IMPACTS OF FLUORSPAR MINING ON THE PHYSICAL ENVIRONMENT: A CASE STUDY OF KIMWARER AREA KERIO VALLEY, ELGEYO-MARAKWET COUNTY, KENYA

DIXON KIPTANUI

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DECLARATION

DECLARATION BY THE CANDIDATE

This thesis is my original work, which has not been presented in any other university for a degree.

Signature Date

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DIXON KIPTANUI
(SES/PGP/20/11)

DECLARATION BY THE SUPERVISORS

This thesis has been submitted with our approval as university supervisors.

Signature Date

………………………………… …………..……………………………...

Prof. Elias K. Ucakuwun
School of Environmental Studies
Department of Environmental Earth Sciences
University of Eldoret

Signature Date

………………………………….. ………………………………………

Dr. Thomas M. Munyao
School of Environmental Studies
Department of Environmental Earth Sciences
University of Eldoret

DEDICATION

I dedicate this work to my parents, Mr. and Mrs. John Tomno Cheserem, to my brothers, Rogers, Denson and Alex, to my sister, Emma and to all my friends.

ABSTRACT

The research is based on the Impacts of mining fluorspar on the physical environment at Kimwarer Area, Kerio Valley Elgeyo-Marakwet County, Kenya. Therefore this study has been carried out to establish environmental impacts of fluorite mining industry on topography and land cover. The objectives of the study were to; determine the trend and extent of fluorite mining on topography; assess the rate of change on the land cover in the fluorite mining environment and establish the amount of materials generated over a given period of time. The scope of the study area was approximately 7000 acres covering the mining lease area and some areas outside the lease. The target factors of the physical environment that were considered were the topography and land cover. Data was collected by the use of geological field methods, land survey, photography, observation and remote sensing. The salient data displayed a significant change in topography where the mining area increased from 37 acres in 1984 to 461 acres in 2010. The change is evidenced by the presence of open pits, dam tailings and waste dumps within the mining area. The data also displayed the change in land cover especially the forest land decreasing from 2717 acres in 1984 to 1835 acres in 2010. The change is evidenced by the bare land, areas of settlement and also areas that have been cleared for mining. In conclusion, fluorite mining has had major impacts on the physical environment with change in topography and vegetation cover. These changes are more on the negative than on the positive. This study recommends adopting various methods of rehabilitation of mined out areas and reforesting the areas that had been cleared and are not under mining anymore and government implementation on rehabilitation processes in the mining sector.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

LIST OF PLATES

ACRONYMS

CaF_2 : Calcium Fluorite (Fluorspar)

DEM : Digital Elevation Model

DTM : Digital Terrain Model

EPA : Environmental Protection Agency

GIS : Geographic Information System

GPS : Global Positioning System

JORC : Joint Ore Reserves Committee

KFC : Kenya Fluorspar Company

NLCD : National Land Cover Data

NRC : National Research Council

UNESCO : United Nations Educational Scientific and Cultural Organization

USGS : United States Geological Survey

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To Kenya Fluorspar Mining Company, who gave me the opportunity to do this research within their jurisdiction and the vital information that made the research a success. And to Geologist Christopher Cheruiyot and Surveyor Hillary Cherop, thank you for moving with me out in the hot scotching Kerio valley sun to collect data. Not to forget, my heartfelt thanks to ‘Mama Kibiwott’ for the accommodation during the field data collection.

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CHAPTER ONE

INTRODUCTION

1.1. Background Information

Mining entails removing of materials from the surface or subsurface of the earth, separating the required ore from the gangue and dumping the unwanted rock and other solid waste materials. Mineral deposits exist in some prescribed locations dictated by geology and therefore mining activities are not subject to rational selection or advanced planning as in the case of renewable resource activities such as fishing, forestry and agriculture. Minerals further exist in unique physical conditions associated with their location; there is no choice about the characteristics of their ecological setting, biological and chemical features and mineral compositions. All these factors influence the ultimate design, layout and size of the operation as well as common environmental considerations (Davies, 1993).

The situation facing mining and mineral processing industry has been particularly demanding in recent decades, as the extent of its effects on the environment has become clearer and the general public concern over this issue has increased (Ripley, 1996). These minerals are materials which are the foundation of our contemporary way of life and society expects to be able to continue using them. Ripley still notes that environmental impacts of mining are an extremely complex topic because it involves so many geographical, technical, scientific and socio-economic issues.

Problems can arise if no measures are taken to rehabilitate a mining area and make it safe. Unrehabilitated mines can cause visual pollution. If rehabilitated the area can be made safe again and it can be returned close to its original state. Habitats are often destroyed when a mine is built and this can have a serious impact on the ecosystem of an area. The creation of a mine can cause habitat destruction for many animals and plants and threaten their existence. Some mining activities require a considerable amount of water and in an area where water is a scarce commodity this can cause huge problems (Barnard, 1998).

Fluorite is an important industrial mineral composed of calcium and fluorine (CaF_2). It is used in a wide range of varieties of chemical, metallurgical and ceramic processes. Fluorite is deposited in veins by hydrothermal processes. In these rocks it often occurs as a gangue mineral associated with metallic ores. Fluorite is also found in the fractures and cavities of some limestones and dolomites. In the mining industry fluorite is often called ‘fluorspar’ (geology.com 2005).

Mineral fluorite occurs in Kimwarer are, Kerio Valley, Elgeyo-Marakwet County in Kenya. The Kerio Valley fluorite deposit is one of the major suppliers of acid grade fluorspar to the world market. To date it has produced more than half a million tons of acid grade, (+ 97% CaF_2 mostly within the last seven years) and about 175,500 tons of metallurgical grade (+ 75% CaF_2 mostly in the year 1975 but later abandoned production of this grade) (KFC 2008).

1.2. Statement of the Problem

Mining activities have been viewed by both environmentalists and conservationists as causing environmental problems. These activities have resulted in varying degrees of environmental damage in the mining areas, which are mainly located in remote areas. Mineral existence in some prescribed areas has resulted in human displacement and health problems; the indigenous people are forced to settle in adjacent areas. This has resulted in heavy de-vegetation to pave way for settlement and agricultural activities, which accelerate soil erosion and land degradation.

(Farkas, 2005) concedes that mining activities changes the landscape as well as land use pattern of an area. Some of the conspicuous environmental impacts of mining include destruction of the landscape, therefore, causing aesthetic problems (through degradation of visual environment); disturbance of water courses; destruction of agricultural and forest lands; sedimentation and erosion as well as land slide and/or subsidence.

Some of the major economic minerals in Kenya (such as fluorite) are mined using open cast technique, which is environmentally destructive relative to underground mining. Over the past fifteen years or so, there has been a marked increase in open cast fluorite mining in Kenya from 96,000 metric tonnes to 200,000 metric tonnes per annum in 1981 and 1996 respectively (Republic of Kenya, 1996). The geological nature of this valuable rock (occurring at the surface or near surface) has prompted the use of the open cast mining technique.

Physical impacts occur as a result of mining activities on any area during and after the mining operations. During mining or quarrying, vegetation and soil covers are removed to facilitate the extraction of minerals or rocks by digging pits, trenches, etc. Explosives may be used to blast the rocks. This leads to the distortion of the landscape into scarred, disfigured and very different from the original state. These results in soil erosion by wind and run-off water that leave the rocky outcrops bare. It also causes pollution as dust and fumes are injected into the atmosphere while soil particles end up in watercourses as sediment.

Unfilled pits and trenches of varying sizes and depths may act as water reservoirs during the rainy seasons, which may become dangerous death traps for human and animal population. They may also become breeding areas for harmful insects such as mosquitoes and other microorganisms. Excavations and use of explosives near roads and water or oil and gas pipelines can influence localized earth movement such as mudflows and landslides that cause damage to the environment.

Mining is an activity that takes place in series or phases beginning from exploration to appraisal to mineral exploitation to transportation and finally selling the end product to the market. All these stages of mining result to some degree of environmental disturbance and finally destruction mainly to the landscape and the natural fauna and flora. In Elgeyo-Marakwet County, fluorspar mining in Kerio Valley has gone through all these phases and mining activities are still ongoing. Anthropogenic processes such as mining has been known as one of the cause that result in movement of large amount of material within a very short period of time hence causing significant environmental impacts as compared to other land use activities.

1.3. Main Objective of the Study

To study the impact of mining fluorspar on the physical environment in Kimwarer Area, Kerio Valley.

1.3.1. Specific Objectives

The Specific objectives were;

- i. To determine the trend and extent of permanent change in topography as a result of fluorite mining in Kerio Valley.
- ii. To assess the rate of change in land cover in the fluorite mining environment.
- iii. To establish the amount of overburden and mine tailings generated from the fluorite mine over a given period of time.

1.3.2. Research Questions

- i. What are the main factors that are responsible for the trend and extent of topography change within the mining environment?
- ii. What was the state of the land cover before mining and how is the state currently?
- iii. What quantity of mine waste is generated within a given period of time and where is the waste dumped?

1.4. The Study Area

1.4.1. Location

The Kenya Fluorspar Mines concession is situated at the head of the Kerio Valley in Kimwarer Area, Elgeyo-Marakwet County within the East African Rift System. The area is bounded by 0°19’N and 0°22’N latitudes and 35°35’E and 35°38’E longitudes. The Kimwarer River and other small rivers, tributaries of the Kerio River, originate in the escarpment headlands to the south and flows past the mine site (UNESCO report, 1981).

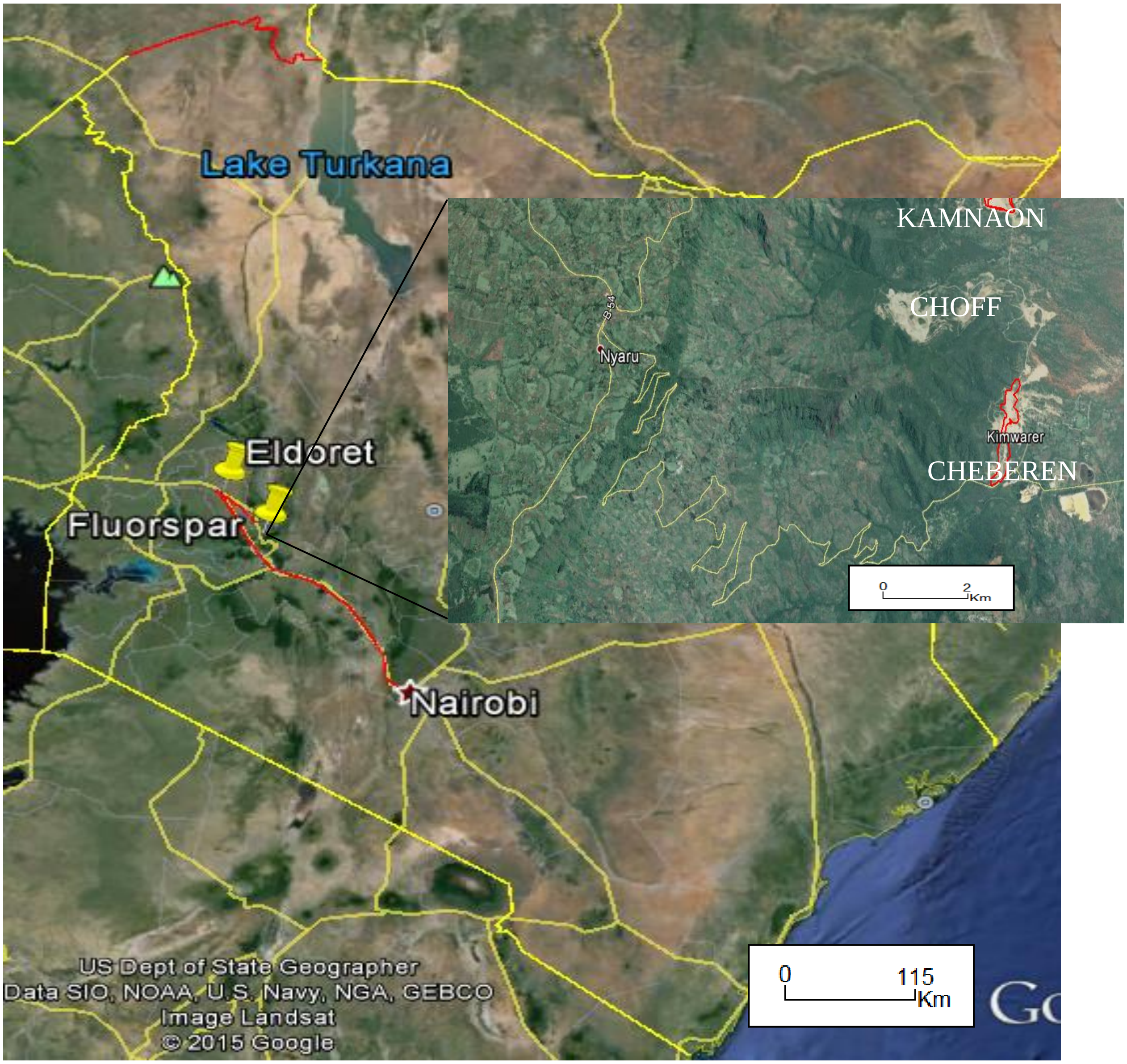


Figure 1: Google earth map showing location and road map to Kenya Fluorspar Mine (Source: Google Earth, 2015)

1.4.2. Accessibility

From Eldoret Town, the fluorspar mine can be accessed most directly through the Eldoret-Eldama Ravine tarmac road up to Nyaru. An all-weather road maintained by the mining company descends into the Kerio Valley from Nyaru through the rift escarpment; a distance of about 24 km to the mine**.**

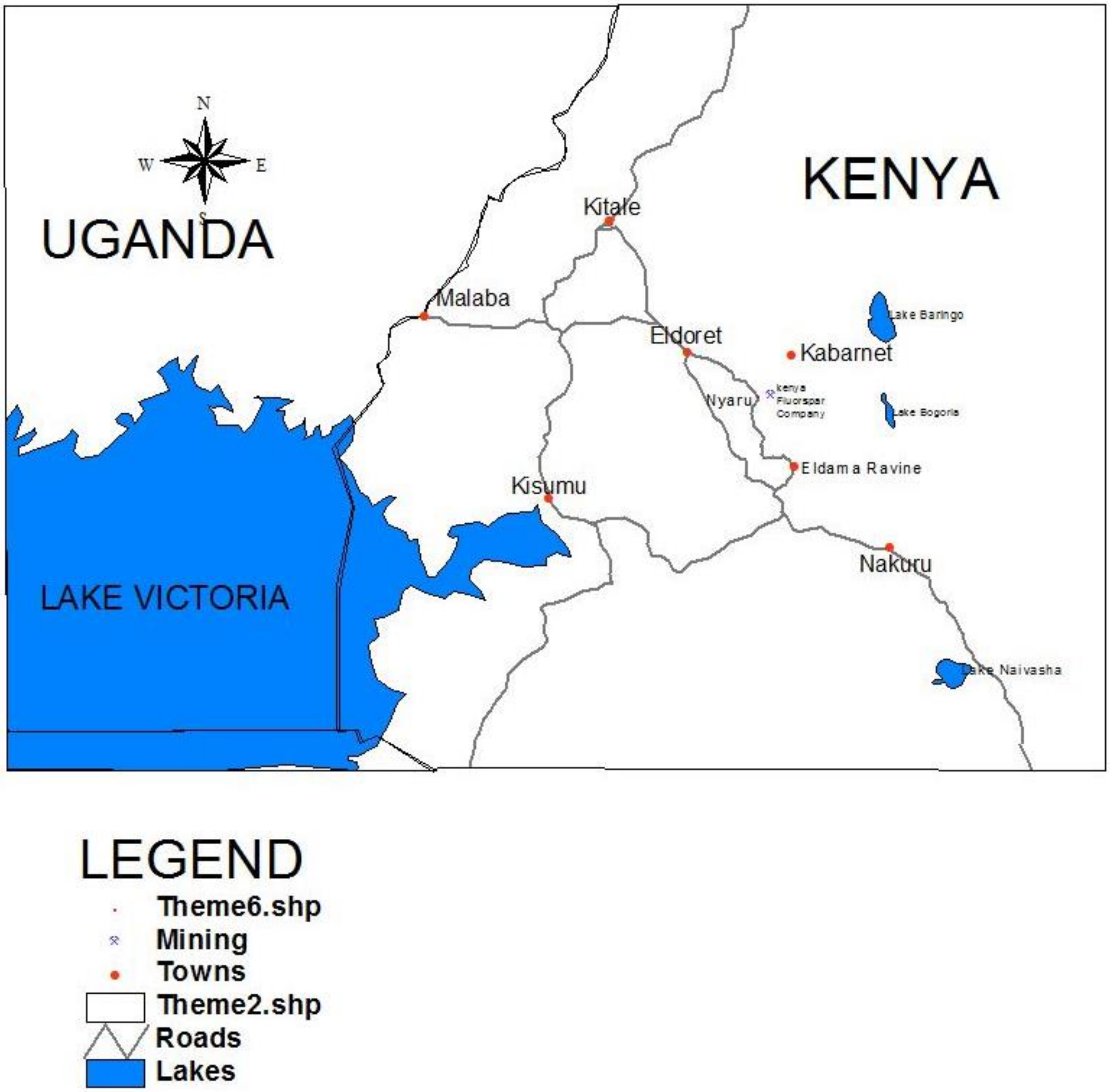


Figure 2: Sketch map showing location of the Study Area (Source: author, 2013)

1.4.3.Geology

Kerio Valley is an elongate, cone-shaped Tertiary tectonic graben within the Gregory Rift of Kenya. Its narrow southern tip straddles the highest culmination of the Kenyan dome of uplift, volcanicity and faulting. Towards the north, it fans out into a broad, shallow, alluvial-filled depression that contains the Lake Turkana inland drainage basin.

The western wall of the rift, standing at about 2700 m altitude in the south, is represented by the Elgeyo Escarpment. To the east lies a complex igneous horst which forms the Tugen Hills (average altitude 2500 m) and whose valley floor lies at about 1300 m altitude in the south, and slopes northwards to Lake Turkana.

The Kerio Valley is unique in that it forms a window in the greatest pile of the rift volcanics, to reveal the foundation of metamorphic rocks. These rocks have an important bearing on the concept of global tectonics. These foundation metamorphic rocks are mineralized by the Tertiary hydrothermal fluids directly related to the genesis of the Rift Valley (UNESCO Report 1981).

The fluorite deposits occur within the Basement rocks of the Mozambique Belt in the Kerio Valley. The mineral has been deposited from hydrothermal solutions emanating in tension fractures and along late minor faults. The fluorite bodies have largely replaced crystalline limestone and to a minor extent the fault-breccias. Four colored varieties of fluorite have been found in the area, namely white, yellowish-brown, dark-grey and violet varieties. The paragenesis of the different varieties of fluorite consists of three stages of deposition which, however, appear to have been continuous and gradual. The study of the paragenesis of the three stages is based on the apparent stratified form of the varieties of the fluorite bodies as observed in the field, the crystallization temperatures of the associated minerals, a complexity of crystal forms in the different varieties of fluorite: white and yellowish-brown varieties were deposited first, followed by dark-grey one and lastly the violet variety. The crystallization temperature decreased with the sequence of deposition in the three stages (Nyambok, 1975).

The mineralized zones at Kimwarer are situated within north, northeast, and northwest trending shear zones with intense hydrothermal alteration. The host rocks are alternating units of steeply dipping to sub-horizontal quartzofeldspathic gneiss, marble, biotite gneiss and quartzite of Precambrian age. Surface traces of the mineralized units, interlayered with the metasedimentary rocks, indicate that they may represent an isoclinal folded sequence. In general, the surface traces of the mineralized zones coincide with topographic contours, and in places, with areas of topographic lows and the alteration/mineralization zone ranges in width from 50 m to 140 m. The main lithological units observed on the property consist of (Nyambok, 1978):

- Hornblende-biotite gneiss: Dark, coarse-grained, poorly to well foliated rock, with minor garnet and pyrite.
- Quartzofeldspathic gneiss: Grey, pink to brown, coarse-grained rock with common sericitic mica, and medium- to coarse-grained garnet porphyroblasts.
- Pegmatite: Composed of coarse feldspar, quartz and biotite.
- Marble: White, pink and brown crystalline rock.
- Diabase dykes

1.4.3.1. Lithology

The crystalline, reworked, metamorphic rocks are seen as outcrops in the foothills of the Elgeyo Escarpment. These are assigned to the Basement System of the Upper Precambrian age; they were affected by the last orogenic cycle, termed the Mozambiquian event. The bulk of the crystalline rocks are paragneisses that is hornblende, and hornblende-biotite gneisses. There are numerous intercalations, generally narrow and lenticular, of calcareous and psammitic gneisses such as marbles and quartzfeldspar granulites and quartzites. The hornblende and hornblende-biotite gneisses are generally dark, coarse grained and show poorly developed foliation. There is a tendency in these rocks for the light components of feldspar and quartz to segregate from the dark minerals such as hornblende and biotite (Compton, 1965).

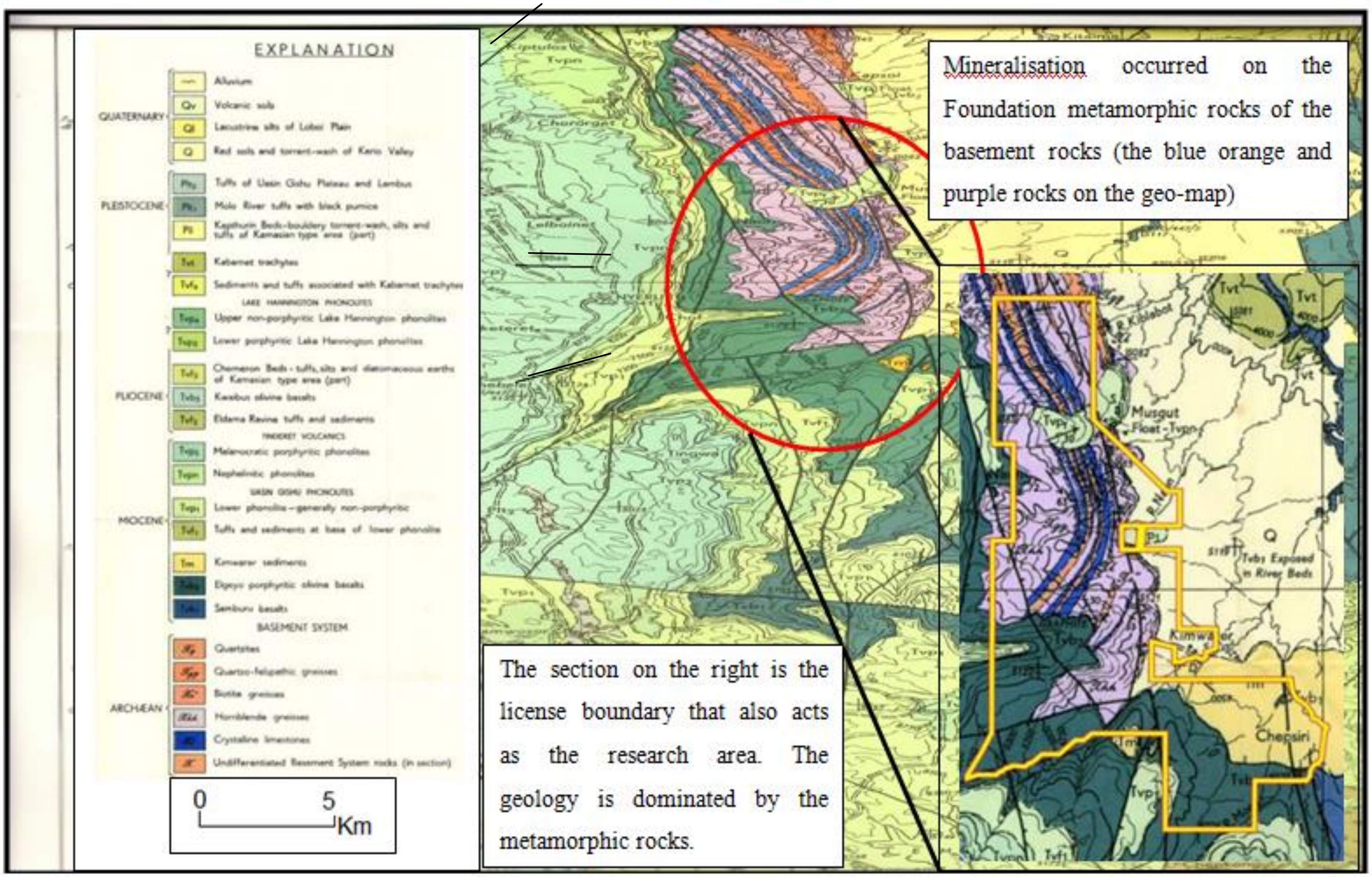
The quartz-feldspar gneisses and quartzites are generally light in colour to almost pure white, but are frequently iron stained to reds and browns. The grains are coarse and show poor foliation, the texture frequently approaching that of granulites. There are almost always a few flakes of mica between the grains of quartz. Only very minor amounts of crystalline limestone are encountered in the southern part of the mines area, but further north they become more pronounced. When seen, they range in colour from pale white and pink to mottled browns and black. They are generally fine grained, but recrystallization results in granular textures. These Precambrian metamorphic rocks are overlain by Tertiary sediments, which are conglomeratic at the base, passing upward into finer members, through grits to sands and silts. The latter are generally well lithified, creamy to pale buff in colour, and obviously derived from the older metamorphic rocks. However, in the upper members of the fine grained sediments, some tuffaceous material is also present. These sediments in turn are overlain by Tertiary lavas and pyroclastics. The Elgeyo volcanic sequence passes underneath the Tugen Hills and is composed of a similar and correlated sequence of basalts, phonolites and trachytes (Nyambok, 1975).

1.4.3.2. The Orebodies

The fluorite orebodies occur along a tract some ten kilometres long and about three kilometres wide, at the foot of the Elgeyo escarpment, and stretch from Kimwarer ridge to Muskut (Figure 10). That the mineralization (introduction of fluorite, silica, iron ores, etc.) was fault controlled is indicated by its Tertiary age, the parallelism of the line of ore deposits, and the location of the source in the waning phase of an igneous cycle. However, the localization of conformable deposits suggests that replacement of lenticular limestone bodies occurred.

There are three main orebodies that stretch the ten kilometers (UNESCO Report, 1981), these include:

i. Cheberen Orebody
ii. Choff Orebody
iii. Kamnaon Orebody



Mineralisation occurred on the Foundation metamorphic rocks of the basement rocks (the blue orange and purple rocks on the geo-map)

The section on the right is the license boundary that also acts as the research area. The geology is dominated by the metamorphic rocks.

Figure 3: Geologocal map of the Eldama Ravine – Kabarnet area; Degree map sheet 34; Ministry of Natural resources and Wildlife; (Source: Mines and Geology Department, Kenya)

1.4.4. Climate and Vegetation

The climate and vegetation of the mine area are controlled by the terrain. The present rift morphology evolved from the last three principal pulses accompanied by the concomitant down warps of the rift axial zone, voluminous flooding by eruptives and followed by spectacular fault displacement. The Elgeyo escarpment which reaches about 2700 m at Nyaru has a temperate climate and lush vegetation, while the mine area below in the valley, at about 1350 m, is rather warm and semi-arid with its stunted thorny bush, characteristic of most of the axial rift zones of Kenya (UNESCO Report, 1981).

1.5. Justification of the Study

Fluorite mining is a good thing as the minerals mined are used to improve our standards of living yet it is also considered destructive to the environment. However, despite the economic value fluorite mining has on the Kenyan economy in terms the foreign exchange earned, the whole process of mining on the resource has been responsible for the physical environmental impacts on the Kerio Valley Environment. This research therefore ought to study the extent to which fluorite mining has influenced the change in vegetation cover and topography.

This is not the only mine in Kenya and moreover many new discoveries of minerals are made in the country. This means that mining will not stop as long as there is demand for minerals. The aim of this research is to try and understand more on the relationship between mining and the environment.

Though mining is considered temporary and the companies involved have decommissioning plans ahead of the mining activities, the damage that is done to the environment extends to very large expanses and remediation is of less importance. Thus there is need to undertake this important study to provide information on the physical environment vis a vis topography and land cover and to determine ways of minimizing the negatives and maximizing the positives; provide information for future reference in the study of mining and the environment.

CHAPTER TWO

LITRATURE REVIEW

2.1. Mineral Economics

Ore is a word used to prefix reserves or body but the term is often misused to refer to any or all in situ mineralization. The Australasian Joint Ore Reserves Committee (2003) in its code, the JORC Code, leads into the description of ore reserves in the following way: "When the location, quantity, grade, geological characteristics and continuity of mineralization are known, and there is a concentration or occurrence of the material of intrinsic economic interest in or on the Earth's crust in such form and quantity that there are reasonable prospects for eventual economic extraction, then this deposit can be called a mineral resource. Mineral Resources are subdivided, in order of increasing geological confidence, into Inferred, Indicated, and Measured categories."

The JORC Code then explains that "an ore reserve is the economically mineable part of a Measured or Indicated Mineral Resource. It includes diluting materials and allowances for losses that may occur when the material is mined. Appropriate assessments, which may include feasibility studies, have been carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social, and governmental factors. These assessments demonstrate at the time of reporting that extraction could reasonably be justified. Ore Reserves are sub-divided in order of increasing confidence into Probable Ore Reserves and Proved Ore Reserves."

"The term 'economic' implies that extraction of the ore reserve has been established or analytically demonstrated to be viable and justifiable under reasonable investment assumptions. The term ore reserve need not necessarily signify that extraction facilities are in place or operative or that all governmental approvals have been received. It does signify that there are reasonable expectations of such approvals." An orebody will be the portion of a mineralized envelope within which ore reserves have been defined. Ore minerals are those metallic minerals, e.g. galena, sphalerite, chalcopyrite, that form the economic portion of the mineral deposit.

“Industrial minerals have been defined as any rock, mineral or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels and gemstones” (Noetstaller, 1988). They are therefore minerals where the mineral itself, e.g. asbestos, baryte, or the oxide, or some other compound derived from the mineral, has an industrial application (end use). They include rocks such as granite, sand, gravel, and limestone, that are used for constructional purposes (these are often referred to as aggregates or bulk materials, or dimension stone if used for ornamental cladding), as well as more valuable minerals with specific chemical or physical properties like fluorite, phosphate, kaolinite, and perlite. Industrial minerals are also frequently and confusingly called nonmetallic (Harben and Kuzvart, 1997), although they can contain and be the source of metals, for example sodium derived from the industrial mineral halite. On the other hand, many deposits contain metals such as aluminum (bauxite), ilmenite, chromite, and manganese, which are also important raw materials for industrial mineral end uses.

2.2. Mineral Mining

Mineral products are at the core of today’s civilized world that we live in. The manufacturing sector, the high technology industries and even the resource industries are all dependent, in one way or the other on the mining industry. In order to achieve national and industrial development, any country including Kenya requires large supplies of raw materials such as aggregates for the construction industry and other metallic and nonmetallic industrial minerals. Mining must be carried out in the process of trying to satisfy this demand.

Mining is any activity that involves excavating the earth surface for the purpose of exploiting and processing the mineral wealth for economic and industrial development both for local and export markets. This process normally has a negative impact on the environment.

There are two main methods of mining;

a) Underground mining
b) Open cast mining

Mining involves removal of rocks from the ground (Hartman, 1987). In general, deposits within 100m of the surface are extracted from open pit mines and those at greater depths come from underground mines (Figure 4). Deposits with intimate mixtures of ore and worthless rock are usually mined by bulk extraction methods, whereas rich zones of ore are often mined by more selective methods. Open-pit mining is always less selective than underground methods. In general, the cost and difficulty of mining increase with depth and extremely deep ore deposits are not minable at a profit by any method.

A typical open pit mine removes ore and overburden, the worthless rock that overlies ore. The ratio between the volumes of overburden and ore, known as stripping ratio, rarely exceeds 10 and commonly less than 5. The overall slope of the pit wall must be low enough to prevent failures by landslides and the pit walls have steps known as benches that prevent rock from falling to the bottom where people are working.

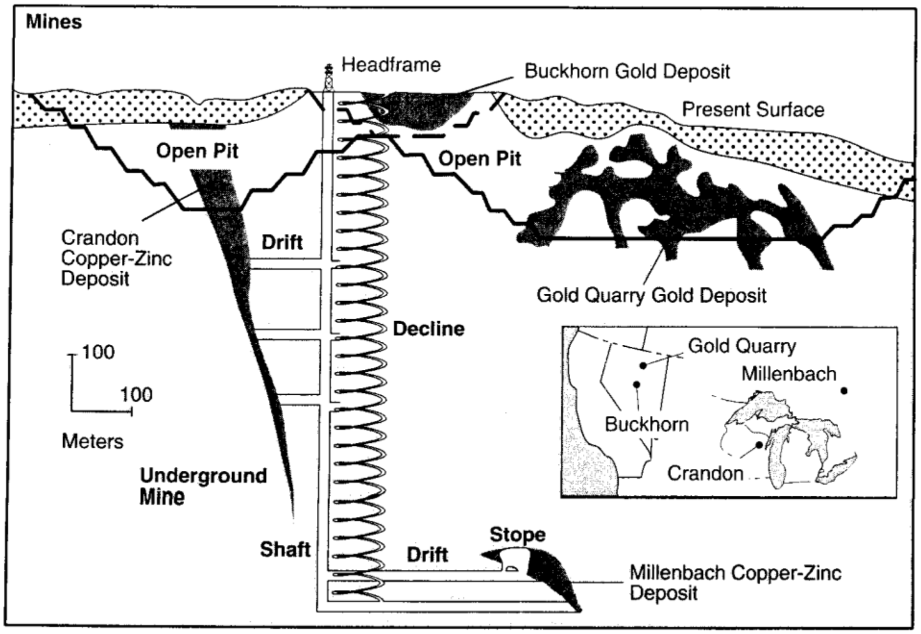


Figure 4: Case Model showing the workings of both surface and underground mining: the case of Millenbach, Buckhorn and Crandon of the United States (Source: Stephen K, 1994).

2.2.1. Open-casting Mining

This refers to uncovered excavations made on the ground for the purpose of mineral or rock exploitation such as the open quarries, pits and trenches. This is the most common method of mining in Kenya, in particular in the Coast Province where there are abundant mining activities. Examples of these includes gemstone mines like Kapanga, Kasigau and Mangare areas of Taita-Taveta district, Bamburi Portland cement quarries, Jaribuni, Iron ore works, Roka gypsum workings, Kokotoni Ballast quarries, Maji ya Chumvi slab quarries at Mariakani and Taru all in Kilifi district and Msambweni glass sand or silica sand quarries, just to mention some (Republic of Kenya, 1996).

Mining activities, whether done by open cast or underground method, affects the environment. However, of the two methods, opencast is more environmentally destructive. Inclusion of environmental protection costs in a mining activity increases costs of production and ultimately prices, hence becomes less competitive in world markets. Integrated mineral policies in developing countries in particular are desirable. In Thailand for example, a combination of mineral policies, environmental policies, legislation and administration has resulted in a balance between mineral development and environmental concerns (Interapravich and Clark, 1994).

However, not all mining activities adversely affect the environment. Environmental degradation resulting from mining activities depend on the technology, existing land rehabilitation policies and personal ethics – for one to feel obliged to reclaim the land after mining. Hadoto (1995) supports this idea; and that Kilembe Mines in Uganda did not have extensive and blatant adverse environmental impacts from 1956 to 1976 because the mine employed safe and standard methods of exploration, development and exploitation. It mainly used wet ‘cut- and- fill’ mining methods, planned and stabilized stacking of tailing and the cobalt-bearing pyrite concentrates were some of the methods used to maintain a clean environment.

Although the local exploitation of minerals may be beneficial as a source of urgently needed as a source employment, the environmental consequences of mining, mineral processing's operations and metallurgical industries must be monitored closely to avoid possible destruction of other natural resources. The problems caused by road constructed without proper consideration of ecological constraints may be somewhat less insidious, although in fragile environments, cuttings and landfills along their route commonly lead to drainage problems and landslides. Furthermore, roads provide increased access to the hitherto remote areas therefore encouraging subsistence farming hence initiating destruction of new areas (Ruddle and Manshard, 1981).

2.2.2. Mineral Mining Techniques and Environmental Effects of Mineral Exploitation

Underground mining affects the environment in two ways: acid drainage, which is caused by air and water coming into contact with sulfur or carbon baring rocks and then groundwater flow, carries this acid to streams. While this problem is not common in Kenya, it is mainly observed in the Appalachians where streams have become too acidic to support fish; the water has become acidic and therefore unfit for human consumption. In some cases, land subsidence is common and this result in structural damage to buildings overlying mined areas and is a prevalent problem in Pennsylvania and other areas where underground operations are taken (Cutter *et al*., 1991).

Open cast mining is an environmentally destructive mining technique compared to underground. The overburden must be removed, and this changes topography and soil pattern of the area. The overburden in most cases is exposed to agents of erosion such as wind and air and this leads to a lot of sedimentation downstream or in the valleys. The runoff water from these areas is usually very acidic and therefore aquatic lives, vegetation, animals and human beings are threatened by this. Land sliding is also an environmental problem of open cast mining, especially in the hilly areas such as those of Kerio Valley (Cutter *et al*. 1991). However, land rehabilitation is the best way of returning the natural scenery of the mined area; that to facilitate this, top soil is removed and kept aside and later used to rehabilitate the area after mining. Planting of appropriate vegetation type is desirable in the mined land.

Mining activities normally generate a lot of noise, dust, toxic fumes and solid or liquid waste effluent which finds its way into the surroundings, causing pollution into the environment. It often competes with ecologically protected zones such as National Reserves and gazetted forests. It poses, just like any other industry, both environmental and safety hazards which are contributed to by tending to mine on a dig-and-dump basis to win both precious, or semi-precious and industrial minerals in increasing quantities causing adverse effects on the environment at local or regional scale.

These effects can either be physically or chemically influenced depending on the mining activities. Mining disturbs land by removing surface vegetation and changing topography and affects hydrological functions and water quality, causes soil erosion and stream sedimentation that cause death of trees along river banks, produces dust, lowers the water tables or destroys wildlife habitat. The additional vehicular traffic around a mine site brings noise, mine accidents and increases wear on the roads.

2.2.3. Mineral Resource Development and Fluorite Mining in Kenya

Mineral resource developments are the chemical and physical processes in which the excavated ores and rocks are prepared for local and export markets either as finished products or preparing them for further industrial processes. These operations involve both physical and chemical treatment methods and vary from one industry to the other depending on the ores being mined. For instance minerals such as barites ($BaSO_4$) or Galena (PbS) are separated from gangue minerals such as quartz, clay and soils by density as they are heavy minerals while gold is separated from its ore or lead from sulphur through complex physical and chemical processes such as floatation, smelting and cyanidation.

Within the fluorspar mine in Kerio Valley, ore from the mine is crushed to produce smaller particles which then undergo floatation. Flotation is the process that concentrates the ore. This is done by agitating the ore slurry in cells with air bubbles. By adding a combination of fatty acid reagents, the fluorspar in the ore attaches itself to the air bubble to float to the top of the cell. This product is skimmed off leaving the waste in the bottom of the cell.

The process is conducted in a series of "rougher" and "cleaner" cells that successively concentrates the ore from 40% CaF_2 in the feed material to a minimum of 97.0% CaF_2 in the final concentrate. The water in the final product is then removed in a thickener and a rotary drum filter. This produces a filter cake concentrate containing approximately 11.0% moisture. The samples are analyzed in the company's assay and research laboratory. The waste product is pumped to the tailings dam and settled water is recycled to the plant for reuse. Figure 5 shows a flowchart of the beneficiation process of fluorite (KFC 2008)

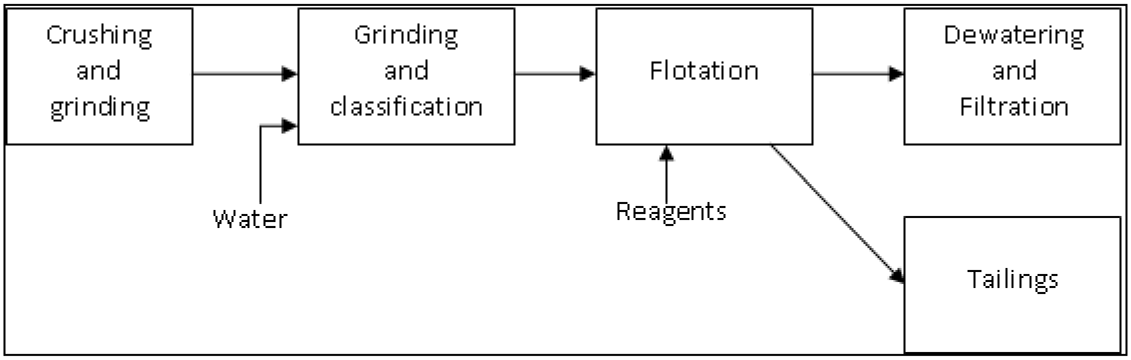


Figure 5: Simplified flow chart of the beneficiation stage of mining where ore is comminuted and separated into its desired concentrate and tailings fraction (Source: Modified from KFC process, 2013)

The department of Mines and Geology in Kenya has continued mineral research aimed at maximizing benefits from its mineral resources (through exploitation of these resources) while occasioning minimum environmental degradation. Mineral resources play a significant role in the country's economy and used as basic raw materials in the industrial sector, involving chemical, building and construction, agriculture, ceramics, metals and engineering, gemstones and jewelry. Those outstanding economic importance including soda ash from Lake Magadi, fluorite from Kerio Valley and limestone from Mombasa (Republic of Kenya, 1996).

2.2.4. Significant Topographic Changes in the United States

Direct anthropogenic processes create several types of landform modifications that remain as a distinct imprint on the topographic landscape.

According to the label assigned from the National Land Cover Data Base (NLCD) to each change polygon, mining is the predominant land use/land cover represented in the topographic change inventory. This is not surprising, as surface mining operations have been previously identified in the literature as the largest direct anthropogenic process in terms of the amount of material moved. Further evidence of the dominance of mining as the primary human geomorphic activity is seen in its contribution to the total volume of material moved as calculated from the entire topographic change dataset (USGS, 2008).

The polygons labeled with mining as the majority land cover account for 57.5 percent of the total number of change polygons, but they contribute 74.9 percent of the total volume of material moved. It is likely that this contribution from mining is even higher, as many of the polygons included in the change mask because of their close proximity to mine locations also are probably mines that were not yet in operation at the time of NLCD source data collection (USGS, 2008).

Some of the most notable examples of the topographic surface changes resulting from mining are seen in the Appalachian coalfields where mountaintop mining is a commonly used approach for coal extraction. Although the practice of mountaintop mining has been used since the 1970s, it continues to be a controversial issue, with ample documentation both supporting and criticizing it. Regardless of the arguments for and against mountaintop mining, it is without dispute that a significantly altered landscape is the result of the practice (USGS, 2008).

Remote sensing and other geospatial data, including multi-temporal elevation data, have been used to successfully map and describe landform features associated with mountaintop mining. In mountaintop mining operations the ridges are removed to expose the coal seam, and the overburden from the excavation is deposited into the heads of adjacent valleys, graded, and stabilized. In terms of topographic change detection through DEM differencing, the area of ridge removal is indicated by a significant decrease in elevation, while the adjacent valley fills appear as areas of significantly increased elevation. In the context of movement of materials by geomorphic processes, the mountaintop removal is the initiation of motion (erosion), the agent of motion (transportation) is the dragline excavator and truck, and the cessation of motion (deposition) is the valley fill (USGS, 2008).

Figure 6 shows a mountaintop mining area in Perry County in eastern Kentucky. In the middle panel, the blue areas represent significant elevation decreases (mountaintop removal), and the red areas represent significant elevation increases (valley fills). The spatial arrangement of the adjacent blue and red polygons (cuts and fills, respectively) separated by a thin area is the characteristic signature of mountaintop mining in the highly dissected topography of the central Appalachians. Clearly, the areas between the leveled ridges and filled valleys have also been disturbed, although the observed vertical differences in those areas were not large enough to exceed the significant change threshold bounds. This illustrates one of the limitations of using just elevation change to detect human geomorphic activity: the individual change polygons may not delineate the entire disturbed area. Although the elevations between adjacent cut and fill polygons have not changed enough to be detected, mining has generally flattened the entire area, so the distribution of local slope and aspect values has been significantly altered (USGS, 2008).

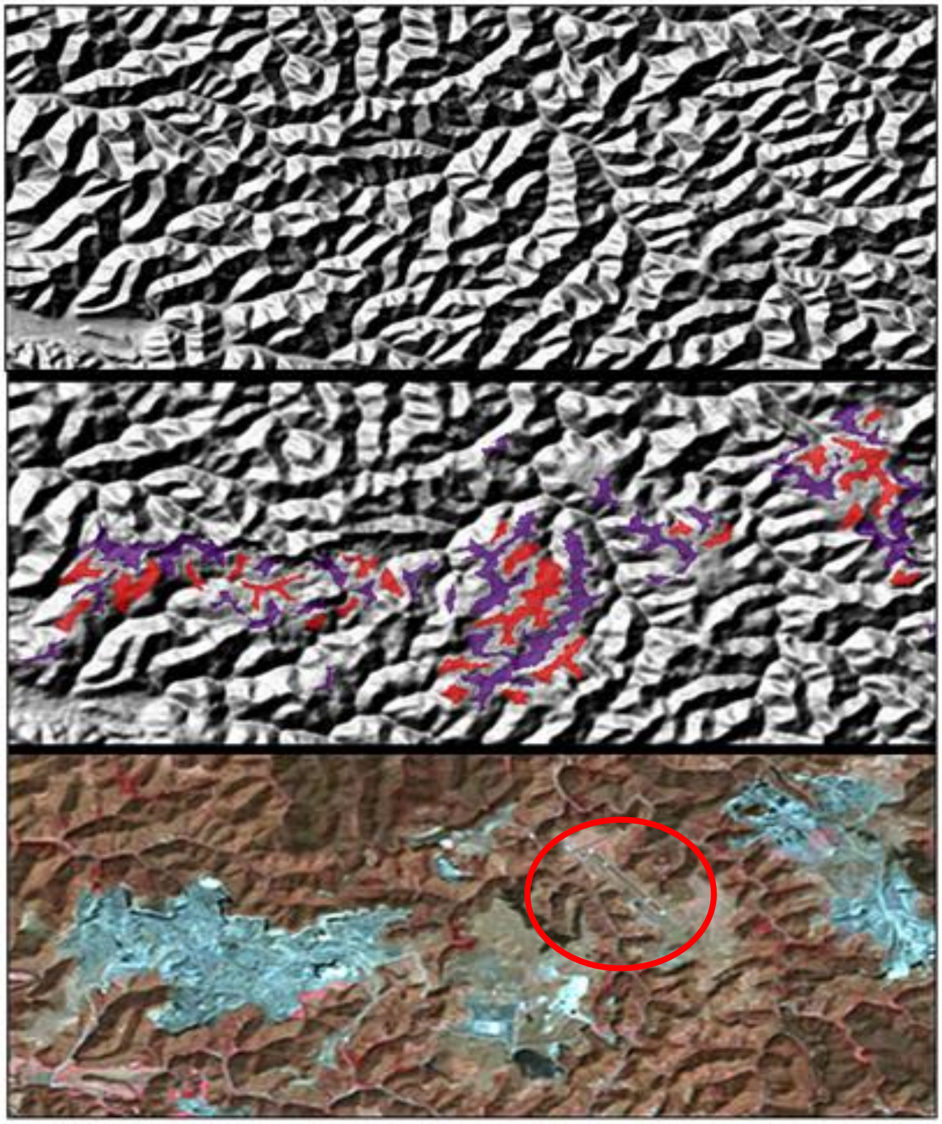


Figure 6: Example of topographic change caused by mining in Perry County, Kentucky. The images are NED shaded relief (top), cuts (blue) and fills (red) overlaid on SRTM shaded relief (middle), and Landsat image (color infrared rendition). The arrow points to an airport built on new flat land created by the mining process. The area shown is about 12.5 km east-west by 6.5 km north-south. (Source: USGS, 2008)

The Landsat image (bottom panel) in the figure above illustrates an important aspect of topographic change due to mining in Appalachia. There is a corresponding change in land cover as the forest is removed prior to mining operations. Monitoring of the land cover trends in this region indicates that coal mining is the dominant driver of land cover change, especially forest conversion, in the years from 1973 to 2000. Analysis of the polygons included in the topographic change mask due to their close proximity to mine locations shows that the majority (more than 54 percent) are labeled as forest according to the NLCD. Many of these polygons are likely located in the eastern United States coalfields because of the high density of mines in central Appalachia. In contrast, shrub land, agriculture, or grassland was identified as the majority land cover category for 16 percent, 14 percent, and 10 percent, respectively, of the polygons located within 500 meters of known mines. It is likely that many of these polygons are located near expanding mines in the western United States (USGS, 2008).

The Land sat image in the bottom panel of the figure above also includes a feature that illustrates an interesting issue associated with mountaintop mining, that of post mining land use. Active mining operations coincide with many of the change polygons, although the image indicates that some of the disturbed area has already been reclaimed and re-vegetated. In the right central portion of the image, an airport runway (at the centre of the red circle) has been built on newly available flat ground that resulted from mining operations. Such post mining development has been touted as one of the advantages of mountaintop mining (USGS, 2008).

2.2.5. Impacts of Mining on Vegetation and Rivers in the United States

Below the densely forested slopes of the Appalachian Mountains in southern West Virginia is a layer cake of thin coal seams. To uncover this coal profitably, mining companies engineer large—sometimes *very* large—surface mines. This time-series of images (Figure 7) of a surface mine in Boone County, West Virginia, illustrates why this controversial mining method is also called “mountaintop removal.”(U.S. Environmental Protection Agency, 2010)

Based on data from the Landsat 5 and Landsat 7 satellites (Figure 7), these natural-color (photo-like) images document the growth of the Hobet mine as it moves from ridge to ridge between 1984 to 2013. The natural landscape of the area is dark green forested mountains, creased by streams and indented by hollows. The active mining areas appear off-white, while areas being reclaimed with vegetation appear light green. A pipeline roughly bisects the images from north to south. The town of Madison, lower right, lies along the banks of the Coal River.

In 1984, the mining operation is limited to a relatively small area west of the Coal River. The mine first expands along mountaintops to the southwest, tracing an oak-leaf-shaped outline around the hollows of Big Horse Creek and continuing in an unbroken line across the ridges to the southwest. Between 1991 and 1992, the mine moves north, and the impact of one of the most controversial aspects of mountaintop mining—rock and earth dams called valley fills—becomes evident.

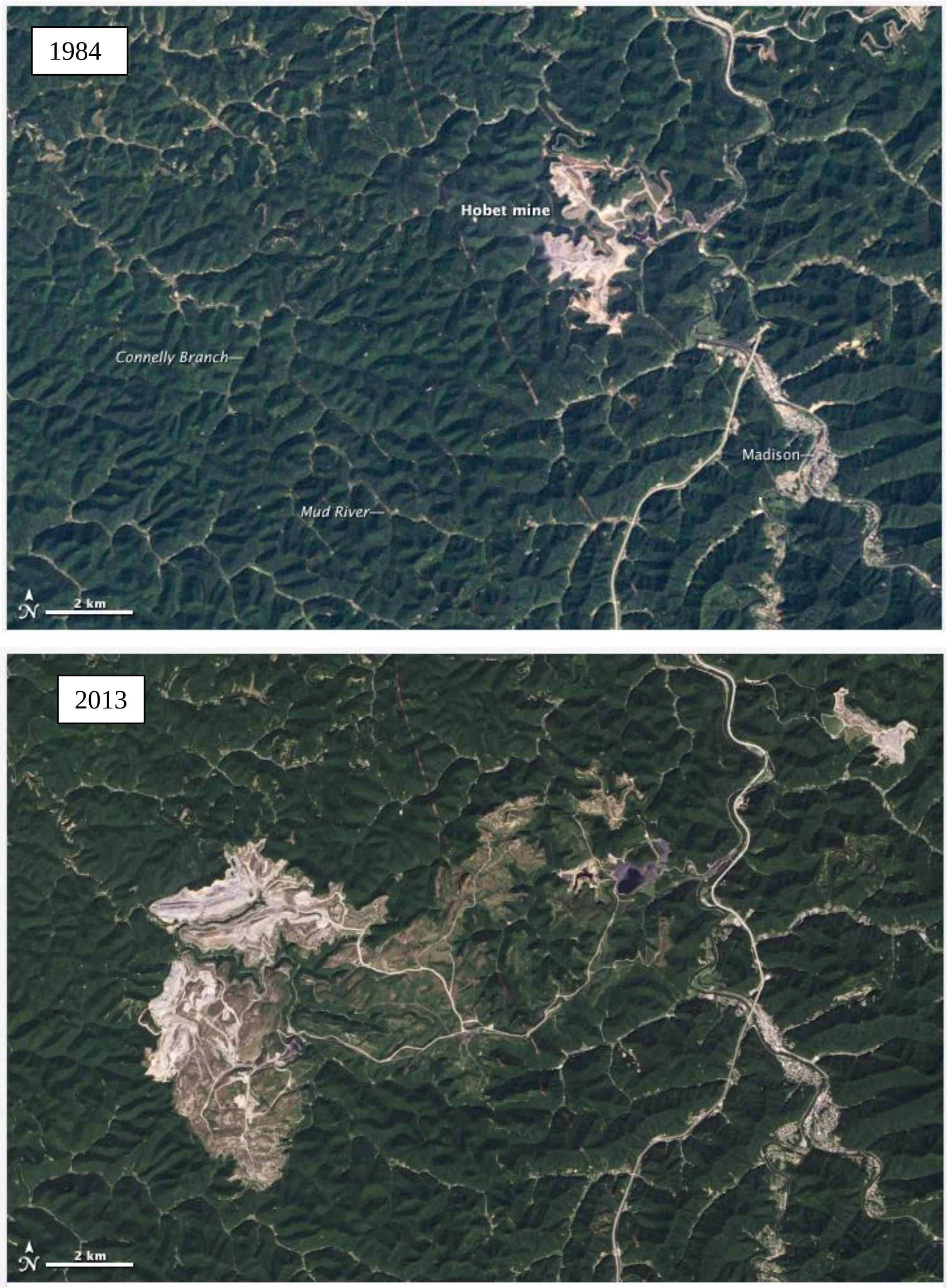


Figure 7: Time series Landsat Images between 1984 and 2013 showing significant impacts of mining on topography, stream characteristics and vegetation. (Source: Google Earth Image, 1984 &2013)

The law requires coal operators to try to restore the land to its approximate original shape, but the rock debris generally can’t be securely piled as high or graded as steeply as the original mountaintop. There is always too much rock left over, and coal companies dispose of it by building valley fills in hollows, gullies, and streams. Between 1991 and 1992, this leveling and filling in of the topography becomes noticeable as the mine expands northward across a stream valley called Stanley Fork (image center) (U.S. Environmental Protection Agency, 2009).

The most dramatic valley fill that appears in the series, however, is what appears to be the near-complete filling of Connelly Branch from its source to its mouth at the Mud River between 1996 and 2000. Since 2004, the mine has expanded from the Connelly Branch area to the mountaintops north of the Mud River. Significant changes are apparent to the ridges and valleys feeding into Berry Branch by 2009. The image from 2013 shows apparent green-up of restored lands. The image also shows expanded operations in the southwest and northeast. Over the 29-year period, the disturbed area grew to more than 10,000 acres (15.6 square miles).

According to a report from the U.S. Fish and Wildlife Service (1998), nearly 40 percent of the year-round and seasonal streams in the Mud River watershed upstream of and including Connelly Branch had been filled or approved for filling through 1998. In 2009, the EPA intervened in the approval of a permit to further expand the Hobet mine into the Berry Branch area, and worked with mine operators to minimize the disturbance and to reduce the number and size of valley fills. In 2010, the EPA reported that Hobet 45 mine met the requirements of the Clean Water Act.

Still, some scientists argue that current regulations and mitigation strategies are inadequate. In February 2010, a team of scientists published a review of research on mountaintop mining and valley fills in the journal *Science*. The scientists concluded that the impacts on stream and groundwater quality, biodiversity, and forest productivity were "pervasive and irreversible" and that current strategies for mitigation and restoration were not compensating for the degradation (Palmer *et. al., 2010*).

2.3.Fluorite Mining Operations at the Kerio Fluorspar Mine and Uses of Fluorspar

Fluorspar is an essential additive to create flux in aluminium smelters and the fluorine derived from the fluorspar is a crucial part in the hydrofluorocarbons (HFC) used as refrigerants in fridges and air conditioners, and in the propellants used in aerosols. It also goes into the manufacturing of non-stick cooking pots, fireproof plastics, anesthetics and a host of other every day products.

South Africa is the third largest producer of fluorspar. In 2003, China was the major producer of fluorspar, producing over 50% of the world's supply. However, in China there is now a lower extraction, less readily available deposits, higher environmental and safety considerations, and greater encouragement for domestic value added use. This has put up pressure on the world prices (Witkop Mine Report, 2006).

The fluorspar factory is situated close to the ore deposit in the valley about 1 km upstream of the confluence of Kimwarer and Mong rivers. Water for industrial purposes is diverted from the Mong River and pumped through a pipeline to the factory. Crushing of the ore takes place in the crusher jig before it is ground in a conventional rod and the ball mill circuit. The fluorite is separated from the silica and iron oxides by froth floatation at pH of approximately 10.3.

Different grades of fluorite are produced at the factory, mainly for the use in steel and aluminum industries and also in chemical industries and laboratories to produce hydrofluoric acid.

2.4.Objectives and Methods of Land Reclamation

Land reclamation in the mining areas has been largely used as a tool to counter negative environmental effects of mineral extraction. It is a comprehensive disciplinary subject, which involves activities of landscape redevelopment and the restoration of its natural productivity, ecological status, economic and aesthetic values. Chadwick (1987) argues that mined lands constitute a form of environmental cost of production, which in the long run results in minimal waste discharge.

Most mining methods have generally adapted a sequential procedure in land reclamation activities. The first stage entails planning, then research and development. The second step involves site preparation for a specific use and this consist of earth moving and shaping of the surface, water regime control and possible application of productive layer such as top soil or organic material on the surface. The third is about biological reclamation, which will allow the development of restored landscape/site: this stage mainly focuses on restoration of fertility and biological productivity of the damaged land.

Depending on the natural and socio-economic factors of the locality, reclaimed land can be utilized for agriculture, forestry and recreation, and water use, construction or as wildlife habitats. Nevertheless, all the reclamation depends on the factors as the nature of the land disturbance, the climatic and environmental conditions, prevailing consideration and social as well as legal requirements.

Sanitary landfill is another strategy of reclaiming land. These landfills are located so as to reduce water pollution from runoff and leaching. It is cheap, quick and can handle massive amounts of solid wastes. After a landfill has been filled and left to settle for some years, then it can be used for other economic or social activities. Miller (1990) however, comments that landfill activities have demerits of being noisy, dusty, and involve heavy traffic during operation. Wind can also carry litter and dust to far places particular before each day’s load of trash is covered with soil.

2.5. Mining in Kenya

According to Advameg Inc. (2007), mining and quarrying accounted for less than1% of Kenya’s GDP in the year 2000, having declined steadily since the end of World War II. Kenya was chiefly known for its production of fluorspar, limestone, gemstones, salt, soapstone and soda ash. Cement was a leading industry and export commodity in 2002;

production fell by half from 1996 to 2000 because of economic difficulties and decreasing export demand. Lake Magadi had substantial resources of salt, Trona (12.6 million tons) and soda ash (7 million tons).

2.6. Mining Impact in Kenya

Mining in Kenya is mainly open cast due to the nature and occurrence of minerals mined. Instances of environmental degradation due to mining are therefore more severe and are reflected in the waterways of most nearby environments. For example the possible pollution of the atmosphere and water ways of Greenstone Belt of western Kenya by mercury which is used in amalgamating the alluvial gold in the area, the dust produced in the mining and processing of diatomite at Kariandusi in Gilgil and the effect of escaped volatiles and spent liquor in the processing of Trona at Lake Magadi and Energy production at Geothermal Station in Hells Gate, Naivasha (Mathu and Davies, 1996).

In the quarries doted all over the country, dust and sound pollution has adversely affected the neighborhood residents. The Karen-Ngong Environmental Self Help Group of Nairobi is instrumental in stopping of quarrying for dimension stones in Ololua Forest. The quarrying had been authorized by the City Council of Nairobi in conjunction with the Forest Department, which incidentally, falls under the Ministry of Environment and Natural Resources. Kayole Residents' Association in Nairobi effectively managed to relocate the huge stone crushing industry from their area, but not after the impact on their buildings and health had been felt. Dust and dynamite explosive impacts were responsible for lung-related diseases and the cracks developed on the buildings in the area. The huge open cast left behind however, poses a high risk to residents and their children. Several deaths (which may be as a result of water borne diseases from water ponding in the abandoned quarry or as a result of mine accidents) have occurred in the nearby estate, Doonholm where such abandoned quarry mines were left uncovered (Mines & Geology Department, 2001).

Sand harvesting has caused a lot of soil erosion, particularly in the neighboring Machakos District, which is the main supplier of sand to the Nairobi construction industry. The Government has constantly intervened in the process but to very little effect. Large tracts of land and fertile soil has been washed downstream and gone to waste due to the practice (Mines & Geology Department, 2001).

2.7. Summary

Mineral fluorite from Kerio Valley has become one of the few very important discoveries of deposits in Kenya. As a mineral, fluorite mining in Kerio valley has undergone the three major stages of exploration, appraisal and the final exploitation. It is one of the major foreign exchange earners for Kenya.

Like any other mineral, fluorspar has been mined by open cast method of mining where surface excavations have been made to access it. This has led to clearance of vegetation, development of open pits like the mines in the United States. The trend of mining and impacts to topography, vegetation and drainage systems is dependent upon the mode of mineralization relative to the geological formations that host the mineral deposit.

Environmental impacts as result of mining is always expect but the rate of negative impact can always be mitigated through proper mining policy like that of Kilembe Copper Mines of Uganda. “Kilembe Mines in Uganda did not have extensive and blatant adverse environmental impacts from 1956 to 1976 because the mine employed safe and standard methods of exploration, development and exploitation. It mainly used wet ‘cut-and- fill’ mining methods, planned and stabilized stacking of tailing and the cobalt-bearing pyrite concentrates were some of the methods used to maintain a clean environment”.

Previous works that have been written on mining and its impacts on the environment have shown that mining has both advantages and disadvantages. The area that is being excavated for mining has been demonstrated to increase as mining is in progress for the successive years. This has been demonstrated by the mines in the United States clearly revealing the impacts of fluorspar mining on the physical environment.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Research Design

The main research design adopted in this study was diagnostic research study, which is concerned with the frequency with which mining of fluorite occurs and the impacts it has on the topography and land cover. However, a number of methods have been employed in trying to explore and analyse the trend of change on topography and land cover. The aim of these methods was to identify factors that account for the change patterns of a given unit and its relationship with the environment.

3.2. Sample Selection

Based on the mineralization of the fluorite deposit in Kerio Valley, there are three major mines that have been opened up for extraction of the fluorite ore. Currently the area under mining is approximately 469.3 acres. A samples size of about 7413 acres was determined as the total area that is directly affected by mining. The target factors of the environment include the topography that is the hills and the valleys and vegetation cover both shrub lands and forest cover. Data of the target area in 1984 is shown on Table 3.1

Table 3.1: Area (in ha) covered by the various components of the environment and the mining area in 1984

Components	**1984 (Ha)**
Forestland	1100
Scattered Trees	475
Bare lands and Settlements	126
Mine areas	15

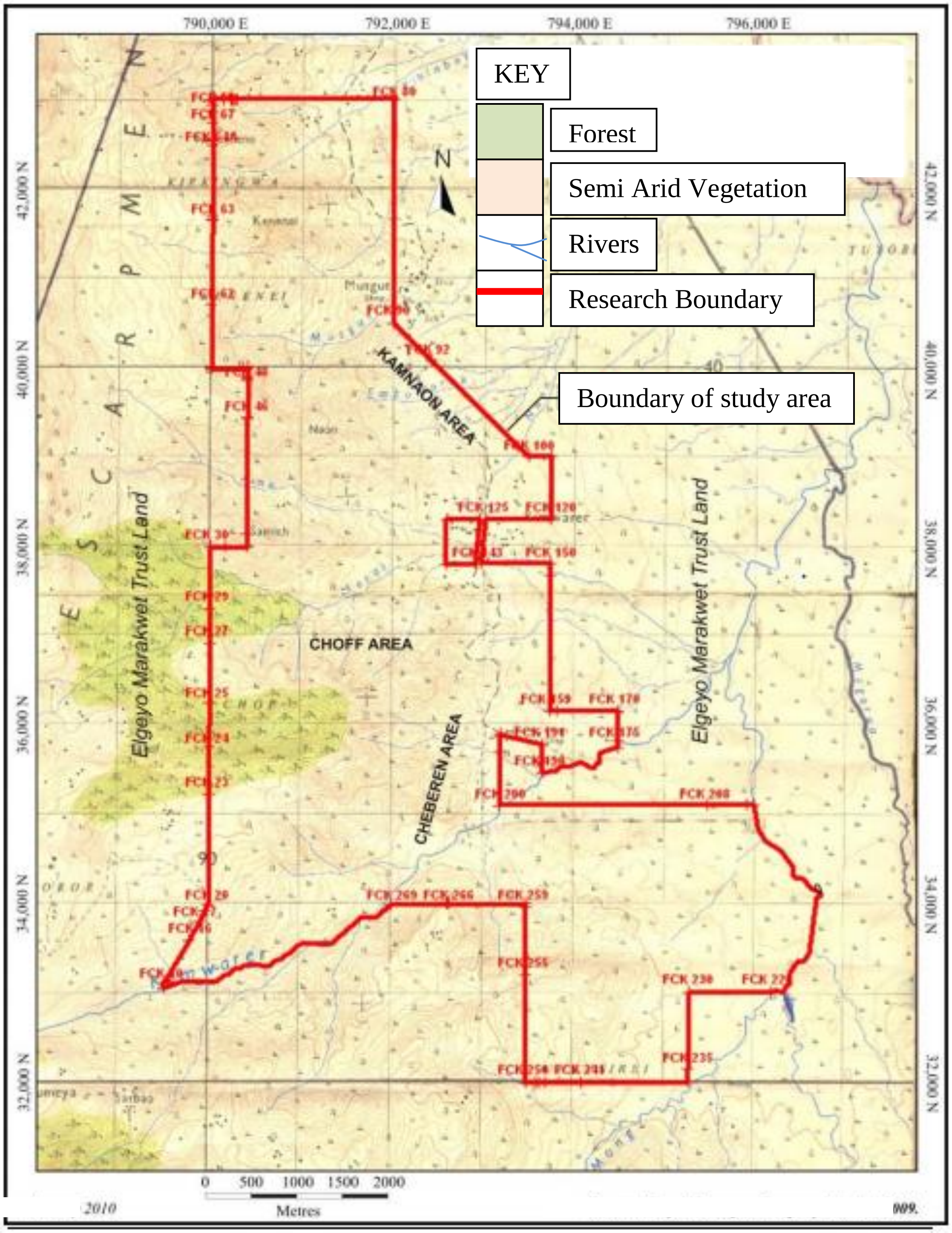


Figure 8: Topo-section of the project study area showing the extent and scope of the research area (Source, KFC, 2008).

The extent of the study area is shown on Figure 8 marked by the red line which is also the lease area under mining by the Kenya Fluorspar Company. The areas under mining have clearly been labeled, Cheberen area to the south, Choff area at the centre and Kamnaon area to the North. Rivers that traverse the mining area are visible on the map as well as the forested land on the eastern section. The area covered by this study is enough to detect environmental impacts of mining on the physical environment.

3.3. Methods

3.3.1. Field Methods

Survey was conducted in the field to determine exposures of the fluorite ores in all the mine sites to get an idea of how mining is done and in what direction in terms of opening up new areas of mining an important aspect in topography changes. The silva compass for this stage was very important.

The method of mineralization of the fluorite deposits were confirmed form the existing exposures within the mining areas. The dips and strikes of the fluorite deposits were also determined to understand the direction and depth of mining.

3.3.2. Land Survey Application for Volume and Area Estimation of the Pits and Materials Mined

Tools

- Total Survey Station
- Prism (reflector) Rod
- Tape Measure

3.3.2.1 Method Description

This method was mainly applied because of constrains that were incurred by other methods (tape measure and strides) in determining mainly the extent of the areas that have currently been mined out. Constrains include the hilly topography, thick vegetation on the periphery of the mines and the steep dangerous cuts that have resulted from mining. The method used here is the collection of elevation data and the E/N coordinates of the mining area from already two known points of the backsight and the foresite as demonstrated below

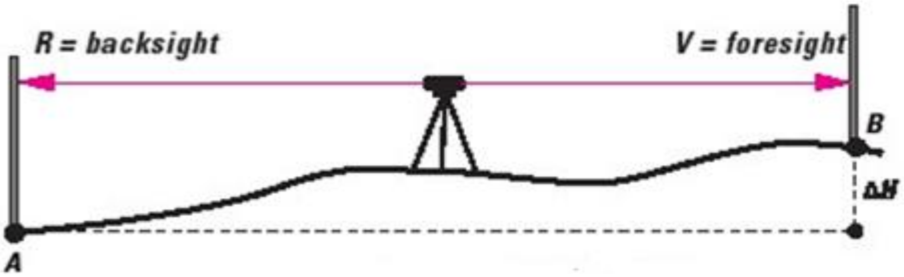


Figure 9: Positions of the backsight and foresight during survey

After enough data was collected from the field, it was then analyzed using Model Maker computer software giving the area and the volume of the already mined out areas for the three major mines

Plate 1: Total survey station on a tripod used for survey in the field. Data collected is the elevation and location points used for the calculation of area and volume (Source: Author 2013)

3.3.3. Observation and Photography

The method was used to assess the visible physical environmental impacts as a result of fluorspar mining. Observations were made on how the different processes from ore extraction to the final processing of the end product. Disposal of waste generated from mining and processing was also observed. Areas that were under vegetation and degradation of the mined areas were observed. The information was recorded by the use of a camera.

3.3.4. Remote Sensing and Image Classification

The process of determining the changes that have occurred in Kerio Valley site involved the processing of Landsat images (Landsat 5 and 7) for 1984, 1989, 2000 and 2010.

The images were downloaded and extracted to obtain the individual bands. These bands are then layer stacked to create one composite image for the stated years of study. To extract the exact area of study covering the mine site, a shapefile of the site was generated from a high resolution image and used to clip out the study area in a process referred to as subsetting. The extracted image was used to carry out an unsupervised classification process intended to obtain 4 classes as; 1. forestland, 2. scattered trees, 3. bare lands and settlements, 4. mine areas.

The process of unsupervised classification groups pixels in clusters based on the reflectance properties of the pixels. The user defines the number of clusters they wish to generate from the image, for instance, 4 classes for this study site. However, it is always advisable to generate more classes and then apply merging techniques to combine some similar classes extracted. The software applied an iterative process of clustering these pixels i.e. ISODATA (Iterative Self-Organizing Data Analysis Technique) to generate 10 classes that will thereafter be merged to obtain 4 classes.

The extracted classes were thereafter merged, recoded and identified as above through ground knowledge and with aid of other reference material such as high resolution maps and past studies. Calculation of land cover areas was done to obtain the areas of these classes in acres.

3.4. Data Analysis

Microsoft Excel computer program was used for data entry and analysis of data according to the information that was collected. Data was presented by use of both statistical and graphical techniques based on information collected.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Historical Background of the Study Area

Kenya Fluorspar Company Ltd (KFC) is one of the few large-scale mining and metallurgical operations in Kenya and ranks as one of the country's leading foreign exchange earner. It is also at the forefront of community development in the remote area in which it operates, the Kerio Valley (KFC, 2005).

The fluorite deposits, which are specifically located in the areas of Kimwarer, Choff and Kamnaon, were first discovered in 1967 by a prospector searching for semi-precious stones, who initially mistook the purple fluorite for gemstone.

A hand-mining operation was started and the fluorspar was supplied to the Bamburi Portland Cement Company in Mombasa. At its peak, the operation, which relied on donkeys to transport the fluorspar, produced around 400 tons per month of high grade fluorspar. In 1971 the Fluorspar Company of Kenya (FCK) was established, under the auspices of the Kenya government, to exploit the deposits on a larger scale (KFC, 2005). Four years later the government gazetted its intention to purchase the land and compensate the owners. This exercise was completed in 1986.

Various problems encountered over the years, including technical, financial and market-related, culminated in FCK going into receivership in 1979. Kenya Fluorspar Company, a wholly government-owned company, bought the assets and continued the operation. This coincided with an improvement in the fluorspar market and long-term customer contracts.

In 1996 the company was privatized under the terms of a governmental reform policy. The privatized company, Kenya Fluorspar Company, entered into a 20-year lease with the government, leasing an area of 3,664 hectares. This entitles the company to mine all minerals and continue with mining operations including exploratory drilling (KFC, 2005).

The company has seven active mining sites available from which ore can be mined depending on the grade and quality required. In 2003 the company made a major investment in earth-moving equipment and plant upgrading.

4.2. History and Mode of Fluorite Mineralization

From background information, mineralization of the fluorite deposit in Kerio Valley occurred during the Tertiary age from hydrothermal fluids at the waning stage of an igneous cycle. The deposits were hosted by the Basement rocks. In the Basement System rocks the lineation directions vary between N45^{0}W and N10^{0}W.

From the field a number of dips and strikes measurements were carried out on the exposed ore by the use of a silva compass. These measurements were very important as they determine the direction and depth an ore can be mined. Below is the general strike and dip for three major mines.

i. **Cheberen:** Strike-North South
Dip 40º to 50º East

ii. **Choffs:** Strike: East West
Dip: 35º South

iii. **Kamnaon**: Strike: North West-South East
Dip: 40º South West

For the Cheberen mine, the direction of the mining is N-S but the width of the mine is opened up in an eastern direction. Choff is mined in an E-W direction with mines opened up in a southern direction. Kamnaon is mined in a NW-SW with the mine being opened up in a south western direction.

The angles of dip are very important in determining the depth of the mine. High angles greater than 45º will result to very deep pits within the mining area. An average and of 40º of the ore in Kimwarer area have led to formation of mine pits that are ranging from 40 to 60 meters deep. Such deep pits have always required a larger area of clearance and safety resulting to large quantities of waste rock.

The size, shape, and nature of ore deposits affect the workable grade. Large, low grade deposits which occur at the surface can be worked by cheap open pit methods, whilst thin tabular vein deposits will necessitate more expensive underground method of extraction. Open pitting, aided by the savings from bulk handling of large daily tonnages (say >30 t), has led to a trend towards the large scale mining of low grade ore-bodies. As far as shape is concerned, ore-bodies of regular shape can generally be mined more cheaply than those of irregular shape, particularly when they include barren zones. For an open pit mine the shape and attitude of an ore-body will also determine how much waste has to be removed during mining. The waste will often include not only overburden(waste rock above the ore-body) but also waste rock around and in the ore-body, which has to be cut back to maintain a safe overall slope to the sides of the pit, (Charles *et al*., 2006). Maintaining a safe overall slope to the sides of the pit means more waste being dug out, further destruction of vegetation and creation of larger mine pits in all types of mines including the fluorite mines of the Kerio Valley.

4.3. The Fluorite Orebodies in Kerio Valley

The fluorite orebodies occur in a tract of country some ten kilometers long and about three kilometers wide, lying at the foot of the Elgeyo escarpment, and stretch from Kimwarer ridge to Muskut (Figure 10). That the mineralization was fault controlled is indicated by its tertiary age, the parallelism of the line of ore deposit, and the location of the source in the waning phase of an igneous cycle. However the localization of conformable deposits suggests that the replacement of lenticular limestone bodies occurred (KFC, 2010).

Figure 10: The three major fluorite orebodies in Kerio Valley (Source: KFC 2010).

Figure 11: Google Earth Image representation of the study area. The white patches on the northern section of the map show the mine pits and some section of the damping site for the wastes. White and brown patches on the south eastern section show the tailings section and water dams (Source: Google Earth 2014).

4.3.1. Cheberen Orebody

The Cheberen orebody is by far the largest, containing some 3 million proven tons of fluorite, with a similar probable tonnage. It has produced the bulk of the acid grade concentrate for export to date. It is the southernmost body and stretches north across five hillocks over a distance of more than a kilometer. Table 4.1 shows results of the fluorite reserves for Kimwarer deposit for the recent survey that was done by Kenya Fluorspar Company. It consists of 3 lenses, 10 meters, 15 meters and 50 meters thick, with the 50-metre lens occurring in the southernmost hillock called Cheberen. However, beyond this hillock only one vein persists for the remainder of the distance. The orebodies dip at 50^0 and 60^0 to the east in conformity with structure of the host rock (Jones, 1982).

Table 4.1: Reserve Summary for the Cheberen Ore Deposit

Location	Material	Tonnages	CaF_2	S-Ratio	S Wilson	CaF_2
Cheb 1	Ore	1,480,504	39.68	6.58	1,815,000	42.70
Cheb 1	Waste	9,748,061				
Cheb 3	Ore	1,711,232	36.05	8.00	1,713,000	38.50
Cheb 3	Waste	13,683,926				
Cheb 4	Ore	5,764	33.14	62.41	195,000	27.10
Cheb 4	Waste	359,710				
Cheb 5	Ore	137,787	30.77	8.26	485,000	28.80
Cheb 5	Waste	1,138,472				

NB: Cheb 1 to Cheb 5 are the 5 major sections of the Cheberen Mining site located at the southern end (Fig 10). CaF_2 is the grade of fluorite that is expected when the fluorite is mined. S Wilson is the Reserve estimate in tonnes that was done by Scot Wilson in 2010 while S Ratio is the strip ration that is expected if the reserve is mined.

From the table above the total ore reserves is approximately 3.32 million tons which is closely related to the survey that was done in 1981 with an average strip ration of 7 not considering Cheberen 4 (one of the mine sites of the Kimwarer Complex).

Kimwarer deposit is still workable and for the months of May, June and July 2013 there were developments and mining. Development has been done so that the fluorite deposit can be accessed and also create a safe environment for mining. The table 4.2 below shows the statistical data for fluorspar mining in the months of May June and July.

Table 4.2: Statistical data of fluorite mining at the Cheberen deposit for the months of May, June and July 2013

Month	**Total Ore (tons)**	**Total waste (tons)**	**Average CaF_2 (grade)**
May	0	63185	0
June	8010	58025	42.5
July	8525	99224	44.1
TOTAL	**16535**	**224434**	**43.3**

From this data the strip ratio for the period of three months is 13 meaning for every 1 ton of ore taken to the processing plant 13 tons of waste was being thrown away. The high ratio of 1:13 resulted from the fact that during development ore was not taken to the plant for processing. The grade of the fluorite was good and higher than the expected as can be seen on the reserve table which has an average of 36.05% compared to the value of 43.3%.

4.3.2. Choff Orebody

At Choff a series of small but high grade deposits occur in an east-west line of fault breccias. Individual deposits are some 100-200 metres in length and 10-20 metres in width. A reserve estimate (Aljabri, 1980) stands at 500,000 tons. Five separate bodies from individual deposits are aligned in about the same direction. The fluorite bodies are in contact with the basement system of rocks, namely, mixed thin bands of biotite and hornblende gneisses, hornblende gneisses and quartzofeldspathic gneisses.

Choff is a deposit that is still under mining with ore that is mined on several isolated hills as can be seen in figure 10 above. Table 4.3 shows the reserve estimates for Choff that was measured by Kenya Fluorspar Company in 2009.

Table 4.3: Reserve Summary for the Choff Ore Deposit

Location	Material	Tonnages	CaF_2	S-Ratio	S. Wilson	CaF_2
Choff 1	**Ore**	**849,806**	**34.87**		**1,010,000**	**32.20**
Choff 1	**Waste**	**12,054,686**				
Choff 2	**Ore**	**120,339**	**29.57**			
Choff 2	**Waste**	**530,012**		**4.40**	**1,025,000**	**33.50**
Choff 4	**Ore**	**1,052,067**	**38.54**	**12.33**	**1,910,000**	**32.10**
Choff 4	**Waste**	**12,969,418**				
Choff 5	**Ore**	**180,816**	**41.38**		**345,000**	**31.80**
Choff 5	**Waste**	**2,023,986**				
Choff 6	**Ore**	**379,155**	**42.40**	**19.42**	**810,000**	**45.20**
Choff 6	**Waste**	**7,362,947**				
Choff 9	**Ore**	**39,015**	**34.06**	**19.84**	**1,280,000**	**31.70**
Choff 9	**Waste**	**773,875**				
Choff 10	Ore	**128,463**	**33.53**	**21.52**	**535,000**	**45.80**
Choff 10	**Waste**	**2,764,373**				

NB: Choff 1- 10 are sections of the Choff mining profile (Fig 10).

As stated previously Choff deposit is scattered on isolated hills that is Choff 1 to Choff 10. Currently active mining is being carried on Choff 1, Choff 4, Choff 6 and Choff 9. The grade of fluorite on these four hills varies, with high grades mainly on Choff 6 and Choff 9. The fluorite grade is not the only determinant factor on the need for fluorite ore but also the amount of Carbonate and phosphates. On hills 9 and 6 the fluorite grade is high as well as the carbonate hence this fluorite ore has to be mixed with ore from another hill with low carbonate content. The table below shows the average fluorite ore, average waste tonnage and the average fluorite grade that was mined at the Choff Ore-body for the months of May, June and July in 2013.

Table 4.4: Statistical data of fluorite mining at the Choff deposit for the months of May, June and July 2013

Month	**Total Ore (tons)**	**Total waste (tons)**	**Average CaF_2 (grade)**
May	4879	33965	45.2
June	7543	177035	48
July	19550	95140	45.3
TOTAL	**31972**	**306940**	**46.2**

The strip ratio for the three months is 9.6; meaning that for every 1 ton of ore that was mined 9.6 tons of waste was thrown out and placed on a nearby dump sites. The ratio is not very high as the mine had good amount of ore that could be mined without a lot of development. For example Choff 9 and Choff 4 did not need development and ore was readily exposed to be taken to the processing plant.

4.3.3. Kamnaon Orebody

This is the northernmost orebody, and was worked during the initial stages of mining. It is a high grade ore-body occurring in brecciated zones and marbles, striking northwest and dipping to the west at a steep angle. The ore-body is formed of a mass of fluoritized marbles and breccias of which the principal one has a strike length of about half a kilometer and an aggregate width of about 100 meters. Several veins cluster together, ranging in thickness from 5 to 15 meters. The ore is typically granular, fine grained and friable, ranging in color from grey, brown or black to purple. The gangue includes silica, limonite, calcite and graphite.

Parts of the ore-body which are wedged between unreplaced marbles show thinning. Elsewhere kaolinisation of feldspar is a notable feature. The footwall, which has been replaced completely, is biotite gneiss passing in depth to quartz-feldspar gneiss, while the hanging wall tends to be hornblende-biotite gneiss (UNESCO, 1981).

The Kamnaon deposit is still under mining and the fluorite has shown no signs of getting depleted yet despite about two-thirds of the 1972 estimate of about 910,000 tons that was mined. In 2009 Kenya Fluorspar Company did reserve estimates for this orebody and this is summarized in table 4.5.

Table 4.5: Reserve Summary for the Kamnaon Ore Deposit

Location	**Material**	**Tonnage**	**CaF_2**	**S-ratio**	**S Wilson**	**CaF_2**
Kamn	**Ore**	**1,860,666**	**38.99**	**7.19**	**3,145,000**	**36.70**
Kamn	**Waste**	**13,375,611**				

NB: Kamn is the Kamnaon Section of the Mine site (Figure 10)

With these reserves of approximately 1.9 million tons, development has been part of the mining to create accessibility to the ore which strike below the hills at the Kamnaon site. For the months of May, June and July the sum of the fluorite ore as can be seen in table 4.6 below was taken to the plant for processing and the waste was dumped at sites nearby the mine.

Table 4.6: Statistical data of fluorite mining at the Kamnaon deposit for the months of May, June and July 2013

Month	**Total Ore (tons)**	**Total waste (tons)**	**Average CaF_2 (grade)**
May	4884	36540	38.58
June	3782	13300	39.61
July	6472	8000	39.85
TOTAL	**15138**	**57840**	**39.35**

From this data the strip ratio for the period of three months is 3.8 meaning for every 1 ton of ore taken to the processing plant 3.8 tons of wastes were thrown away. The low ratio of 1:3.8 resulted from the fact that during mining the ore deposit contained high amount of fluorite.

4.4. Materials Extraction Rate

From the successive years since 1981, the rate of mining has been increasing with demand and the advancement in technology. As in the problem statement, the amount of processed fluorite mined in 1981 to 1996 was 96,000 and 200,000 tons respectively hence the rate of change in production is calculated as follows:

Inititial quantity (1996) (tons) = 96,000

Quantity after 15 years (tons) = 200,000

Change in quantity (tons) = 104,000

Rate of change (%) = {(Final-Initial)/initial x 100%}/15yrs

= {(200,000 – 96000)/96,000 x 100}/15

= **7.2%**

Assumption: Linear approach

The rate of change for the last 15 years is assumed to be 7.2% per year from the calculations. Considering all other factors constant but with improvement in technology and increase in demand, the rate of change from 1996 to 2013 is expected to be as illustrated below.

Initial quantity (1996) (tons) = 200,000

Rate of change (%) = 7.3 %

Quantity after 17 years (tons) = {(17 x 7.3)/100 x 200,000}

= 248,200 tons

Cumulative total of CaF_2 by 2013 = 200,000 + 248,200

= 448,200 tons

Assumption: Linear approach

From data collected in the field, the total amount of processed ore in 2013 is approximately 178,206 tons. Rate of change from 2006 is calculated as follows.

Initial quantity (1996) (tons) = 200,000

Quantity after 17 years (tons) = 178,206

Change in quantity (tons) = 21,794

Rate of change (%) ={(Final-Initial)/initial x 100%}/17yrs

={(178,206 – 200,000)/200,000 x 100}/17

= **0.641%**

Assumption: Linear approach

The table below is a graphical representation of the change in the amount of ore that was mined, waste that was generated and the tailings that was thrown away after processing since 1981 to 2013. Several assumptions have been made to get approximate tonnage of the total material based on the data collected in the field and the data from 1981 and 1996.

Assumptions:

- Linear decreasing rate
- Assumed a year has 365 days

Table 4.7: Change in Tonnage of Materials from 1981 to 2013

Changes from 1981 to 2013 based on past data			
Year	CaF_2 in tons	Ore in tons at 70%	Total Waste Generated
1981	96,000	137,184	274368
1984	116,794	166,899	467317
1987	137,587	196,612	747126
1990	158,381	226,327	1086369
1993	179,174	256,040	1485032
1996	200,000	285,800	1657640
Year			
1996	200,000	285,800	1657640
1999	243,200	347,533	2362224
2002	286,000	408,694	2779119
2005	331,220	473,313	3691841
2008	372,800	532,731	4155301
2011	416,000	594,464	5231283
2013	448,200	640,478	5636506
Change from 1996 to 2013 based on field data			
Year			
1996	200,000	285,800	1657640
1999	196154	280,304	2362224
2002	192308	274,808	2779119
2005	188462	269,313	3691841
2008	184616	263,816	4155301
2011	180770	258,320	5231283
2013	178206	254,656	5636506

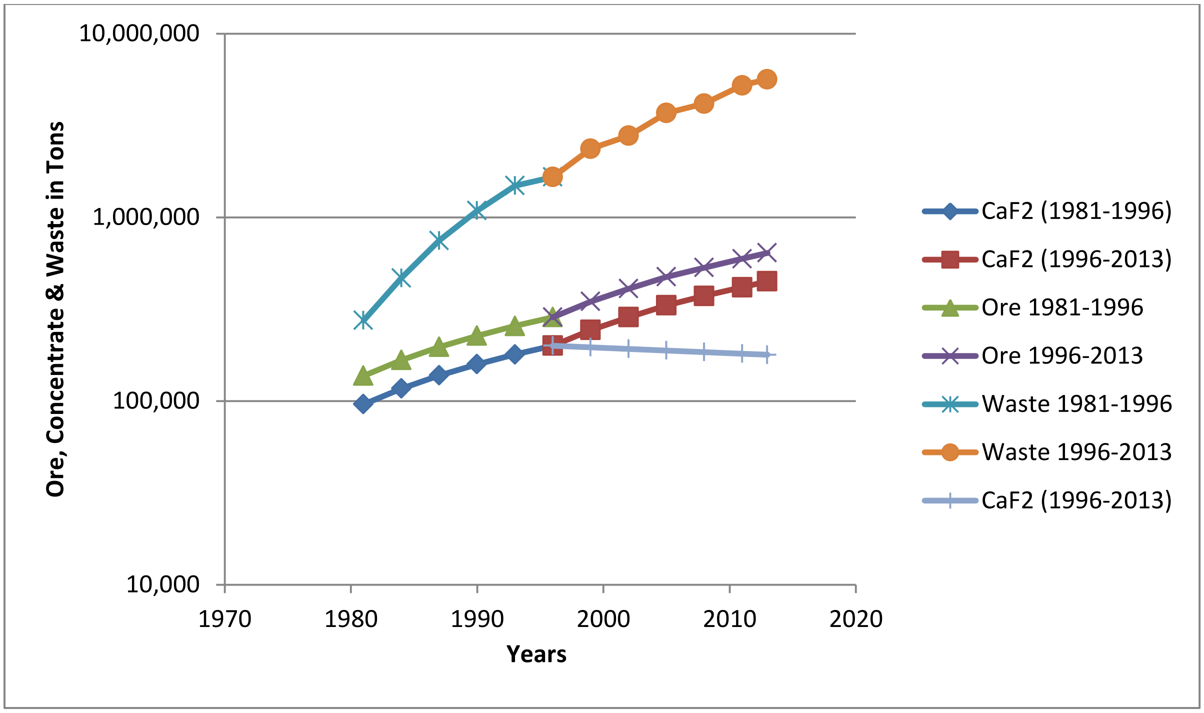


Figure 12: Graphical representation of the changes that have taken place for the past 32 years.

The approximate total amount of all the materials moved from1981 to 2013 at a linear rate of 7.2% is;

Processed fluorite = 3,185,356 tons

Ore tonnage = 4,451,875 tons

Overburden waste = 31,231,766 tons

The approximate total amount of all the materials moved from 1981 to 1996 at a linear rate of 7.2% and 1996 to 2013 at a linear rate of 0.641% is;

Processed fluorite = 2,008,452 tons

Ore tonnage = 2,869,599 tons

Overburden waste = 31,231,766 tons.

Based on the assumption, the total amount of ore mined for the period June, July and August is as stated earlier in the aspect of shape, ore bodies of regular shape can generally be mined more cheaply with minimum environmental damage than those of irregular shape, particularly when they include barren zones. For the case of the study area the fluorite ore body is irregular in shape and there consist some barren zones encountered during mining, hence contributing largely to the impact on the physical environment because of the need to develop a larger area for the safety of mining.

From the tables 4.2, 4.4 and 4.6, the amount of fluorite ore that is extracted for the three months in all the three major mines is still high with a higher amount of waste being extracted as well. The rate of mining is determined by the availability of a high grade ore as well as the world fluorite market. With the reserve of the mineral fluorite still very high for all the three mines, mining will not stop any time soon so long as the demand for the fluorite is still there in the market. Figure 13 shows a model of a section of Cheberen mine which has undergone mining for the last four and half decades.

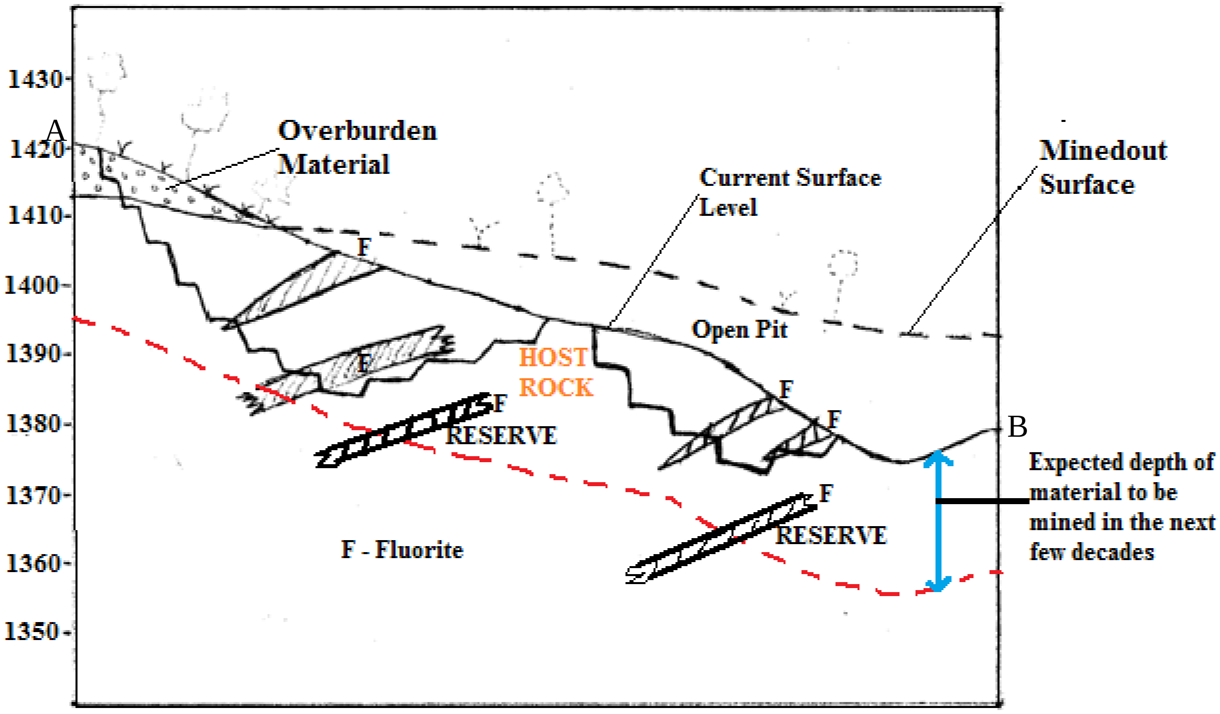


Figure 13: A model cross section of Cheberen open pit.

A cross section of a typical open pit mine is depicted on Figure 13 After removal of overburden, the ore body is mined by making successively deeper cone shaped cuts. The cone shape of the excavation facilities access to the ore-body and, most importantly, avoids the potential instability of steep pit walls. On average in the Kenya fluorspar mine, for each ton of usable ore extracted from a pit, 8 ton of waste rock must be removed. The ratio of waste to ore, called the stripping ratio, varies from 8 to 12 for individual mines. The amount of waste is highly dependent on the wall slope required for safety, and this in turn depends on the mechanical strength of the rock (Coates and Gyenge, 1972). Slopes ranging from 20 to 60 degrees are found in the fluorspar mines of Kerio Valley.

The environmental impacts of such mining tend to be local, associated with formation of large pits and destruction of land cover. For mining to take place vegetation has to be cleared for construction of infrastructure and settlement of workers, for extraction of mineral ore and for areas where waste can be dumped. For the months of May, June and July 2013 Kenya Fluorspar Company was busy with its mining activities in the Kerio Valley, with several tons of ore mined and taken to the mill for processing, development of the mining areas to expose ore and opening new sites for mining to take place. Discussions from the next sections give an insight to the effects of mining on the physical environment.

4.5. Topography Changes within the Study Area

i. Open Pits

For several decades mining of fluorspar in Kerio Valley has been active and the search for better grades (in terms of the quality of the fluorite) is the order of the day. Fluorite has been mined using the open cast method of mining that have resulted in open and abandoned pits within the mining area.

From the statistical tables in section 4.5 the amount of fluorite that is yet to be mined in terms of ore reserve is still high and according to the company, the fluorite will still be mined for the next 50 years. This means opening up of new areas for mining and extending areas that have already been mined if the fluorite keeps on dipping into the hills within the mining area. Figure 14 is an abandoned mine pit signifying a disfigured topography.

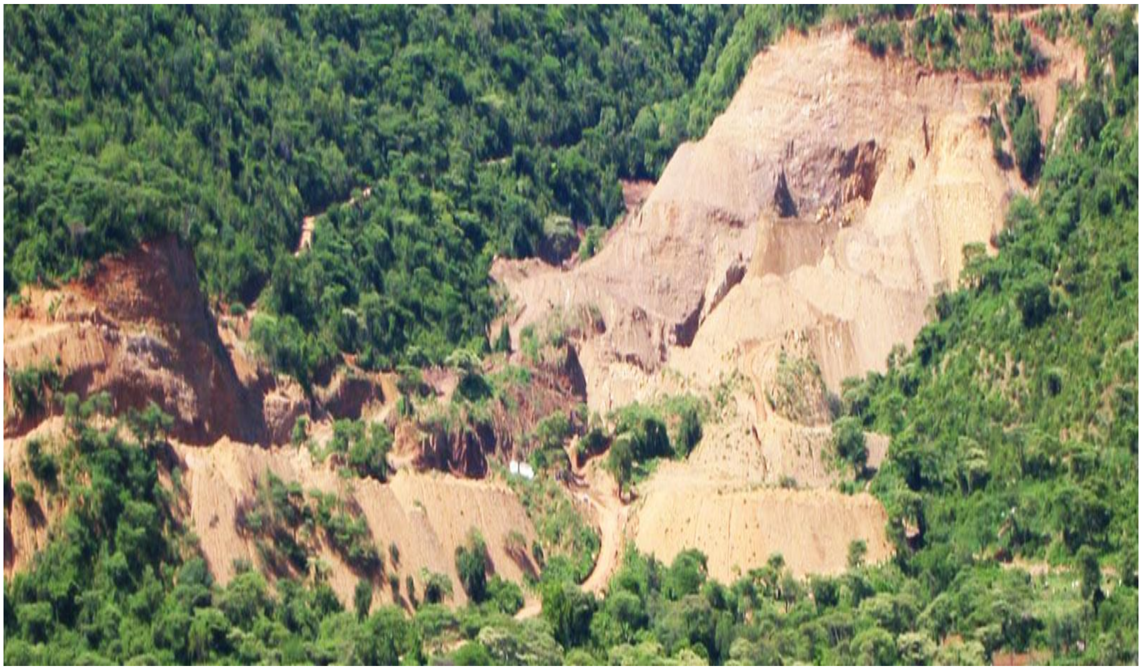


Figure 14: An abandoned pit after mining within a section of the Choff mining area. Vegetation has started to grow on the flanks of the mined out area (Source: Author 2013)

Figure 15 is a contour map for Cheberen mine site that was generated and Table 4.7 shows the pit area and volume calculated after generating the contour map. The Line A-B on the contour map was used to generate the mining model.

The contour map is a topographic representation of the changes that have taken place as a result of mining. At the centre of the map, the contour values are low relative to the adjacent areas and hence signify the area that has already been excavated and mined. Mining is extending westwards and a map generated few years to come will have changed and will show the extended area of the mine.

This small change that will take place signifies the amount of material that has been removed, which is quite a lot within a short period of time compared to the natural process of soil erosion by rain water and wind.

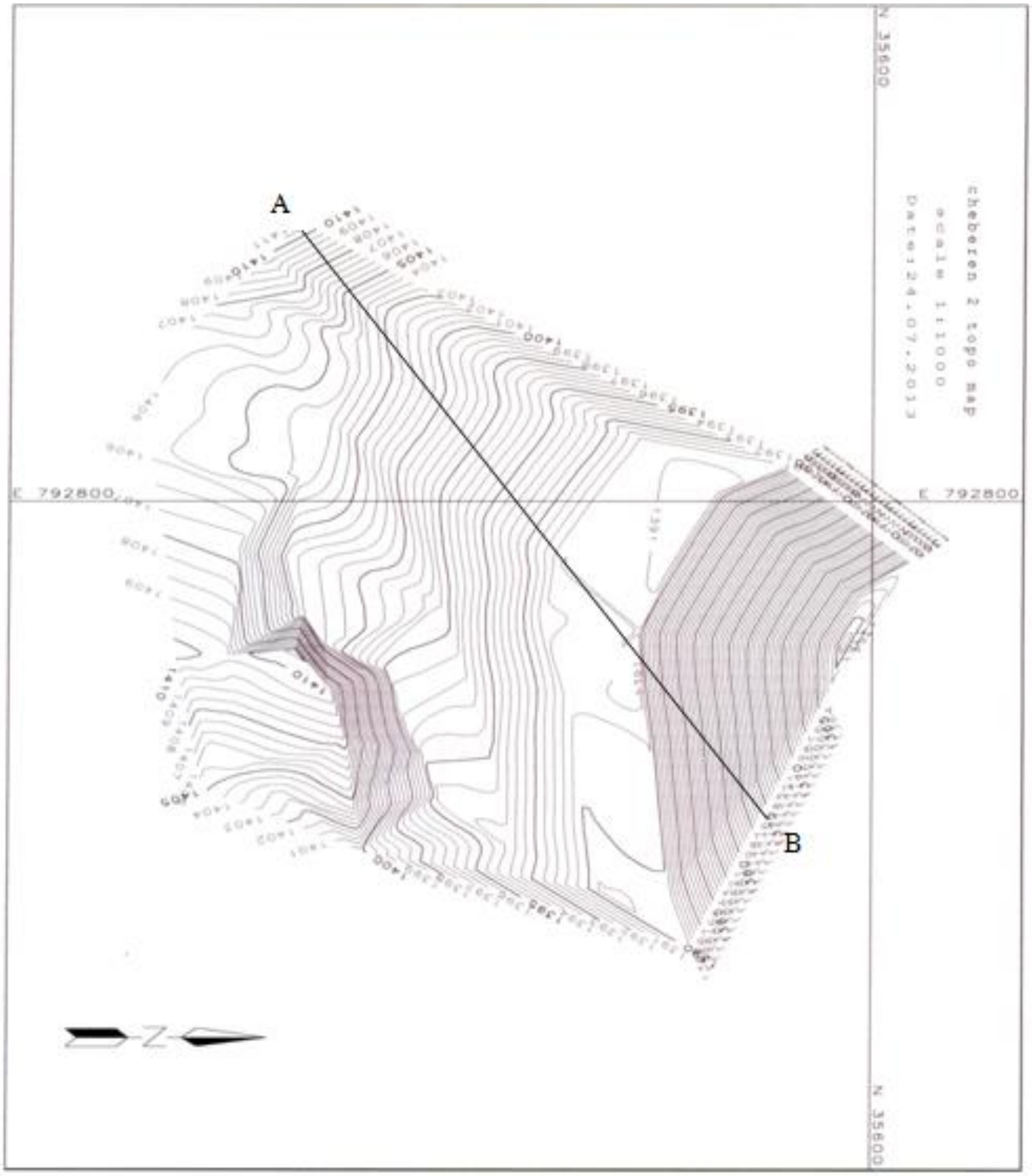


Figure 15: Contour map for Cheberen Mine in 2013 that was generated to calculate the current area and volume the Cheberen mine pit.

Table 4.8: Calculated area and volume of the mine sites

Number	Location	Area	Volume
1	Kamnaon	309441.69 m^2	4537349 m^3
2	Choffs Total	1004102.50 m^2	19812780 m^3
3	Kimwarer	606037.36 m^2	6562227 m^3
4	Kimwarer New	16233.12 m^2	45743.25 m^3

In table 4.8, area is the size of the pit (in terms of length and width) that has been created as result of mining while the volume is the approximate total amount of material that has been mined out of the pits that have been left open. These mine materials include; Overburden material, mine wastes and the fluorite ore that is taken to the processing plant.

Serious mining in Kerio valley began in the late 80’s. Mining was originally done on only one mine site but after some successful explorations were conducted two other mine site were opened up to increase the amount of fluorite that was mined. The processed remote sensing images below (Figure 16 and 17) for the years 1984, 1989, 2000 and 2010 show changes that have taken place on the environment.

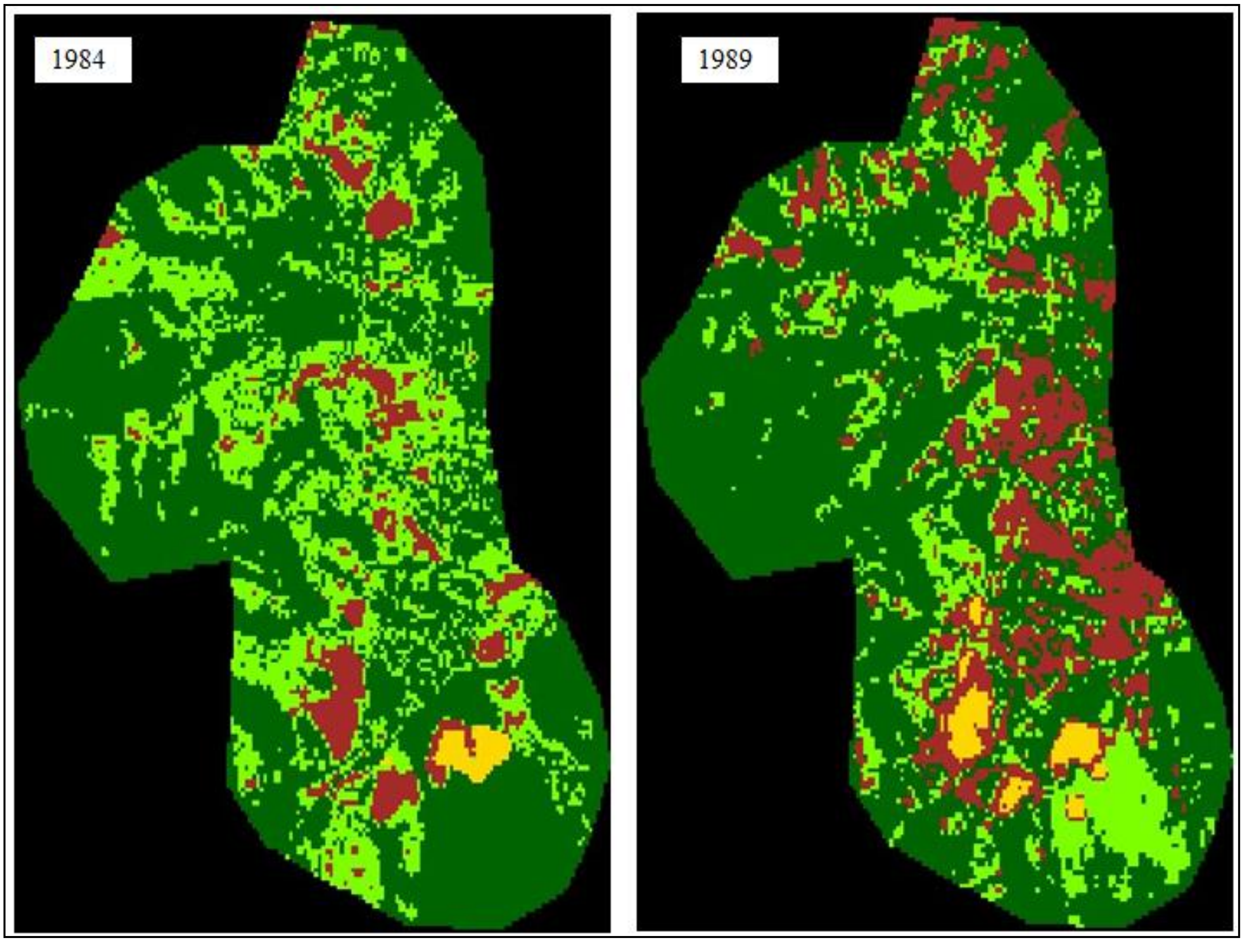


Figure 16: **Remotely sensed processed images showing changes that have occurred in the years 1984 and 1989 in mine area, vegetation cover and settlement (Source: author 2013)**

KEY

Class Name	**Color**	**Area in acres for 1984**	**Area in acres for 1989**
Forest Land	🟩	2717	2675.01
Scattered Trees	🟩	1173.25	760.76
Bare Land and Settlements	🟫	311.22	731.12
Mine Areas	🟨	37.05	71.63

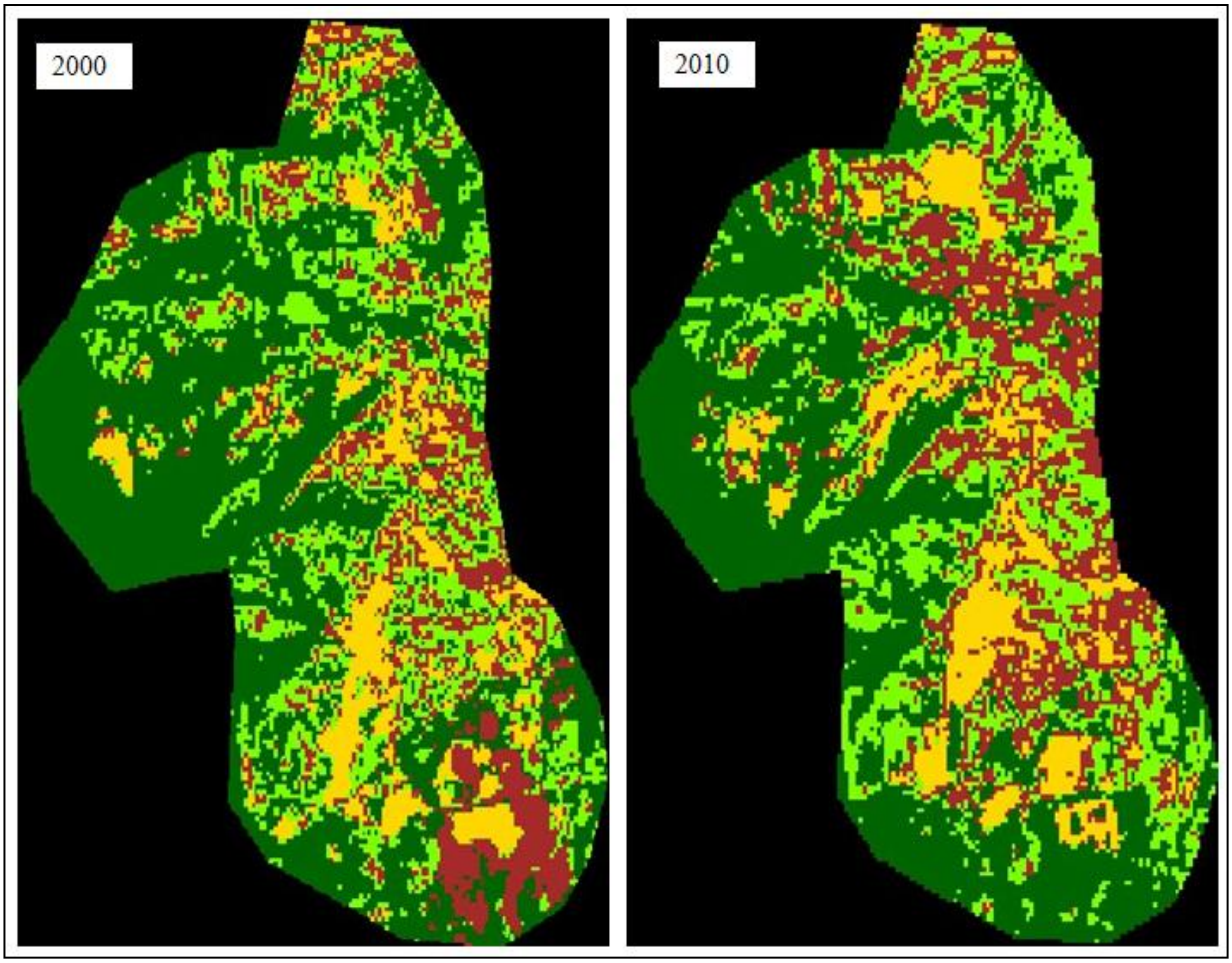


Figure 17: Remotely sensed processed images showing changes that have occurred in the years 2000 and 2010 in mine area, vegetation cover and settlement (Source: author, 2013)

KEY

Class Name	**Color**	**Area in acres for 2000**	**Area in acres for 2010**
Forest Land	🟩	2069.86	1835.21
Scattered Trees	🟩	1007.76	1062.10
Bare Land and Settlements	🟫	733.59	881.79
Mine Areas	🟨	407.55	461.89

Figure 16 and 17 is a time series processed images that has tried to show the changes that have taken place in the last 26 years from 1984 to 2010. The area under mining has increased from 37 acres in 1984 to 461 acres in 2010 an increase of about 424 acres. This is a result of increased demand of fluorite, better methods of exploration and improvement in the technology that has been adopted for mining.

The change in topography that is evidence of the areas are the open pits such as on figure 18, on the western section of the mines, the waste dumps on the eastern section and the mining tailing piles on the south eastern section.

Figure 18: An excavated pit where ore is extracted, the pits are extended depending on the strike and the attitude of the mineral deposit (Source: Author 2013).

ii. Dam Tailings

Tailings that result from the processing of the ore is dumped about a kilometre away from the processing plant. The dumps develop a rectangular shape polygon that is about 30 to 40 meters high. In the images on figure 4.7 a and b, the yellow patches on the South Eastern section began to be visible fron the year 1989 when the fluorite began to be processed at the mining area. Figure below is a structure that is adopted as the tailings are being thrown away.

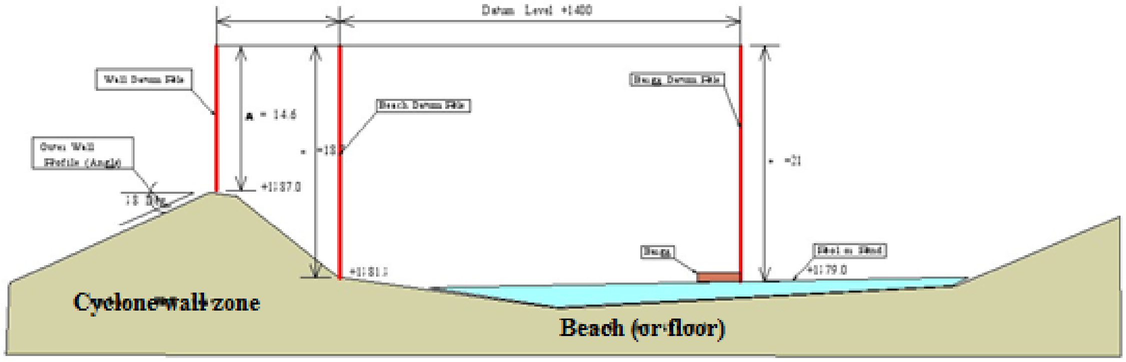


Figure 19: The structure that has resulted from the dam tailings

There are three tailing dams A, B & C where tailings (slimes) are deposited. When no slimes are deposited on Dam A which is allowed to rest and consolidate. Slimes are deposited on dam B through a spray bar system. Deposited slimes are allowed to dry and then packed to form the outer wall for the dam. The spray bar pipes are reinstalled on the wall and the process repeats itself. Water is temporaily decanted and pumped for reuse in the plant. Dam C acts as a return water facility. The total area covered by the three dams is approximately 55 acres with an average height of 25 metres (Figure 21 and 22).

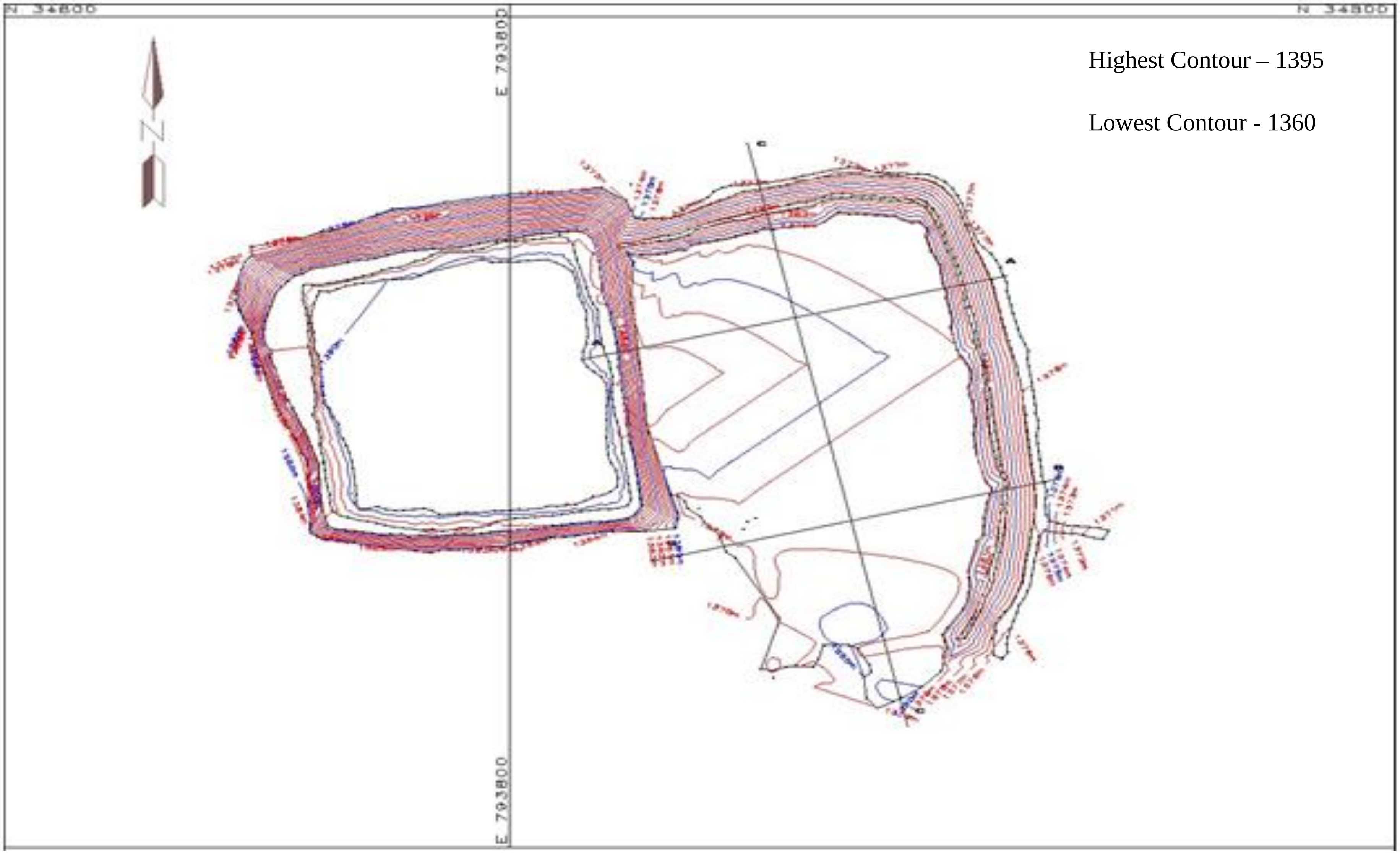


Figure 20: : Contour map of the tailing site.

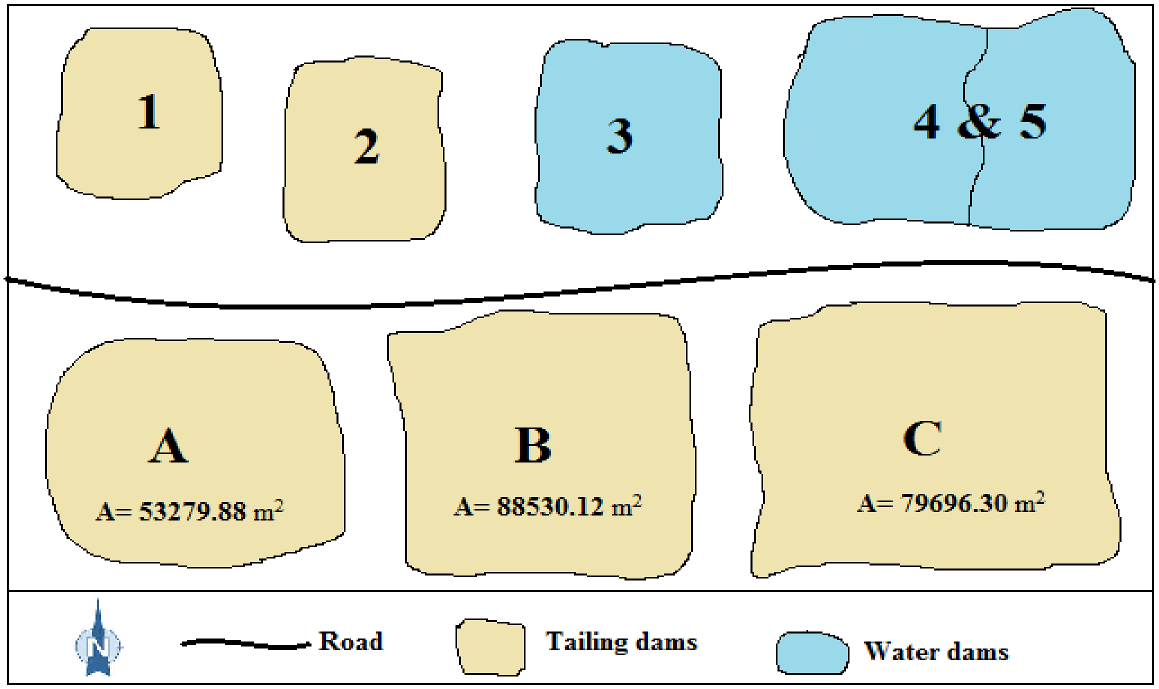


Figure 21: Sketch map showing position of the tailing dams within the study area.

Figure 22: Google Earth Image of the Tailings Dump Site.

From the previous analysis in section 4.5 the grade of the fluorite in the ore is at an average of 40%, the ore is usually processed to 70% and 30% is thrown away as waste. The fluorite at Kenya fluorspar is usually processed to 97% purity. After processing, the waste that comes out usually has approximately 20% fluorite grade which could still be processed in South Africa where their fluorite ore grade is at an average of 11%. Currently, cleaning the 20% grade at Kenya Fluorspar would be uneconomical because grades higher than this can be found at the mine sites, maybe this waste that is piled at an isolated site close to the mine can be reprocessed in future when the fluorite grade would be lower in the mine sites and the cost of mining will be higher than at present.

These processing (tailings) wastes have been piled at a site not very far from the processing plants and since the year mining commenced in the 1980's these wastes have been piled leading to the formation of artificial hills that have also contributed to the modification and change in the topography as the contour map (Figure 20) can demonstrate.

The highest contour (Figure 20) lies at an average of 1395 m and the normal contour level (original ground level) at that site is 1360 m, a difference of about 35 m high created by these waste dams. This is a very significant change in the local topography; a process of literarily moving part of a hill from one area and taking it to another as shown in Figure 23.

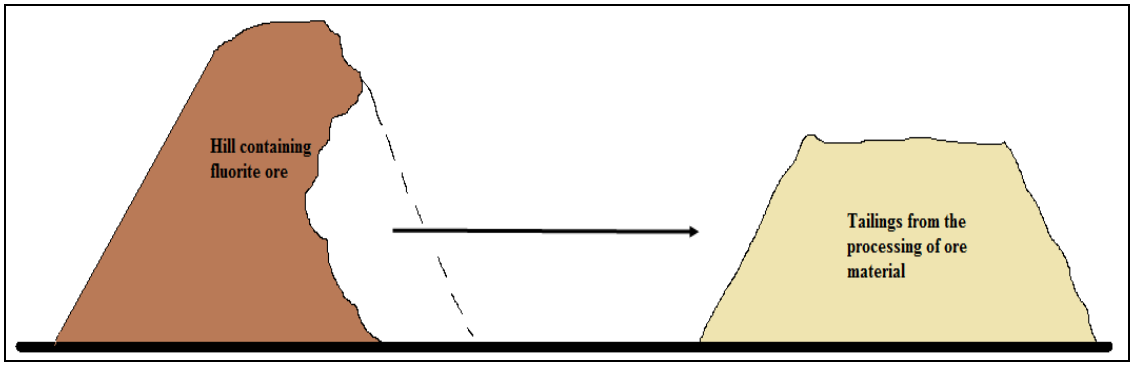


Figure 23: Model showing Changes that occur as a result of mining.

4.6. Impacts of Mining on Land Cover

Table 4.9 is a statistical data table that shows changes in vegetation cover as result of mining within the Kimwarer environment.

Table 4.9: Statistical data on the land cover changes for the forest land and scattered trees in 1984, 1989, 2000 and 2010.

	1984 (acres)	**1989 (acres)**	**2000 (acres)**	**2010 (acres)**
Forestland	2717.00	2675.01	2069.86	1835.21
Scattered Trees	1173.252	760.76	1007.76	1062.10

The total forest land that has been cleared from 1984 is approximately 882 acres to the year 2010. The rate of change for the forest land within the area of study from 1984 to 2010 is approximately 32% which is a considered very high. In the next few years as with mining still ongoing the clearance will grow at a much faster rate.

This has been the result of mining i.e. clearing of vegetation to open up areas that will be mined for the ore, clearance of vegetation to open up areas for settlement of workers that work in the mine areas. In 1981 the area of bare land and settlement increased at a very high rate as a result of the need to employ a big number of people that work in the mining.

There was also development of small trading centres that came up to serve the mining community. These include Kabokbok and Kimwarer Shopping Centres located at the heart of the mining areas. The need for wood as the major source of energy for the community living in the area has also contributed in the change of vegetation cover. The bare land (brown) on the periphery of the mining areas (yellow) are areas that have been cleared for the mining areas to be expanded as the ore keeps on dipping in the rocks.

Between the years 2000 and 2010 there was an increase in the area covered by scattered trees. This could be a result reforestation that is practiced by the mining company within the area and their residence. The reforestation program has faced a number of challenges including the harsh climate that do not support some other species of trees that were planted. The increase can also be as a result of the ban of charcoal burning especially around the mining environment.

Presently more than 900 acres of land has been cleared for mining in the Kerio Valley and this will increase with mining still taking place and also with the opening up of new areas for mining. The main species of trees within the study area include; *Laudetia kagerensis, Acacia tortilis, Combretummolle* (with swollen stem), *Commiphora Africana Indigofera brevicalyx*, *Harrisonia abyssinica*, *Rhynchosia spp.*, *Plectranthus spp.*, *Pellaeaadiantoides* and *P. calomelanos.* Vegetation is usually removed together with overburden material and dumped at a distance not very far from the mine site. These materials have also led to the destruction of land cover where they have been deposited as waste. Figure 24 is an aerial photograph of a section of Cheberen mine that was abandoned and it displays impact of mining of the land cover and the development of infrastructure. Land cover that was within the mine site has been cleared and since mining stopped there has not been any improvement in the state of the land cover and the general surface.

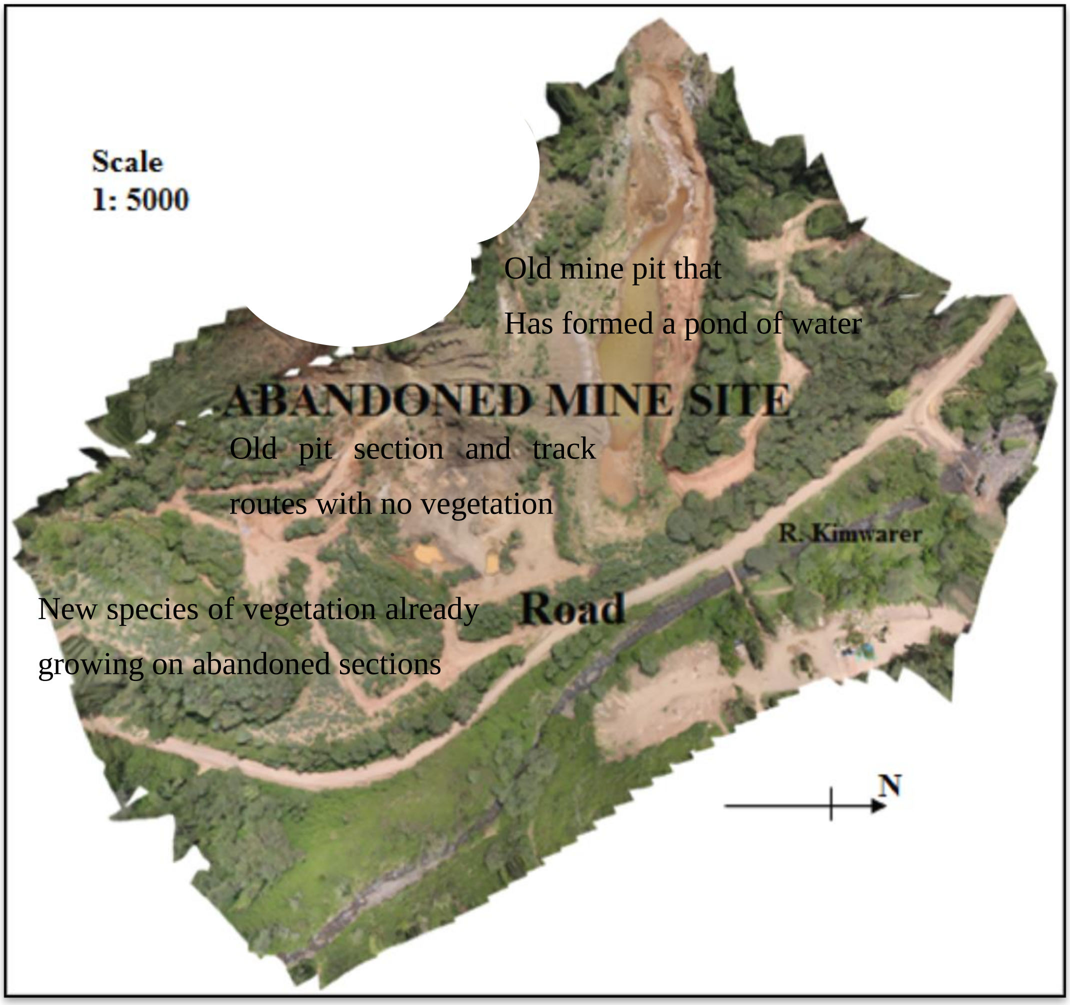


Figure 24: Aerial photograph of Cheberen Mine (KFC, 2014). The brown sections are all areas that have been cleared off vegetation as a result of mining.

Like any other mineral being processed, processing of fluorite requires a lot of water. In Kerio Valley, water required to process fluorite is mainly sourced from there nearby R. Kimwarer and R. Mong. After the mineral is processed, most of the water is removed with the waste and finally stored in ponds close to the tailings, a product of decanting the tailing. The water in these ponds create a modified environment that result in the growth of new type of vegetation that did not exist and could not be supported by the past environmental conditions. The ponds have led to development of an artificial wetland with papyrus reeds as the dominant vegetation type which is a very rare case in the arid and semi arid areas. Water ponds 1 to 5 in Figure 22 are all covered with papyrus reeds a new kind on habitat within the study area, a total of approximately 438177.85 m^2 of the area covered.

With the increase in the activities of the Kenya Fluorspar Company within the Kerio Valley, population is increasing which translates to the clearing of land mainly for settlement. This has further contributed to the impact of mining on land cover even outside the mining lease area. Vegetation will also be cleared to be used as a source of energy and as a matter of fact, the major source of energy in such a rural setting is wood and charcoal. With all these factors contributing, the impact of mining on land cover is not that small with effects mainly felt on the changes on different kinds of habitats.

The trend in the change in vegetation cover has been high rate of clearance at the mining area and areas of settlement especially at the eastern section of the mine which favors settlement from its gently sloping topography.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Open cast mining for a long time has been considered destructive to the environment. Historically, the far greater majority of open pit mines have been constructed as an exercise in economics, constrained by geologic and mining engineering principles with little or no consideration given to the environment in which the mining occurs. By its very nature, open pit mining (also known as strip mining and opencast mining) is environmentally destructive. Surface mining operations, especially those that are large-scale, always alter and disturb the Earth's surface, even if what are usually euphemistically known as "effective" mitigation measures are applied and the site is restored to a condition said to "approach" or "resemble" its natural state. That disturbance, in turn, has numerous direct, indirect, short- and long-term potentially adverse effects on the landscape, including the following and other factors too numerous to detail in this modest definition.

Mining fluorspar in Kenya has been done using the open cast method of mining and this, related to other open cast mines has had adverse impacts on the physical environment including topography modifications, changes in river regimes and destruction of vegetation which are habitats to the wildlife within such an area.

Topographic Modifications

The study established that fluorite mining has been responsible for the significant topography changes within the Kerio Valley environment. Discoveries of new deposits, market demand and the new technologies adopted in mining have been responsible for the fast increase in the area that is under mining.

Signs of topography change within the study areas include open pits, waste rock material piles being dumped close to the mining areas and the processing wastes that are being piled at another section of the mine area. All these signs are very visible in the Kimwarer area of Kerio Valley supporting the fact that change has taken place.

Fluorite, like any other mineral is a non-renewable resource and in the next few decades the mineral will be depleted and mining will stop. But before mining stops the impacts of mining to the modification of topography within Kerio Valley will keep on increasing encroaching towards the Elgeyo escarpment.

Vegetation

Kerio Valley is very rich in natural arid and semi-arid vegetation with species such as *Laudetia kagerensis, Acacia tortilis, Combretummolle* (with swollen stem), *Commiphora Africana Indigo ferabrevicalyx, Harrisonia abyssinica, Rhynchosia spp., Plectranthus spp., Pellaea adiantoides* and *P. calomelanos*. With continuity of mining, there will be a continuous loss of these natural vegetation which takes ages to develop and grow. Introduction of new species of vegetation that has been done by the mining company will not be a perfect replacement of what existed in the past.

The research established that the area under vegetation cover has been decreasing gradually with no signs of others being replanted. Forest land for example has been reduced close to 1000 acres for the last 26 years since mining began. Other human activities are also responsible for the reduction of land cover but mining plays a significant role. Within the mining area, loss of vegetation is evidenced by the mining areas, waste damping site and the settlements that have taken place.

5.2. Recommendations

From the above findings, recommendations had to be made to mitigate the ever increasing negative impacts.

i. The company (KFC) should be responsible for the abandoned open pits by trying to reinstate its original condition and planting of trees to increase on vegetation cover.

ii. The government should follow up on the rehabilitation process that should be carried out of by the company through NEMA and other government agencies.
iii. Research on industrial ecology approach as a rehabilitation method should be conducted if it can be applicable on the fluorspar mining environment. This will help in material utilization and reduce on the negative environmental impacts.
iv. Impacts on ecosystems should be a very important study within the mining environment as large tracts of land are being cleared to open up areas for mining and settlement.

REFERENCES

Australasian Joint Ore Reserves Committee (2003), *The JORC Code.* http://www.jorc.org/main.php. Australasian Institute of Mining and Metallurgy, Carlton, Victoria.

Barbard, P. (1998), *Biological diversity of Namibia* – A Country Study. www.infomine.com/countries/namibia.asp

Charles, J. M. (2006), *Introduction to Mineral Exploration, Second Edition*. Blackwell Publishing.

Chadwick, M.J., Highton, N.H. and Lindman, N., (Eds) (1987), *Environmental Impacts of Coal Mining and Utilization*. Pergamon Press. Newyork p.45.

Coates, D.F. and Gyenge, M. (1972), *Pit slopes angled to the future*. *Geos* 1: 10-11

Compton, R.R. (1965), *Manual of Field Geology* - Wiley Eastern (Private) Ltd.

Cutter, S.L, Renwick, H.L and Renwick, W.H, (1991), Exploration, Conservation Presentation. *A Geographic Perspective on Natural Resources Use*. John Wiley & sons, Inc. New York. p.361-362.

Davies, T.C. (1993), *Mineral Development in Kenya*. In: Geology for Sustainable Development.

Farkas, G. (2005), *Mining and preparation of industrial minerals* – Presenting the perlite mining in the Zemplen – Szerencs, the gate of Tokaj-Hegyalja, ed.: S. Frisnyak, A. Gal, Szerencs, pp. 111-116

Geology.com, (2005), geoloy.com/mineral/fluorite.shtml, Retrieved in 2013

Hadoto, P.M.D. (1995), *Mining Activities and the Environment*- Uganda perspective

Harben, P.W. & Kuzvart, M. (1997), *Industrial Minerals: a Global Geology*, 3rd edn. International Minerals Information, London.

Hartman, H. L. (1987), *Introductory Mining Engineering*. Wiley-Interscience, New York, 633p.

Interapravich, D. and Clark, A. L. (1994), *Performance Guarantee Schemes in the Mineral Industry for sustainable development*. *The case of Thailand. Resource Policy*.T he International Journal of Minerals Policy and Economics. Vol. 20 No. 1 March 1994.

Jones, G.M. (1982) *Kenya Fluorspar*, Mine magazine

Kenya Fluorspar Company Ltd. (2008), *General Corporate Information*.

Kohl, E.R. (1995), *Theoretically Efficient Pricing of Commercial uses of Public Land Resources Policy*. The international Journal of mineral policy and Economics Vol. 21 No. 1 March 1995

Mathu, E.M. and Davies, T.C. (1996), *Geology and the Environment in Kenya*; Journal of African earth Sciences, vol.23, No.4

Miller, G. T. (1990), *Resource Concentration Management*. Wadsworth Publishing Company, Belmont California, P. 466-470

Mines & Geology Department (2001), *Mining Effects on the Environment*, Internal Communication.

Noetstaller, R. (1988), *Industrial Minerals: a technical review*. The World Bank, Washington.

Nyambok, I.O. (1978), *Mineralogy and Paragenesis of the Fluorite Deposits from Kerio Valley, Kenya*. Geologiske Föreningens Stockholm Förhandlingar Vol. 100, Stockholm.

Nyambok, I.O. and Gaciri, S.J. (1975), *Geology of the Fluorite Deposits in Kerio Valley*, Kenya.

Palmer, M. A., Bernhardt, E. S., Schlesinger, W. H., Eshleman, K. N., Foufoula-Georgiou, E. and Hendryx, M. S. (2010), *Mountaintop Mining Consequences*. *Science,* 327(5962), 148-149.

Republic of Kenya (1996), *Economic Survey*, Government Printer, Nairobi. p136-138

Ripley, E.A., Redmann, R.E. and Cooder, A.A. (1996), *Enviromental Effects of mining*. St Lucea press. Delray Beach, Florida.

Ruddle, K. and Manshard, (1981), *Renewable Natural Resources and the Environment*: Pressing problems in the developing world. Tycooly International Publishers Dublin

Stephen, E. K. (1994), *Mineral Resource, Economics and the environment*, Macmillan College Publishing Company.Inc

UNESCO (1981), First UNESCO *Regional Training Programme in Mining Geology*, *Kenya*

USGS, (2011), *Minerals Yearbook*, Kenya [Advanced Release]

U.S. Department of the Interior; U.S. Geological Survey, (2008), http://topochange.cr.usgs.gov/mining.php

U.S. Environmental Protection Agency (2009), EPA Releases Preliminary Results for *Surface Coal Mining Permit Reviews*. EPA.gov.

U.S. Environmental Protection Agency (2010), EPA *Makes Announcement on Two Proposed* West Virginia Mountaintop Coal Mines.EPA.gov.

U.S. Fish and Wildlife Service (1998), *Permitted Stream Losses Due to Valley FIlling in Kentucky*, Pennsylvania, Virginia, and West Virginia: A Partial Inventory. Pennsylvania Ecological Services Field Office, State College, PA.