametric test for sediment Lead

Table Analyzed	Sed Pb Mean		
Kruskal-Wallis test			
P value	0.0273		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	7.200		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstream vs Midstream	-3.000	No	ns
Upstream vs Downstream	3.000	No	ns
Midstream vs Downstream	6.000	Yes	*

Table 4: Results of the Kruskall-Wallis non-parametric test for sediment Zinc

Table Analyzed	Sed Zn Mean		
Kruskal-Wallis test			
P value	0.0390		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	6.489		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstream vs Midstream	-5.667	Yes	*
Upstream vs Downstream	-2.333	No	ns
Midstream vs Downstream	3.333	No	ns

Table 5: Results of the Kruskall-Wallis non-parametric test for Arsenic in the water

Table Analyzed	Water As Mean		
Kruskal-Wallis test			
P value	0.0515		
Exact or approximate P value?	Gaussian Approximation		
P value summary	ns		
Do the medians vary signif. (P < 0.05)	No		
Number of groups	3		
Kruskal-Wallis statistic	5.934		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstream vs Midstream	-4.833	No	ns
Upstream vs Downstream	-4.167	No	ns
Midstream vs Downstream	0.6667	No	ns

Table 6: Results of the Kruskall-Wallis non-parametric test for Iron in the water

Table Analyzed	Water Fe Mean		
Kruskal-Wallis test			
P value	0.0390		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	6.489		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstream vs Midstream	3.333	No	ns
Upstream vs Downstream	5.667	Yes	*
Midstream vs Downstream	2.333	No	ns

Table 7: Results of the Kruskall-Wallis non-parametric test for Zinc in the water

Table Analyzed	Water Zn Mean		
Kruskal-Wallis test			
P value	0.0390		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	6.489		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstream vs Midstream	-5.667	Yes	*
Upstream vs Downstream	-2.333	No	ns
Midstream vs Downstream	3.333	No	ns

Table 8: Results of the Kruskall-Wallis non-parametric test for Lead in the water

Table Analyzed	Water Pb Mean		
Kruskal-Wallis test			
P value	0.0273		
Exact or approximate P value?	Gaussian Approximation		
P value summary	*		
Do the medians vary signif. (P < 0.05)	Yes		
Number of groups	3		
Kruskal-Wallis statistic	7.200		
Dunn's Multiple Comparison Test	Difference in rank sum	Significant? P < 0.05?	Summary
Upstream vs Midstream	-3.000	No	ns
Upstream vs Downstream	-6.000	Yes	*
Midstream vs Downstream	-3.000	No	ns

Table 9: Results of the Kruskall-Wallis non-parametric test for soil Arsenic

Table Analyzed	Soil As Mean				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	4				
F	1788				
R squared	0.9985				
ANOVA Table	SS	df	MS		
Treatment (between columns)	20610	3	6869		
Residual (within columns)	30.73	8	3.841		
Total	20640	11			
Dunnett's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
CP vs FP	-81.66	51.03	Yes	***	-86.27 to -77.05
CP vs SP	-95.37	59.59	Yes	***	-99.98 to -90.76
CP vs TP	-104.5	65.30	Yes	***	-109.1 to -99.89

Table 10: Results of the Kruskall-Wallis non-parametric test for soil Iron

Table Analyzed	Soil Fe Mean				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	4				
F	1342				
R squared	0.9980				
ANOVA Table	SS	df	MS		
Treatment (between columns)	10230000	3	3412000		
Residual (within columns)	20340	8	2542		
Total	10250000	11			
Dunnett's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
CP vs FP	-1086	26.39	Yes	***	-1205 to -967.7
CP vs SP	-2561	62.20	Yes	***	-2679 to -2442
CP vs TP	-1595	38.75	Yes	***	-1714 to -1477

Table 11: Results of the Kruskall-Wallis non-parametric test for soil Lead

Table Analyzed	Soil Pb Mean				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	4				
F	377.4				
R squared	0.9930				
ANOVA Table	SS	df	MS		
Treatment (between columns)	22440	3	7481		
Residual (within columns)	158.6	8	19.82		
Total	22600	11			
Dunnett's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
CP vs FP	-108.9	29.96	Yes	***	-119.4 to -98.43
CP vs SP	-100.1	27.53	Yes	***	-110.5 to -89.60
CP vs TP	-84.43	23.23	Yes	***	-94.90 to -73.96

Table 12: Results of the Kruskall-Wallis non-parametric test for soil Zinc

Table Analyzed	Soil Zn Mean				
One-way analysis of variance					
P value	P<0.0001				
P value summary	***				
Are means signif. different? (P < 0.05)	Yes				
Number of groups	4				
F	408.4				
R squared	0.9935				
ANOVA Table	SS	df	MS		
Treatment (between columns)	27170	3	9057		
Residual (within columns)	177.4	8	22.18		
Total	27350	11			
Dunnett's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	Summary	95% CI of diff
CP vs FP	-117.4	30.53	Yes	***	-128.5 to -106.3
CP vs SP	-110.0	28.60	Yes	***	-121.0 to -98.89
CP vs TP	-99.27	25.82	Yes	***	-110.3 to -88.19