

**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES  
MASTERS THESIS**



**GIS-BASED GEOSTATISTICAL ANALYSIS OF THE  
KENTICHA TANTALUM DEPOSIT AND IMPACT OF THE  
MINING ON THE ENVIRONMENT  
ADOLA, SOUTHERN ETHIOPIA.**

**BY Arsema Girma**

**March, 2007**

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ADOLA, SOUTHERN ETHIOPIA**

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES  
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In partial fulfillment of the requirement for the Degree of Master of Science  
in GIS and Remote Sensing.

by

Arsema Girma

March, 2007

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## List of Acronyms and abbreviations

ASE	Average Standard Error
EMDSh.Co	Ethiopian Mineral Development share company
EMRDC	Ethiopian Mineral Resource Development Company
E – W	East West
GIS	Geographic Information System
GPS	Global Positioning System
Km <sup>2</sup>	Kilo meter square
LUCC	Land use and Land cover changes
m	Meter
MS	Mean Standard
Na <sub>2</sub> O <sub>5</sub>	Niobium
NDVI	Normalized Difference Vegetation Index
N - S	North South
RGB	Red, Green, Blue.
RMS	Root-Mean-Square
RMSS	Root-Mean-Square Standardized
Ta <sub>2</sub> O <sub>5</sub>	Tantalum

## **Abstract**

The developing mineral industry of Ethiopia brings a considerable and irreplaceable input from the country's economy. Mining at present is concentrated in the southern part of the country within a relatively small area, where gold and tantalite ores are being mined by open pit methods and processed. The main target of the mineral development are (i) Adola gold field with its primary gold (Lega Dembi and Shakiso) and numerous rich placer gold and (ii) the Kenticha province of rare metal bearing pegmatite. The present study is concerned with the latter.

The Kenticha area in southern Ethiopia is located in the Neoproterozoic metamorphosed volcano-sedimentary succession of greenschist to amphibolite facies metamorphism. In the studied area, the rock sequences consist of serpentinite, talc, talc-chlorite-tremolite schist, and granite-pegmatite units.

In order to make prognosis on the possible presence of undiscovered ore-shoots in unexplored and under-explored parts of the Kenticha tantalite deposit, Adola Belt, GIS-based geomathematical techniques were tested. Analytical sample data generated from thirty bore holes formed the basis for computing the studies.

The studies consisted of processing the Kenticha mine sample data- width, Ta-Nb-grade, and accumulation from borehole data's to discern patterns and assess the environmental impact associated with the mining activity in the region.

The techniques adopted were frequency distribution, trend analysis, auto-grade correlation, variogram analysis and spatial variation and land use and land cover analysis. The frequency studies show positively skewed distributions for grade and accumulation. Trend analysis indicates certain clear patterns of value distribution. Variogram show high 'nugget' (random) component, anisotropy and nested structure for grade at the Kenticha tantalite deposit.

From an integration of the results of the above different kinds of studies, certain parts of the mine were identified for selective mining of the deposit and to further investigations and exploration in other rare-metal-bearing pegmatite-granite districts of the rare-metal field.

The importance of appreciation of geological factors in interpreting the geomathematical models is stressed.

The impact of the mineral industry on the environment at Kenticha area is considerable. Therefore, the most effective least expensive and quickest means must be identified and urgently implemented to preserve the environment or at least to minimize the undesirable damage to it within the region.

# CHAPTER ONE

## 1. Introduction

### ***1.1. Background***

The Kenticha area belongs to a rare-metal metallogenic province, the only one so far known in the horn of Africa. The Kenticha rare-metal pegmatite in the Adola area was discovered in 1980 by The Ethiopian Mineral Resources Development Corporation (EMRDC) during the course of preliminary and detailed exploration. Mining in Kenticha started in 1991; since then the deposit has produced a total of 870 tons of tantalite concentrates (Ethiopian Mineral Development Sh. Co- EMDSH.Co). Production is now running at about 100 tons/year of tantalum oxide from weathered pegmatite and alluvial ore (EMDSH.Co; Personal communication). In 1988, preliminary reserves were evaluated at 25,000 tons of Columbo-Tantalite ore at a 0.02 – 0.03 % Ta<sub>2</sub>O<sub>5</sub> grade and hard rock ore reserves are currently under evaluation by EMDSH.Co.

Other significant tantalite occurrences have been identified in Kilkile, and Bupo, in the same rare-metal field, while a Nb-Ta and REE - Th pegmatite-related occurrence close to a two-mica granite was discovered near Meleka (Kilenso) in the Sidamo region.

Data from 30 bore holes were supplied by the EMDSH.Co for the study. These holes were drilled on a regular 80 m-80 m grid. The dimension of the area under study for GIS-based geomathematical techniques is approximately 1500 m north to west and 1000 m east to west. All holes were drilled inclined to about 80<sup>0</sup> to the west using core drilling, with hole diameter 75 mm.

### ***1.2. Statement of the problem***

The Kenticha tantalite mine in Adola Belt operated by the Government owned, EMDSH.Co has been in continuous operation for well over 15 years.

There has been a progressive decline in the average recovered tantalite grade in the pegmatite ore and the present recovered grade is from rich ore-shoots. The possible explanation resulted from this study (see later) is that the tantalite values are not uniformly distributed all over the deposit. There are rich ore-shoots, moderate and low-grade sections and barren portions.

Therefore there is an urgent need to locate all possible rich ore-shoots for a higher productivity of the mine. This case study is one such attempt.

The previous knowledge about the Kenticha rare metal deposit was limited to an economical evaluation derived from mining exploration, largely based on preliminary geological approaches. Data generated from the mining activities were not treated by a recent scientific and reliable method to estimate the deposit. Therefore, this work aims at a detailed investigation of the internal mineral structure of the deposit to understand the pattern of rare metal distribution using GIS-based geomathematical approach (technique).

The Kenticha area was largely covered by dense forest with varieties of plant species. Since the mining activity commenced in 1991, the forest cover is being diminishing from time to time, though, the mining activity is not the only factor that resulted the relative deforestation but is considerable to be the major and significant one. Therefore, one of the present works is to assess the scale of environmental impact (in terms of deforestation, land degradation) in the area within the last 15 years and recommend to take remedial measures to minimize the impact.

### ***1.3 Objectives of the study***

#### **A. General Objectives:-**

- Study the spatial distribution of the rare metal element in space.
- Show the general environmental degradation due to the mining activities in the past 15 years.

## **B. Specific Objectives:-**

- To locate potential areas for a higher productivity within the ore bodies of the Kenticha tantalite mine,
- To analyze the impact of mining in terms of deforestation and land cover change.
- To recommend important measures to be taken to minimize the environmental damage.

### ***1.3 Materials and methods***

The study has two phases of analysis the first phase is the geostatistical analysis of the Kenticha tantalum deposit. In this part first the data from 30 boreholes were edited and value distribution and population statistics were calculated. The trend surface analysis was made to see the distribution of the grade values in all boreholes. Frequency distribution of ore grade on normal and log-transformed was made to study the nature of the distribution of assay values. Later, study of variogram analysis and modeling and prediction maps was performed.

The second phase was the environmental impact analysis; in this part images of the years 1986 and 2002 were interpreted and classified by unsupervised classification. After field survey, the unsupervised classifications were edited with ground truth and supervised classification was made. Land use/land cover changes for both years were calculated and image differencing was prepared to observe the rate of changes per year to predict land cover changes in Kenticha area. Based on the Land use / Land cover analysis of the Kenticha Belt and Locality the environmental impacts due to the mining activity are discussed and relevant mitigation methods were forwarded to prevent further impact on the area.

The following materials were used to perform the study: -

1. 30 bore hole data from the Kenticha locality,
2. Topographic map of the Kenticha area in a scale of 1: 50, 000,

3. Landsat TM and ETM+ satellite images of the years 1986 and 2002, (p168r56).
4. Soft wares such as CartaLinx 2, ERDAS Imagine 8.6, ArcGIS 9.0, ENVI 4.1, Surfer 7, and Microsoft Excel softwares to analyze the dataset generated form 30 boreholes and the satellite images.

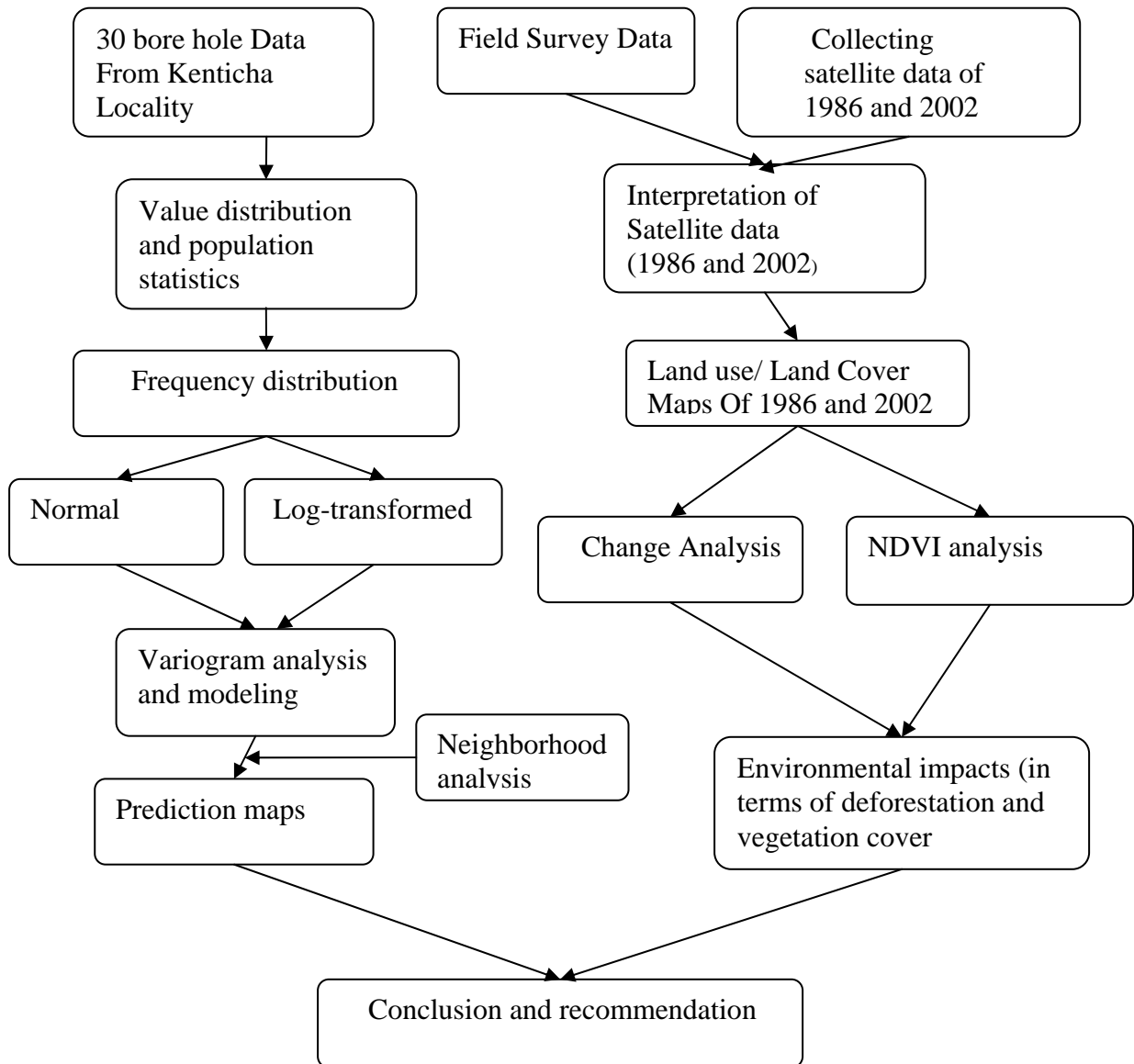


Figure 1.1 Proposed study approaches

## **1.5 Significance of the study**

- From the results of the analysis, treatment, interpretation, and modeling of the data from the Kenticha tantalite, EMDSHCo is considered to be the ultimate beneficiary. The resulting data can serve to upgrade their reserves and to find similar deposits in the Adola area and elsewhere with the same geological settings.
- The results will be useful for both local and foreign investors in the mining sector and governmental and non-governmental organizations engaged in environmental conservation issues.

## **1.6 Limitation of the study**

The environmental change analysis was intended to be done in three phases; pre-mining period, during the commencement and progress of the mining activities and recent period. Images of 1986, 1991 and 2006 of the area were required for the present study. However, it was possible to acquire images for the years 1986 and 2002. Therefore, the absences of adequate images for the various years from the beginning of the mining activities to recent constrained detailed analysis of the area under study. However, the available image data helped to analyze the environmental impact of the area due to the mining activities.

# CHAPTER TWO

## 2. Review Literature

### 2.1 *Geostatistics*

Geostatistics applies the theories of stochastic processes and statistical inference to geographic phenomena. Methods of geostatistics are used in petroleum geology, hydrogeology, hydrology, meteorology, oceanography, geochemistry, geography, forestry, environmental control, landscape ecology, agriculture (UNESCO, 1999).

The geostatistical methods differ from conventional methods as the geographic location of the sample value is given importance. Geostatistics may be defined as the application of the theory of regionalized variables to the study of mineralized volumes of rocks and all considerations arising from this. The regionalized variable has two components 1) the magnitudes of the variables and 2) its position. The assay value is a regionalized variable and is a function of its position. This function can be (i) spatial/structural and or (ii) random (Rendu, 1978).

The basic concept of geostatistics is that of scales of spatial variation. Spatially independent data shows the same variability regardless of the location of data points. However, spatial data in most cases are not spatially independent (David, 1977). Data values which are close spatially show less variability than data values which are farther away from each other (Karim, 2003). The exact nature of this pattern varies from data set to data set; each set of data has its own unique function of variability and distance between data points. This variability is generally computed as a function called semivariance (David, 1977). The objects of geostatistics in evaluation of mineral prospects are to estimate the most likely values of the blocks and to estimate the errors of such estimates (Hutham, 2000).

## 2.2 Semi-variogram (Variogram)

Recognizing the importance of spatial locations of samples in a geological environment, Matheron introduced the concept of regionalized variables and the use of variogram or semi-variance functions to study the nature of variability of mineralization in different directions. The variogram is computed as the difference between assay values (grade) at a particular lag squared, summed and divided by twice the total number of data pairs counted at the lag. The rate of increase of semi-variance indicates the decreasing influence of the regionalized variable (sample value) with increasing distance from the sample location (Golden software manual, 2004). The variogram modelling gives the boundary zone of influence of the sample value, the total variance having the special component and the random component. The variogram reveals the following characteristics- nugget effect, spatial variance, continuity, and anisotropy (David, 1977).

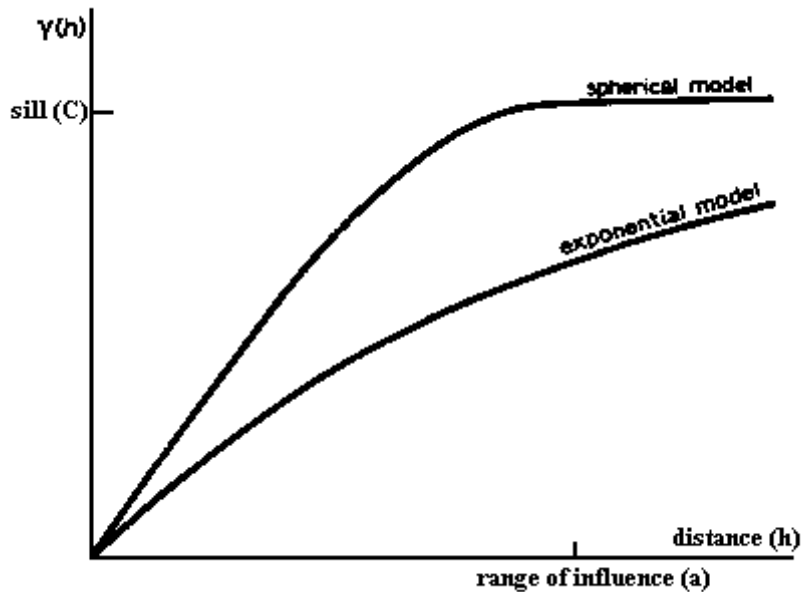


Figure 1. 1. Variogram model

## **2.3 Kriging**

Kriging is a regression technique used in geostatistics to approximate or interpolate data. The theory of Kriging was developed by Danie G. Krige. In the statistical community, it is also known as Gaussian process regression. Kriging is also a reproducing kernel method (like splines and support vector machines).

## **2.4 GIS and Remote Sensing**

A Geographic Information System (GIS) is a system for creating and managing spatial data and associated attributes. In the strict sense, it is a computer system capable of integrating, storing, editing, analyzing, and displaying geographically-referenced information (Truong, 2004). In a more generic sense, GIS is a "smart map" tool that allows users to create interactive queries (user created searches), analyze the spatial information, and edit data. Geographic Information Systems technology can be used for scientific investigations, resource management, asset management, development planning, cartography and route planning.

Remote sensing includes all information collected from sensors which are physically separate from the object. Remotely sensed data plays an important role in data collection. Satellite remote sensing provides an important source of spatial data. Here satellites use different sensors packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed to identify objects and classes of interest, such as land cover. In the context of this thesis, remote sensing was used in deriving information about the land use/land cover to study the land use/ land cover change in different years in the Kenticha Belt and locality.

## **2.5. LUCC and Land degradation**

Land degradation means a reduction or loss, in arid and dry sub humid areas of biological or economic productivity, complexity of rain fed crop land, irrigated crop land, or range, pasture, forest and wood lands resulting from land used or combination of processes. These processes includes those which arising from human activities and habitation patterns such as soil erosion caused by wind or water, deterioration of the physical, chemical, and biological properties of soils as lost of natural vegetation and biodiversity (Turner,.et.al. 1994).

Deforestation also leads to increase over land flow since it removes the vegetation which probably affects rates of run-off more than any other single factor. The rate of run-off is therefore a useful indicator of land degradation and desertification process which results from land use practices (Brandt, 1985). Worldwide, soil loss and degradation and sediment transport have undoubtedly been increased greatly as a consequence of land cover change (Anderson, 1998).

## **2.6 Impacts of Mining on the environment and LUCC**

Mining tends to make a notable impact on the environment, varying in severity depending on whether the mine is active or abandoned, the mining methods used, and the geological conditions (Bell *et al.*, 2001). It causes massive damage to landscapes and biological communities of the Earth (Down, 1977). Natural plant communities get disturbed and the habitats become impoverished due to the mining, which results in a very rigorous condition for plant growth. The traditional mining of mineral deposit posses a serious threat to the environment, resulting in the reduction of forest cover, erosion of soil in a greater scale, pollution of air, water and land and reduction in biodiversity (UNESCO, 1985). The problems of waste rock dumps become devastating to the landscape around mining areas (Goretti, 1998).

As ore deposits consist of relatively small percentages of economically valuable minerals, their extraction and processing involves large amounts of waste material. These wastes are in solid and liquid form. The mining activities also entail deforestation and reshaping of the natural topography around the mine sites. Today, the developed nations generally have stringent guidelines to ensure the rehabilitation of mined areas and many large mining companies are committed to employing the same sound environmental practices in overseas operations, even though the regulations in other countries are not as tight (UNESCO, 1999).

The following are some of the main environmental impacts connected with mining activities.

### **2.6.1 Impacts on land cover and vegetation**

The extraction process entails the removal of large amounts of material, which becomes waste products. These materials are both the overburden that covers the deposits and wastes from the ore that are produced in the processing and concentration of the ore.

When the mine is to be decommissioned, rehabilitation of the mine site involves the removal of mine infrastructure, and the return of native vegetation and contours to rock dumps and capping and revegetation of tailings dams (Goretti, 1998).

### **2.6.1 Impacts on water**

One impact of mining is to bring to the surface large quantities of minerals that are unstable in the weathering environment. In particular, sulphide minerals in waste rock and tailings react to form sulphuric acid ( $H_2SO_4$ ). The resulting acidic runoff can be devastating to the surrounding ecosystem (Kiranmay, 2005). Runoff from mines may also have enhanced levels of metals such as arsenic, copper, lead, iron, cadmium and nickel. In the case of uranium mining, radioactive materials may be exposed at the surface. Treatment processes also introduce liquid wastes, such as cyanide, kerosene, mercury, organic flotation agents, activated carbon, and sulphuric acid. Mining operations are designed so that liquid wastes are part of a closed system. Wastes are stored and treated

on-site until they are clean enough to be released. All effluents leaving mine sites need to be closely monitored (Hutham, 2000).

## **2.6.2 Impacts on Air**

Smelting and refining can produce air pollution of particulates (smoke and fine particles), nitrogen and sulphur oxides and vaporized metals. Dust blown from waste rock dumps and tailings dams may also include hazardous material (Goretti, 1998).

## **2.7 NDVI (Normalized Difference Vegetation Index)**

Normalized Difference Vegetation Index (NDVI) is important tools in the monitoring, mapping, and resource management of the Earth's terrestrial vegetation. They are radiometric measures of the amount, structure, and condition of vegetation which serve as useful indicators of seasonal and inter-annual variations in vegetation. The NDVI is an index that provides a standardized method of comparing vegetation greenness on satellite images. NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light (USEPA, 2000). NDVI has been shown to be correlated with green leaf biomass and green leaf area index. Chlorophylls, the primary photosynthetic pigments in green plants absorb light primarily from the red and blue portions of the spectrum, while a higher proportion of infrared is reflected or scattered. NDVI tends to increase with increases in green leaf biomass or leaf area index (fundamentals of airphoto interpretation, 2000). The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7  $\mu\text{m}$ ) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1  $\mu\text{m}$ ). The more leaves a plant has, the more these wavelengths of light are affected, respectively (USEPA, 2000).

# CHAPTER THREE

## 3. General Description of the Area

### 3.1 Location

The Kenticha rare metal deposit is located in; Oromia Region, Sidamo Zone in Odo Shakiso and Adolana Wereda Southern Ethiopia astronomically located between  $38^{\circ}:57'44''$  E –  $39^{\circ}:06':23''$ E latitude and  $5^{\circ}:10':36''$ N -  $6^{\circ}:04':51''$ N longitude.

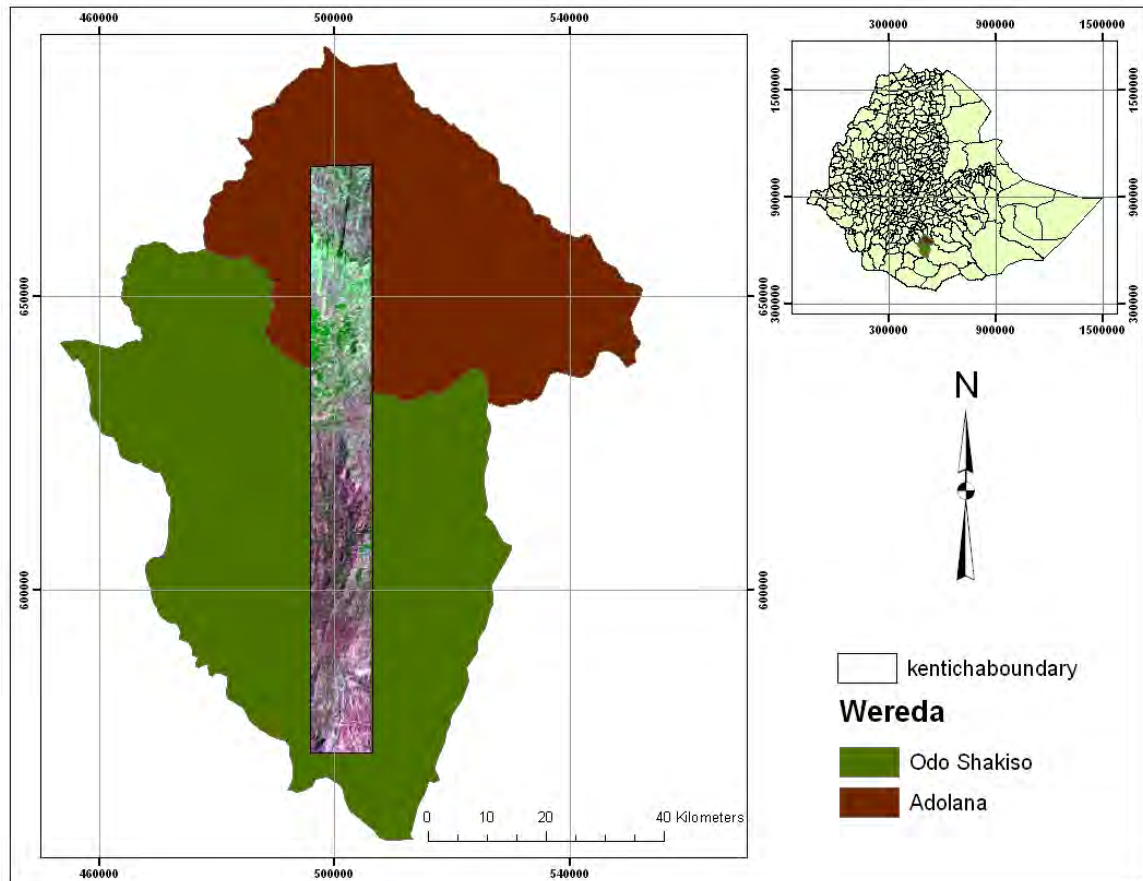


Figure 3. 1 Location map of the Kenticha rare metal element Belt

### **3.2 Topography**

The study area is located within southeastern slopes of the Ethiopian Highlands in the Zone of transition to the Somalian Plateau. Altitudes range from 2250 m and 2300 m a.s.l. The watersheds rise from 250-350 m above the adjacent valleys in the northern part of the areas and covered by basaltic flows and are deeply dissected by erosive activities of the surrounding rivers. In the central and southern parts, the local relief range between 100-150 m. The territory has an overall tilt direction from North - West to South - East and has been a controlling factor in the course of the formation of the drainage system especially along the main streams of the area (Tsfayesus, 1985).

### **3.3 Climate**

The climate is characterized by an equatorial monsoon climate with abrupt changes from dry to rainy seasons. According to the Shakisso weather station, the first rainy season with the heaviest precipitation lasts from end of March to May. The second rainy season is from September to mid November. The main dry season lasts from mid November to March when precipitation is absent. During this period, the maximum daily temperature is 35<sup>0</sup>C. The dry season is also characterized by sharp fluctuations in temperature falling as low as 5<sup>0</sup>C during the night. During rainy seasons the temperature does not exceed 22<sup>0</sup>C and during cloudy days falls to 12-10<sup>0</sup>C at night (Tsfayesus, 1985).

### **3.4 Vegetation Cover**

The northern and central part of the area is covered with evergreen tropical forests having three structural rows. The upper row is represented by individual trees or clumps of trees up to 30 m high. The medium row represents the thick forest with trees 10 - 15 m high. The lower row is represented by the Underwood and bushes of different type everywhere and are difficult to pass through.

The flora of the study area is diverse. Species such as Mahogany wood, Walnut and Iron wood are common. As a whole, the wood of the upper tiered were target for logging during the study. In the southern part of the area the trees are represented by typical throb savannah: there are undersized umbrella acacia trees, small thorny bushes (Tesfayesus, 1985)

### ***3.5 Regional Geology***

The Kenticha rare metal deposits occur in the eastern side of the Adola area, 550 km south of Addis Ababa. The Adola area is known to form part of the Mosambiquean Belt that extends from South Africa across Tanzania and Kenya into Ethiopia and then into North Africa (Gilboy, 1970; Chater, 1971; Kozyrev et al., 1982). In Adola area, the Kenticha rare metal field forms N-S trending belt which is elongated according to the core of a narrow syncline structure (Emlyanov et al., 1986). This structure controls the localization of the rare metal deposits associated with granitoids of acidic composition (Poletayev et al., 1989). As a whole, the rare metal belt is formed by the rocks (from older to younger) of Aflata formation, Kenticha formation, Adola orthometamorphic rock series and early Paleozoic (post orogenic) granites and pegmatites. The most common rock types of the Aflata formation are biotite gneiss, amphibolites and discontinuous beds and interbeds of biotite schists, graphite and marble.

The Kenticha formation occupies a narrow synclinal structure with biotite and muscovite gneiss, garnet amphibolite gneiss, quartz-feldspathic gneiss, fine grained amphibolite, staurolite-garnet-biotite schists, garnet-staurolite schists, two-mica schists and marble (Kozyrev et al., 1982 and Emelanov et al., 1986). The rocks of the Adola orthometamorphic rock series occurring in the area include serpentinite, talc, talc-tremolite-actinolite schists, chlorite schists, metasandstones. The Kenticha serpentinites is the largest body of ultrabasic rocks being the main host rocks of pegmatites within the area. Generally, these ultrabasic rocks form a north-south trending belt, which in the middle part of the study area is divided into two branches. In the region, post-tectonic

granites and rare metal bearing pegmatites occasionally associated with alaskitic granites facies, controlled by regional fault and shear systems, are widely developed.

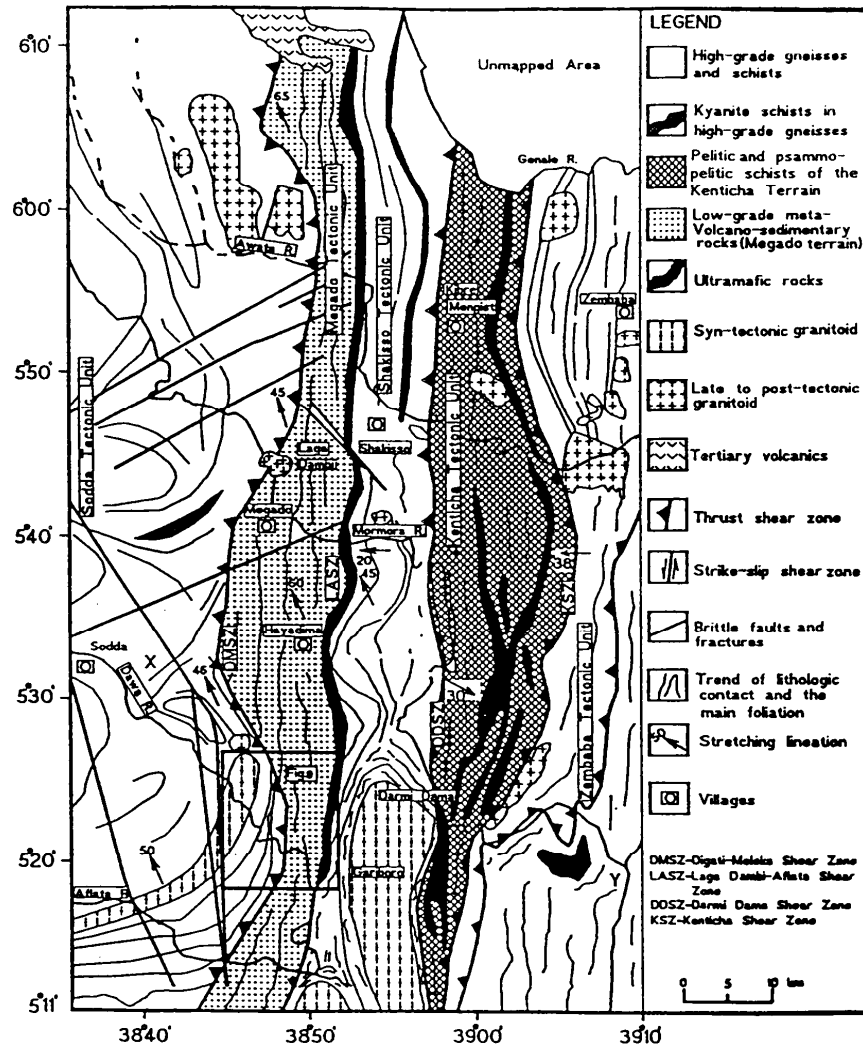


Figure 3. 2 Geological map of Adola Belt, Southern Ethiopia (after Hailu, 1996)

### 3.6 Local Geology

The metamorphic rocks within the Kenticha area encompass biotite, biotite-muscovite, garnet amphibolite, quartzo-feldspatic gneisses, amphibolite, discontinuous beds of biotite, garnet-staurolite and twomica schists (Kozyrev et al., 1982). In addition, there are elongated lenses of ultrabasic rocks serpentinites, talc, talc-tremolite-actinolite and chlorite schists trending north-south. The ages of the rocks range between  $580 \pm 680$  Ma (Chater, 1971).

The grade of metamorphism reaches amphibolite-greenschist facies (Gilboy, 1970; Chater, 1971; Kozerev et al., 1982; Emelyanov et al., 1986). The enclosing rocks of pegmatite-granite are represented by metasedimentary-metavolcanic rocks of the Kenticha formation or by hydrothermally and metasomatically altered pre-or/and syn-tectonic ultrabasic rocks of the Adola magmatic series. The pegmatites in the Kenticha rare-metal field are genetically related to dome and lenticular shaped granitic intrusions. Upwarping of the country rock is common in the vicinity of such intrusions. The granite rocks in the area include biotite granite, two mica granite and alaskitic granite. These granites are post orogenic and are supposed to be the source rocks of the rare-metal enriched pegmatites occurring within the Kenticha rare-metal field. The emplacements of pegmatites are controlled by steep N-S trending older faults, parallel to the zone along which the rare-metal deposits are concentrated. In addition to the older N-S trending faults, two relatively younger normal faults that have NE-SW and NW-SE directions are evident (Fig 3.2). The intersection of these faults with the N-S trending structures appears to be most favorable for the development of post tectonic magmatism and pegmatitic ore formation (Emelyanov et al., 1986).

The pegmatites in the area are arranged in zonal patterns around the source granite following the N-S trending regional fault and shear system. The mineral associations found in the granite-pegmatite rocks include columbo-tantalite group minerals, ixiolite, beryl, lepidolite, staurolite, phosphate (apatite, ambligonite and lithiophilite), tourmaline (schorl and elbaite), garnet (spessartite and manganian almandine), rutile, ilmenite and magnetite (Solomon T. and Zerihun D. 1996).



Figure 3. 3 General panorama of the Kenticha Tantalum Deposit (Adola, Southern Ethiopia)

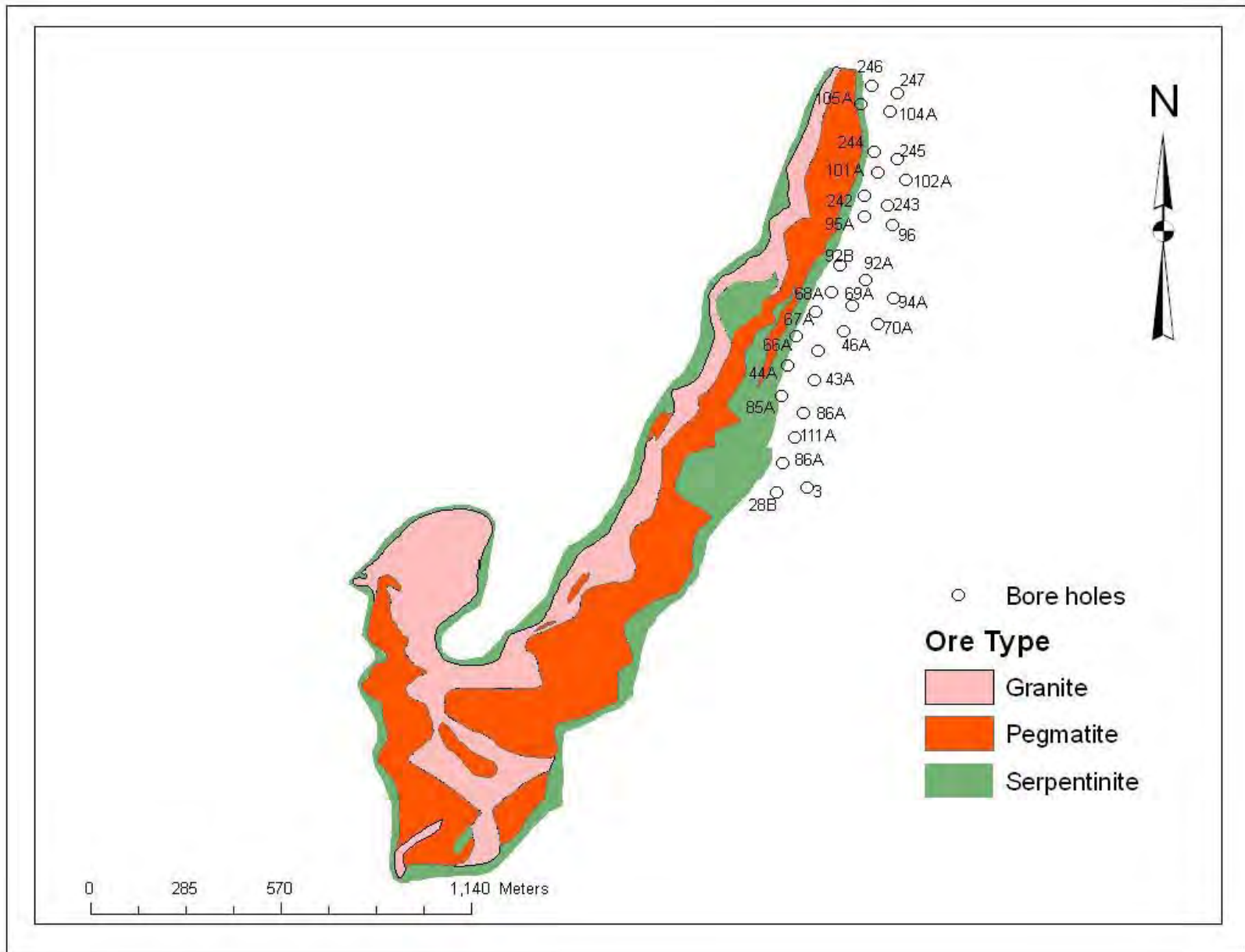


Figure 3. 4 Simplified geological sketch map of the Kenticha Tantalum deposit (Source EMDSh.Co)

## CHAPTER FOUR

### 4. Geostatistical Analysis of the Kenticha Tantalum Deposit

#### 4.1 The experimental data

The present study is based on 1178 point data generated from 30 boreholes provided by EMDSH.Co. The deepest borehole used in the study is 250 m along and the shallowest borehole has a depth of 80 m. Most of the samples were taken at 1.5 m intervals and the bore holes are apart 80 roughly m in X - Y directions. There were no missing values in the data set and the data were used as received originally. The minimum value for both  $Ta_2O_5$  and  $Nb_2O_5$  is 1g/t and the maximum value is 102 g/t and 187 g/t respectively. Most of the values of  $Ta_2O_5$  and  $Na_2O_5$  are concentrated between 2 g/t-11 g/t and 4 g/t-23 g/t respectively. All the values are given in  $10^{-3}$ g/t.

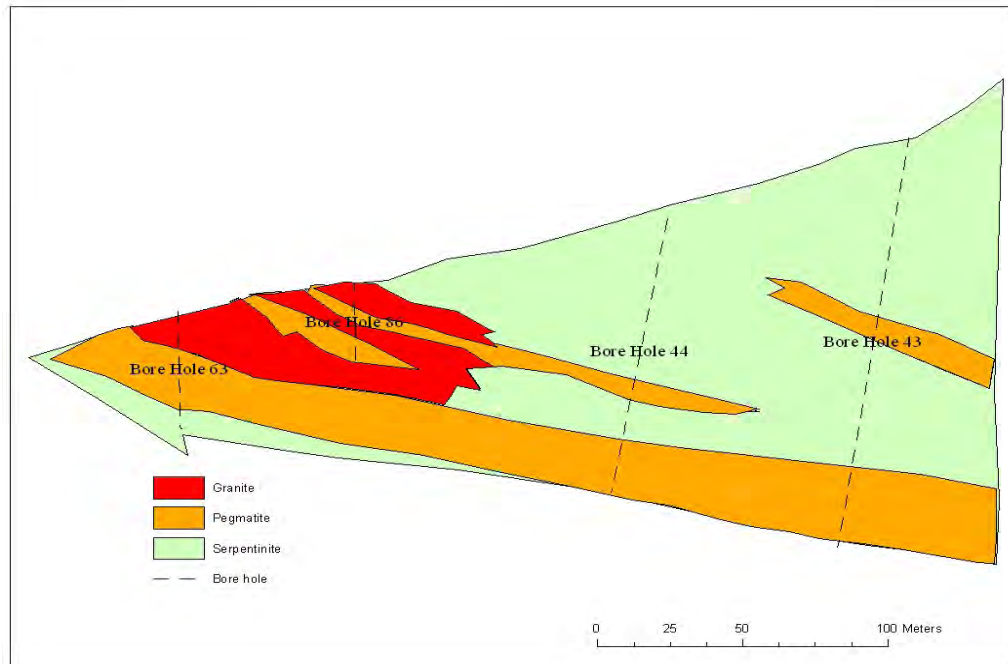


Figure 4. 1 Typical section of the ore bodies with the locations of bore holes in the Kenticha Tantalum deposit (Source EMDSH.Co)

During the preparation of the data, outliers within the normally distributed values were trimmed in order to reduce over estimation in a particular position, as can be seen in

Figure 4.2 and 4.3. high values were observed in the dataset which are considered as outliers which indicate that the distribution do not follow systematic increment in the assay values.

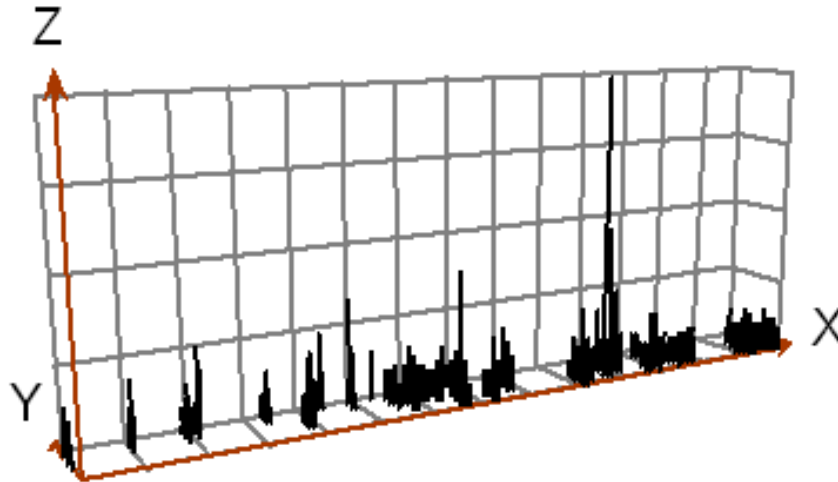


Figure 4. 2 3D base map showing vertical spatial variability of Ta<sub>2</sub>O<sub>5</sub>

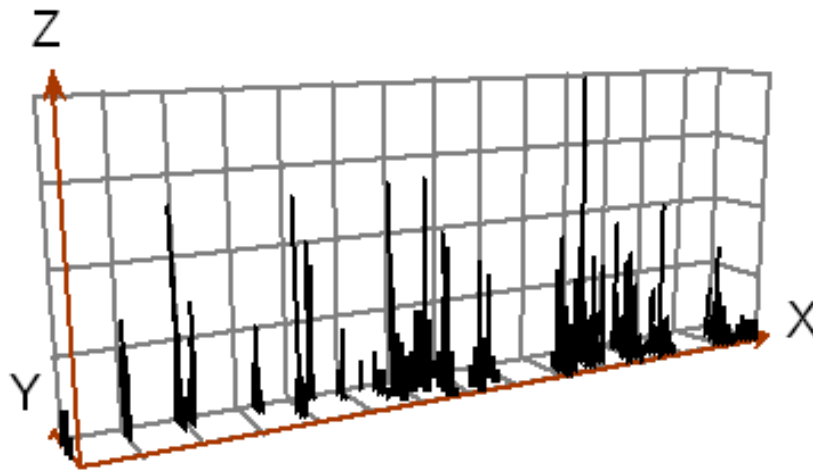


Figure 4. 3 3D base map showing vertical spatial variability of Nb<sub>2</sub>O<sub>5</sub>

Before further analysis of the histograms and variograms, detection of systematic pattern of variation in the database was conducted. Traditionally, detecting a trend in a database can be done in two ways; one way is a simple visual examination of the test results as a function of depth, length or width. In this regards, a glance look at the data set shows no systematic variation from top to bottom for individual boreholes.

### 4.3 Histograms and Statistical distribution

Frequency studies have been made for the 1178 point data to understand the behavior of the values within the ore body. Table 4.1 shows the statistics of point samples in the deposit, based on 30 borehole data spaced approximately 80 meters apart in squared grid, an important aspect in grade estimation is the type of frequency distribution of sample data. In a normal distribution, the curve is bell-shaped and the arithmetic mean grade is a good estimator. In such cases, the ‘mean’, the ‘mode’ and the ‘median’ fall in the same position. In high specific gravity and low concentration ores like precious metals and tantalite, the distribution becomes skewed. If the histogram is positively skewed, as it occurs most of the times, the distribution is likely to be lognormal, and the required symmetry is obtained by the logarithms of the values.

Normal		Lognormal (arithmetic values)	
Mean	0.00054	Mean	
M-2 $\delta$	0.00019	M-3 $\delta$	0
M+2 $\delta$	0.0009	M-3 $\delta$	0.0011
Effective population	745	Effective population	786
Effective < (M-2 $\delta$ )	2	Effective < (M-3 $\delta$ )	0
Effective > (M+2 $\delta$ )	269	Effective < (M-2 $\delta$ )	17
		Effective < (M+2 $\delta$ )	179
<b>Total</b>	<b>1016</b>	<b>Total</b>	<b>1016</b>

Table 4. 1 Statistical distribution of the analyzed samples according to the statistical parameters. Both normal and lognormal distributions are considered with two possible confidence intervals (95% and 99% confidence levels).

The statistics shows that at a normal distribution, the mean is found to be 0.00054, shifting the effective population within the curve of normality to 745 (at M-2 $\delta$  - M+2 $\delta$ ) and 786 (at M-3 $\delta$  - M+3 $\delta$ ), with outliers of 271 and 230 respectively. When the distribution is converted to lognormality the mean changed to 0.00057, shifting the effective data to 820 (at M-2 $\delta$  - M+2 $\delta$ ) and 915 (at M-3 $\delta$  - M+3 $\delta$ ), with outliers of 196 and 101 respectively. In both normal and lognormal distributions, the number of data used was 1016 (see Table 2.1).

After checking the data, the next step was to generate some important graphical representations such as histograms to calculate a summary descriptive statistics. This allowed to study the variation of samples from the central value and the symmetry and pattern of the frequency distributions.

The resulting histograms of  $Ta_2O_5$  and  $Nb_2O_5$  data are shown below. Generally 58 class intervals were used to let high values appear which other wise fall out side the range containing most of the analytical data.

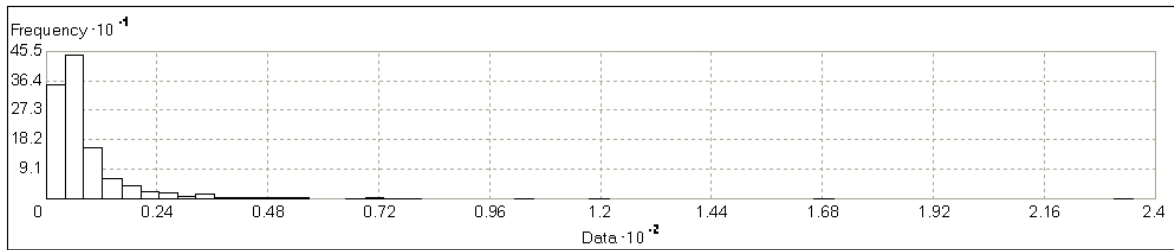


Figure 4. 4 Histogram of total bore hole data for  $Ta_2O_5$

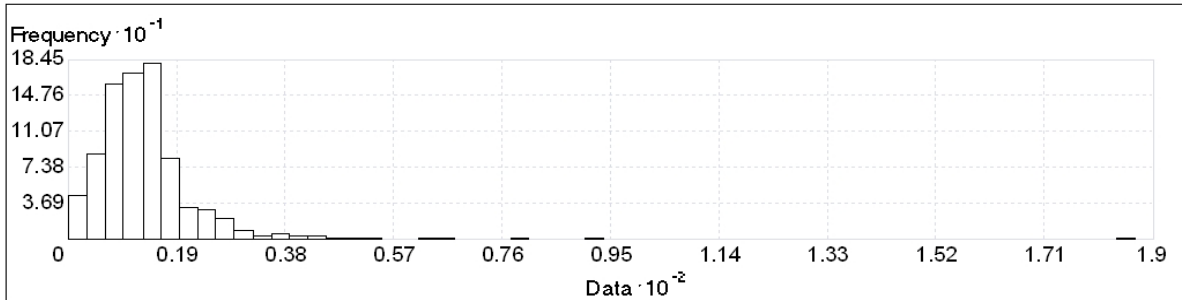


Figure 4. 5 Histogram of total bore hole data for  $Nb_2O_5$

The above histograms for both  $Ta_2O_5$  and  $Nb_2O_5$  revealed that the data is highly positively skewed from the mean. Since, the sample data in the Kenticha tantalite ore shows positively skewed distributions, it was found necessary to transform the values to convert the skewed distribution to the normal distribution. Lognormal transformation of the data gave a good fit indicating lognormal distribution. The log transformation was used with the same class interval and the distribution pattern has improved significantly as shown below.

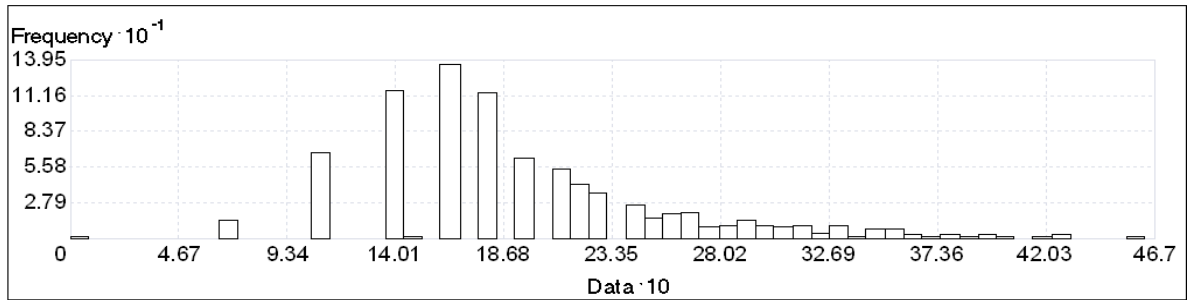


Figure 4. 6 Log transformed histogram for Ta<sub>2</sub>O<sub>5</sub>

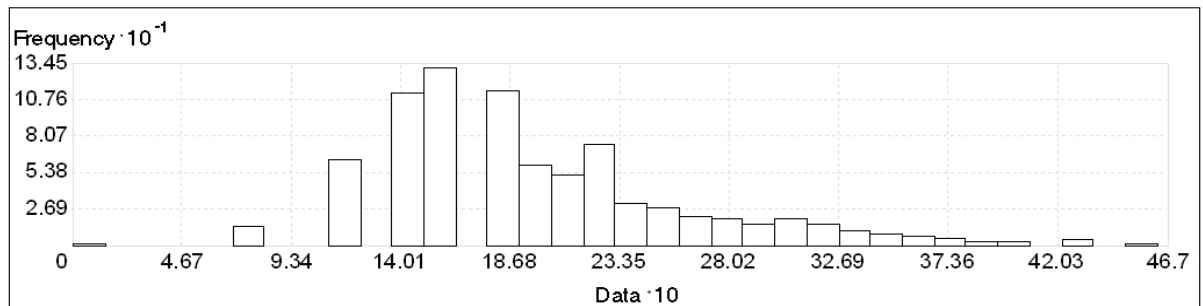


Figure 4. 7 Log transformed histogram for Nb<sub>2</sub>O<sub>5</sub>

From the above histograms, the skewness has changed from 7.76 to 0.84 and from 6.8 to 0.66 for Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub> respectively showing a symmetry to the mean value. The kurtosis also decreased from 102.07 to 3.85 and 96.2 to 5.33 for Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub> respectively indicating minimum likelihood of the distribution to produce outliers; which according to David (1977) indicates that in most geological problems, assay values do not follow a normal distribution rather their logarithms tend to be normally distributed. Thus it can be supposed that the data under consideration follows a lognormal distribution.

The following conclusions were drawn from the above results:

- 1 the distributions are positively skewed and strongly asymmetrical,
- 2 the population is of mixed type and multimodal frequency distribution noticed,

- 3 in spite of the different values of mean and standard deviations for Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub>, the coefficients of variation values are consistent, showing a strong correlation between the mean and variance.

In a Similar way, frequency studies made with log-transformed data shows that:

- 1 The distribution is positively skewed for both Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub> values.
- 2 The distribution approach lognormality with minor deviation.

#### ***4.4 Experimental Variograms***

At the Kenticha tantalite deposit, the geological and structural interpretation of the mineralization has not been conducted in details. The study was therefore made by steps to determine the general tendency of the variability of the mineralization along the thickness and the dip of the ore body and model the tendency.

##### **4.4.1 Variogram along the thickness of the ore body for all bore holes**

The experimental variograms computed along the direction of the thickness of the ore body was in order to analyze the behavior of the spatial distribution of the mineralization in X-Y direction. The parameters used to calculate the experimental variogram along the thickness were average grade values, sample intervals every 1.5 m at 63 layer lags. The parameters considered to observe the behavior of the distribution within the ore body are shown in Table 4.2. The resulted experimental variograms are shown in Figure 4.8 and 4.9. The formula used to calculate the variograms along the thickness (X – Y) direction is:-

Total value of assay values in 1.5 m interval/ number of bore holes = one lag

Sample interval (m)	average grade ( 10 <sup>-3</sup> g/t)		Lag	Sample interval (m)	average grade ( 10 <sup>-3</sup> g/t)		Lag
	Nb <sub>2</sub> O <sub>5</sub>	Ta <sub>2</sub> O <sub>5</sub>			Nb <sub>2</sub> O <sub>5</sub>	Ta <sub>2</sub> O <sub>5</sub>	
1.5	9.16	9.86	1	49.5	13.28	7.64	33
3	7.3	8.86	2	51	13.58	7.25	34
4.5	10.46	11.73	3	52.5	13.1	9.4	35
6	9.7	14.23	4	54	12.9	6.2	36
7.5	9.46	11.23	5	55.5	28.9	5.9	37
9	9.73	8.0	6	57	15	13	38
10.5	10.43	11.03	7	58.5	11.22	9.11	39
12	9.9	8.9	8	60	11.33	7.88	40
13.5	10.16	8.03	9	61.5	14.89	12.33	41
15	13	11.06	10	63	15	7.66	42
16.5	14.93	11.56	11	64.5	17	10.87	43
18	11.13	8.4	12	66	14.25	8.25	44
19.5	10.93	10.16	13	67.5	15.71	11.28	45
21	15.9	12.56	14	69	11.14	7.71	46
22.5	15	9.63	15	70.5	15.17	9.83	47
24	13.14	11.42	16	72	12.83	6.66	48
25.5	13.39	10.28	17	73.5	15.4	10.2	49
27	13.35	9.85	18	75	12.2	5.8	50
28.5	12.77	8.96	19	76.5	12.2	5.2	51
30	14.80	9.11	20	78	15.67	5.66	52
31.5	16.88	8.69	21	79.5	10	4	53
33	18.92	9.52	22	81	11.66	4.33	54
34.5	14.43	7.95	23	82.5	10	5	55
36	16.26	7.78	24	84	10	8	56
37.5	17.66	8.33	25	85.5	11	7.5	57
39	17.48	11.33	26	87	16.5	10.5	58
40.5	14.05	7.52	27	88.5	14.5	6	59
42	14.47	6.52	28	90	11	3	60
43.5	14.66	7.66	29	91.5	14.5	3.5	61
45	16.53	7.70	30	93	14	4.5	62
46.5	14.68	6.93	31	94.5	18	8	63
48	15.53	7.46	32				

Table 4. 2 Parameters used to calculate experimental variogram along the thickness (X - Y) direction of the ore body

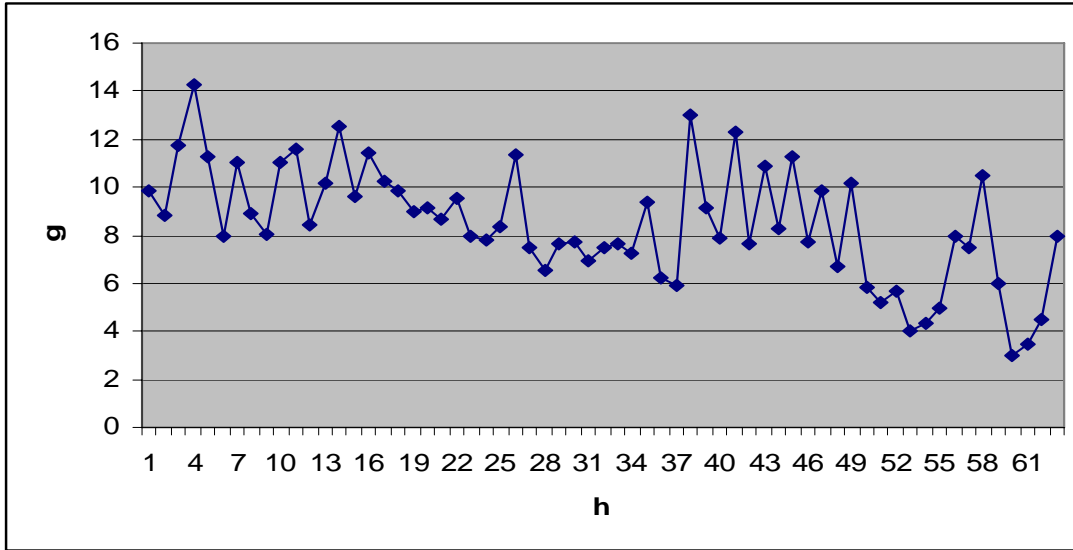


Figure 4. 8 Experimental variogram for Ta<sub>2</sub>O<sub>5</sub> along the thickness of the ore body (X - Y direction)

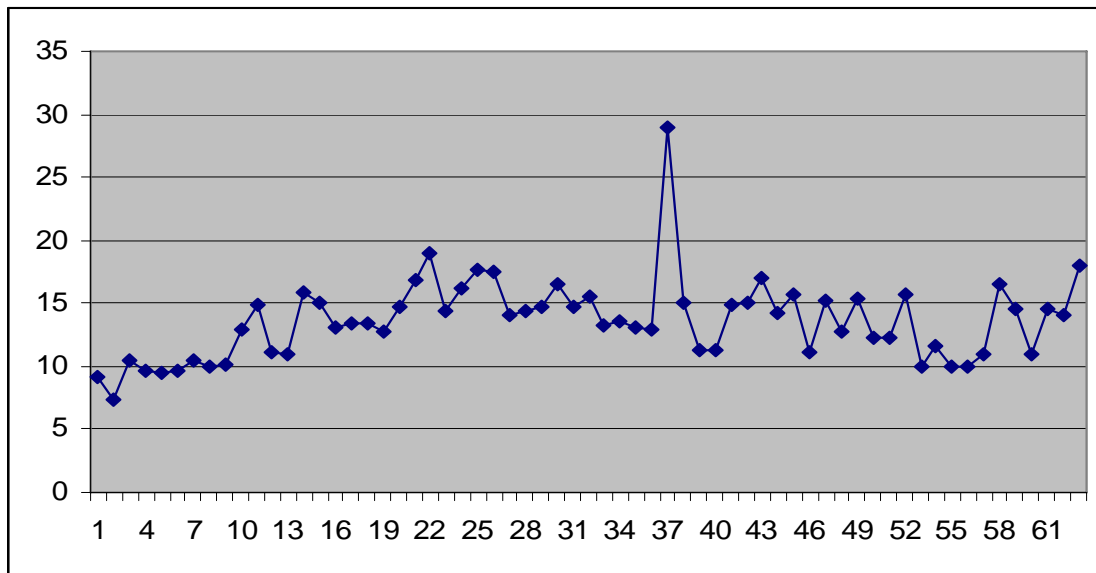


Figure 4. 9 Experimental variogram for Nb<sub>2</sub>O<sub>5</sub> along the thickness of the ore body (X - Y direction)

As shown in figure 4.8 and 4.9, the nature of the experimental variograms is very erratic direction of the thickness (X - Y) of the ore body.

#### **4.4.2 Experimental variograms along the dip of the ore body for all bore holes**

The second type of variograms was computed along the dip of the ore body in order to analyze the behavior of the spatial distribution in the dip direction. The parameters used to calculate the variogram along the dip direction were average grade values, average thickness of the ore body at 30 lag layer (see Table 4.3). The formula used to calculate the variograms along the dip (X –Z) direction is:-

$$\text{Average thickness} \times \text{average grade} = \text{one lag}$$

BH ID	Thickness (m)	Thickness/sample interval (m)	Average grade		Thickness x Average grade		Lag
			( $10^{-3}$ g/t) Ta <sub>2</sub> O <sub>5</sub>	Nb <sub>2</sub> O <sub>5</sub>	Ta <sub>2</sub> O <sub>5</sub>	Nb <sub>2</sub> O <sub>5</sub>	
28	48	32	5.9	16.63	188.8	532.16	1
19 A	49.5	33	2.95	13.32	97.35	439.56	2
43 A	30.75	20.5	10.66	18.71	218.66	383.55	3
44 A	20.9	13.93	15.6	20.4	217.36	284.24	4
46 A	27	18	7.36	17.26	132.63	310.68	5
53 A	23.5	15.66	12.18	13.31	190.84	208.52	6
66 A	31.5	21	10.86	14.48	228.13	304.08	7
67 B	49.52	33.02	5.64	12.17	186.30	401.81	8
68 A	48	32	6.06	9.06	193.39	289.92	9
69 A	46.5	31	14.96	15.4	464.03	477.4	10
70 A	45.25	30.16	12.83	15.19	387.30	458.23	11
85 A	28	18.66	10.86	13.46	202.84	251.25	12
86 A	39.5	26.33	10.58	12.37	278.69	325.74	13
92 B	41.45	27.63	7.27	15.48	201.05	427.76	14
93 A	39	26	10.07	14.4	261.92	374.4	15
94 A	49.5	33	15.32	16.5	505.65	544.5	16
95 A	64.67	43.11	9.22	13.75	397.84	592.85	17
96	56.75	37.83	5.10	10.7	193.25	404.81	18
101 A	93.67	62.44	9.11	12.03	568.95	751.23	19
102 A	34.2	22.8	16.12	12.66	367.65	288.64	20
104 A	75.35	50.23	6.72	14.13	337.84	709.79	21
105 A	70.62	47.08	6.87	11.33	323.69	533.45	22
110 B	25	16.66	11.94	15	199.07	250	23
111 A	39	26.0	15.14	11.37	393.85	295.62	24
242	74.57	49.71	11.86	17.6	590.11	875.01	25
243	95.6	63.73	9.09	12.69	579.76	808.77	26
244	72.7	48.46	9.40	10.28	455.81	498.2	27
245	76.1	50.73	7.88	12.23	399.89	620.46	28
246	85.95	57.3	5.27	12.7	302.41	727.71	29
247	51.1	34.06	4.48	14.18	152.78	483.06	30

Table 4. 3 Parameters used to calculate variogram along the dip (X - Z) of the ore body.

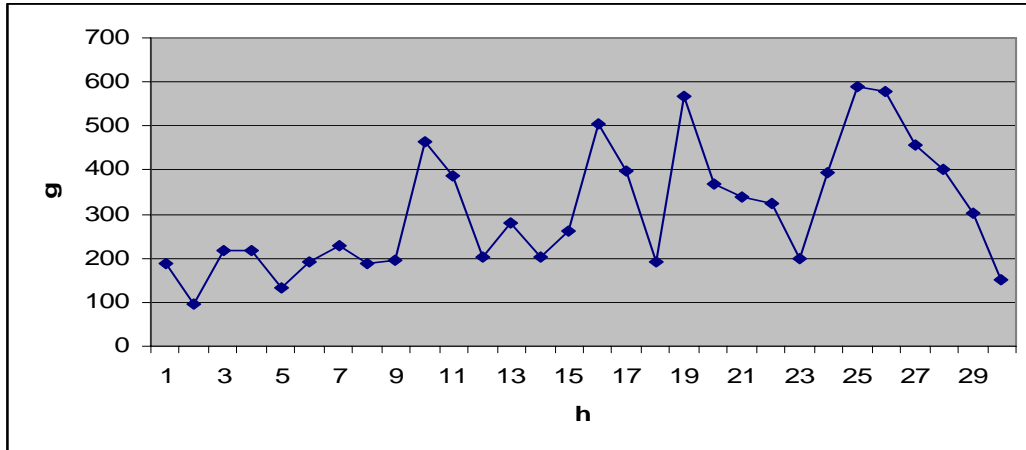


Figure 4. 10. Experimental variogram of Ta<sub>2</sub>O<sub>5</sub> along the dip direction (X -Z direction)

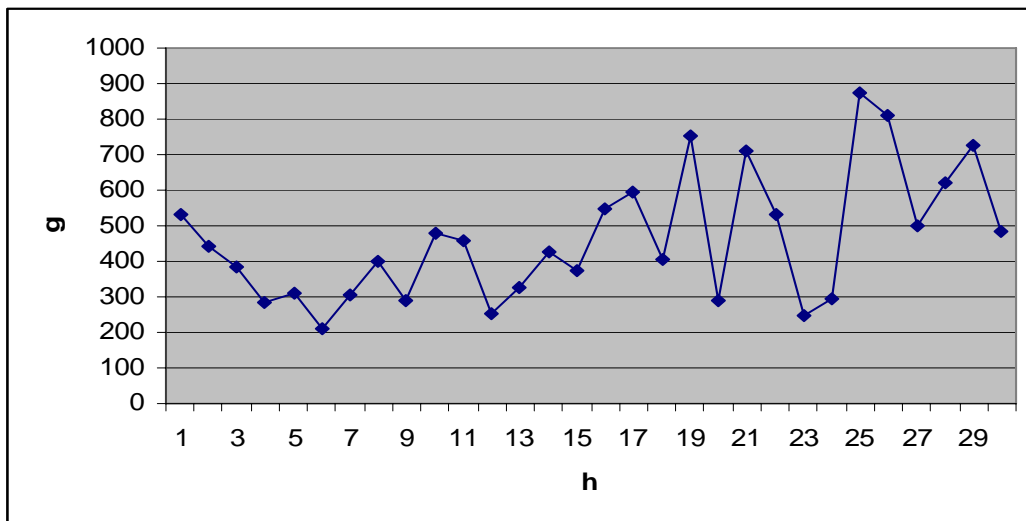


Figure 4. 11 Experimental variogram of Nb<sub>2</sub>O<sub>5</sub> along the dip direction (X - Z direction)

The experimental variograms along the dip (X - Z) direction shows behavior similar to that of the variograms computed along the direction of the thickness (X -Y) of the ore body.

In addition, variograms for individual bore holes along the thickness of the ore body were computed to study the behavior of spatial variation for individual bore holes. The computed variograms also show significant variations for individual bore holes. An

example of experimental variograms computed for individual variograms is shown in Figure 4.12.

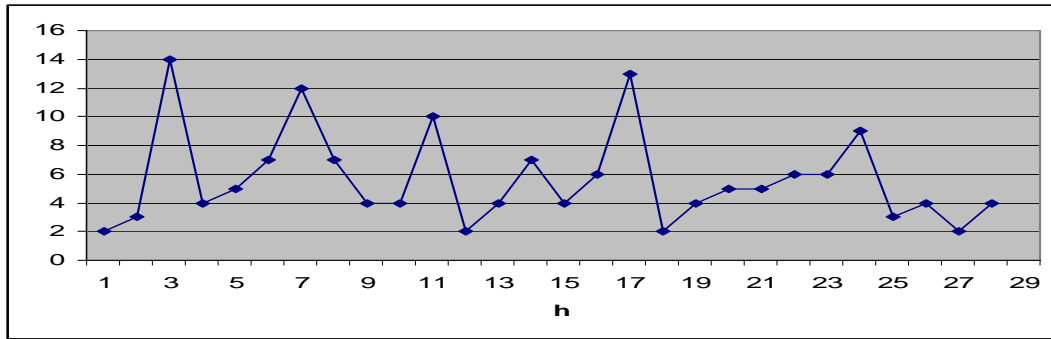


Figure 4. 12 Experimental variogram of bore hole 92 B for Ta<sub>2</sub>O<sub>5</sub>

As observed in both directions, the experimental variograms computed from the dataset has resulted in quantitative grade heterogeneities indicating random spatial distribution of the data under study. In order to check for anisotropy in the data variogram maps of layers in different directions (X-Y, X-Z, and Y-Z) were tested. In all directions, the variogram maps show anisotropy.

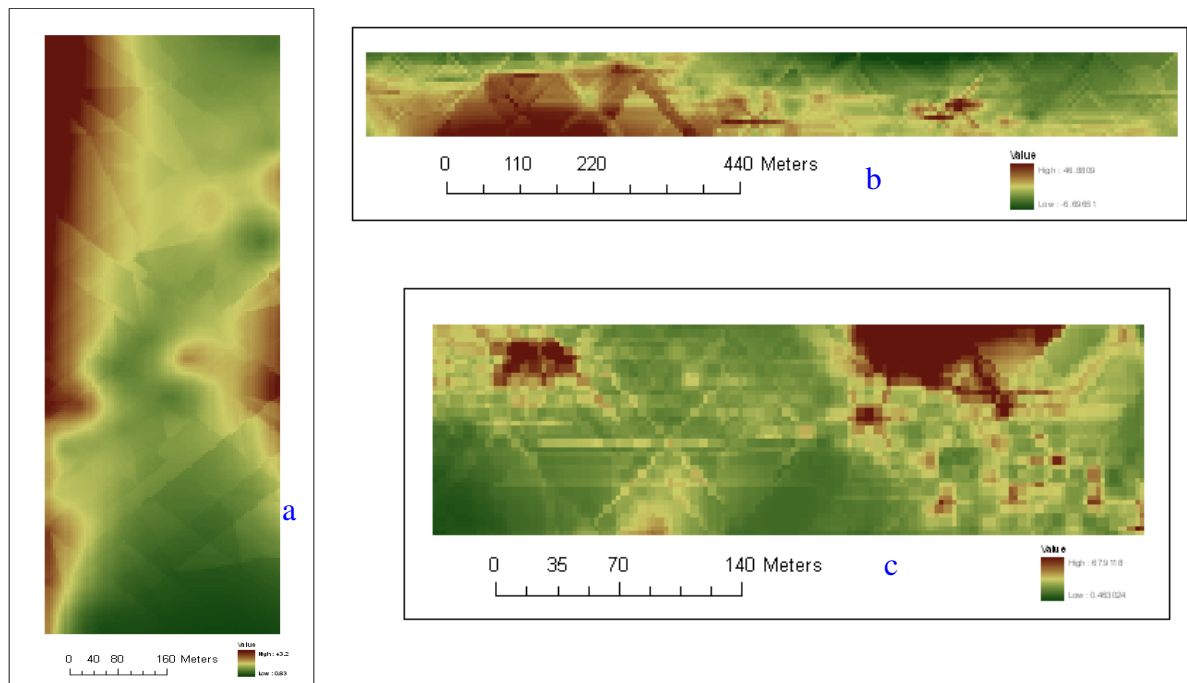


Figure 4. 13 Anisotropy determination a) X-Y direction b) X-Z direction c) Y-Z direction for Ta<sub>2</sub>O<sub>5</sub>.

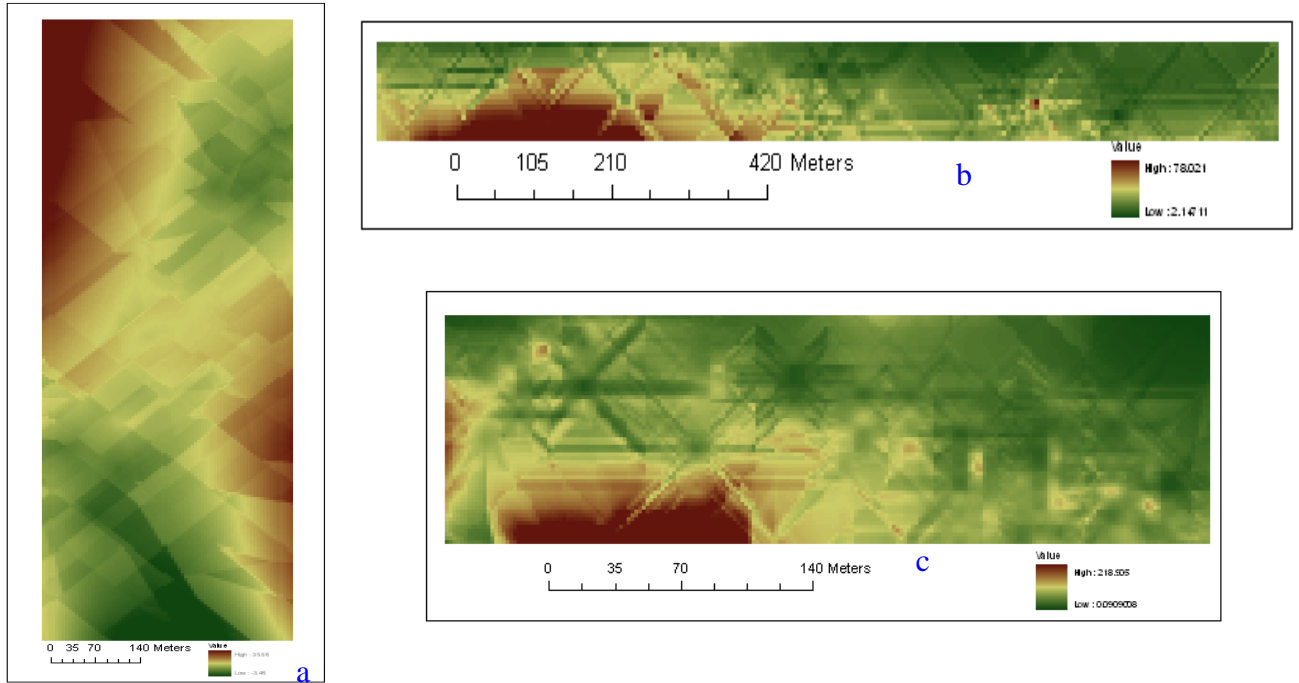


Figure 4. 14 Anisotropy determination a) X-Y direction b) X-Z direction c) Y-Z direction  $Nb_2O_5$

#### 4.5 Variogram modeling

Once the theoretical framework has been setup, the essential step in a geostatistical studies is the definition of a variogram model to represent the spatial variability of the material under study. It is worth pointing out some important features of the variograms; ideally, variogram increases with distance between sample locations, rising to a more or less constant value (the sill) at a given separation distance, called the range of spatial dependence. Finding theoretical models that fit best, the experimental variogram is rather a very difficult exercise. Many basic characteristics of the experimental variograms are needed to be taken into account that the variograms also has to clearly reflect the geological character of the mineral deposit.

The variograms along the thickness (X - Y) and along the dip (X - Z) directions were modeled in the following way to understand the spatial variation of the assay values. Figure 4.15 and 4.16 shows variogram models of  $Ta_2O_5$  in both directions.

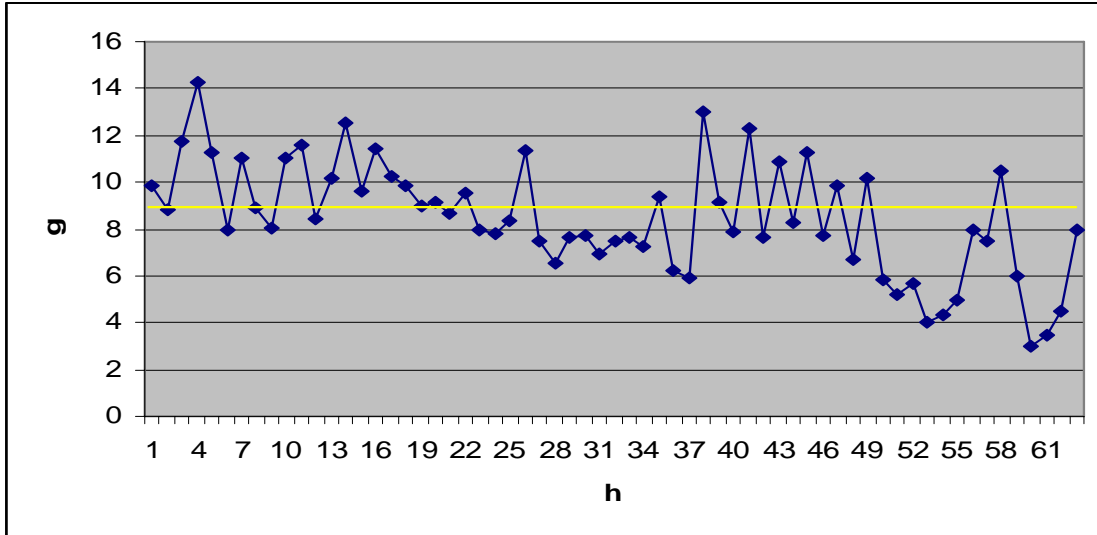


Figure 4. 15 Variogram model along the thickness of the ore body (X - Y direction for Ta<sub>2</sub>O<sub>5</sub>)

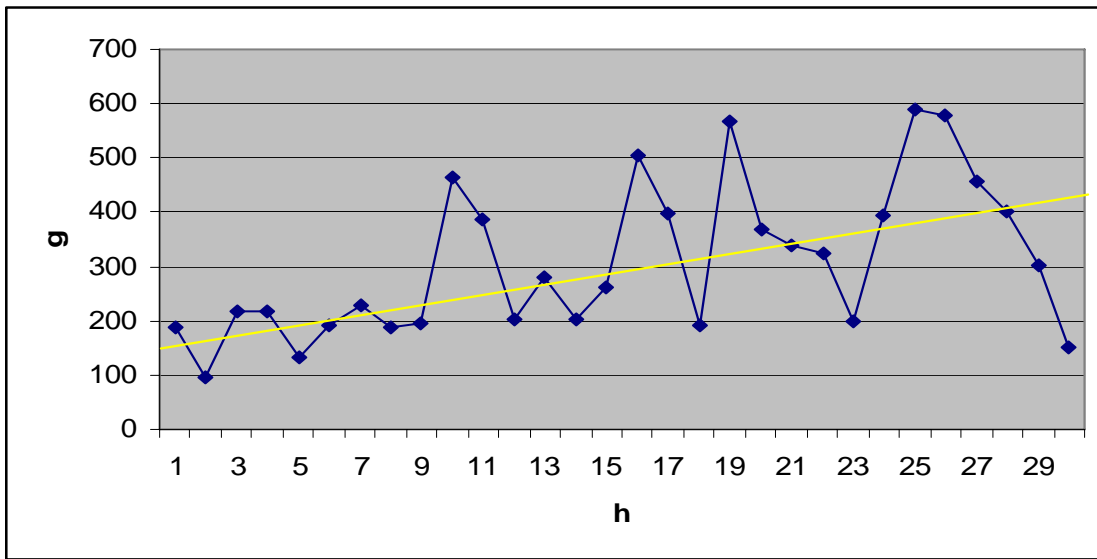


Figure 4. 16. Variogram model along the dip of the ore body (X - Z direction for Ta<sub>2</sub>O<sub>5</sub>)

The same methods were used to model the variogram for Nb<sub>2</sub>O<sub>5</sub> resulting similar trend. The variogram models computed for of Nb<sub>2</sub>O<sub>5</sub> in both directions (along the thickness and dip) are shown below.

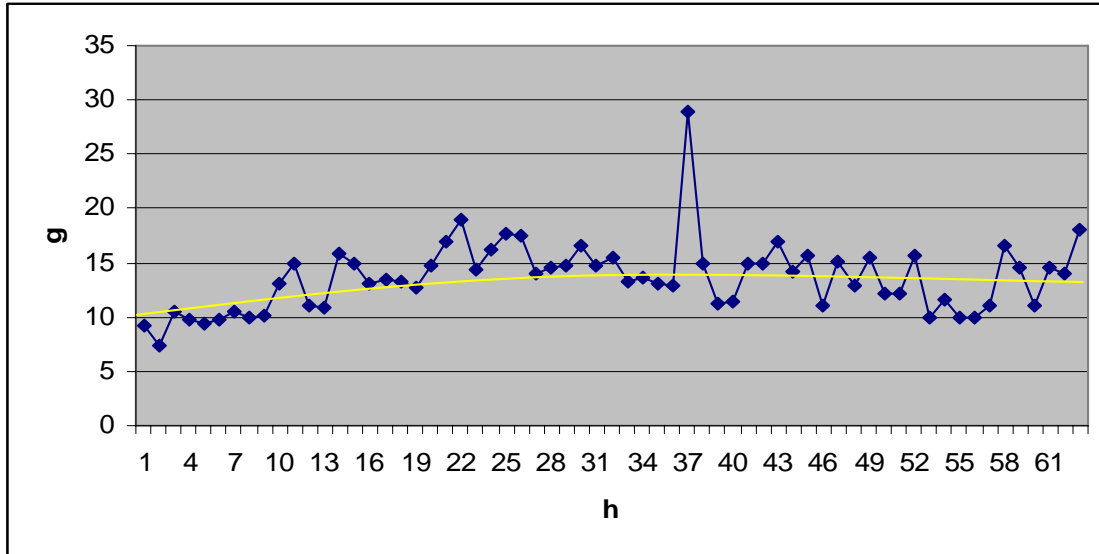


Figure 4. 17. Variogram model along the thickness of the ore body (X - Y direction for Nb<sub>2</sub>O<sub>5</sub>).

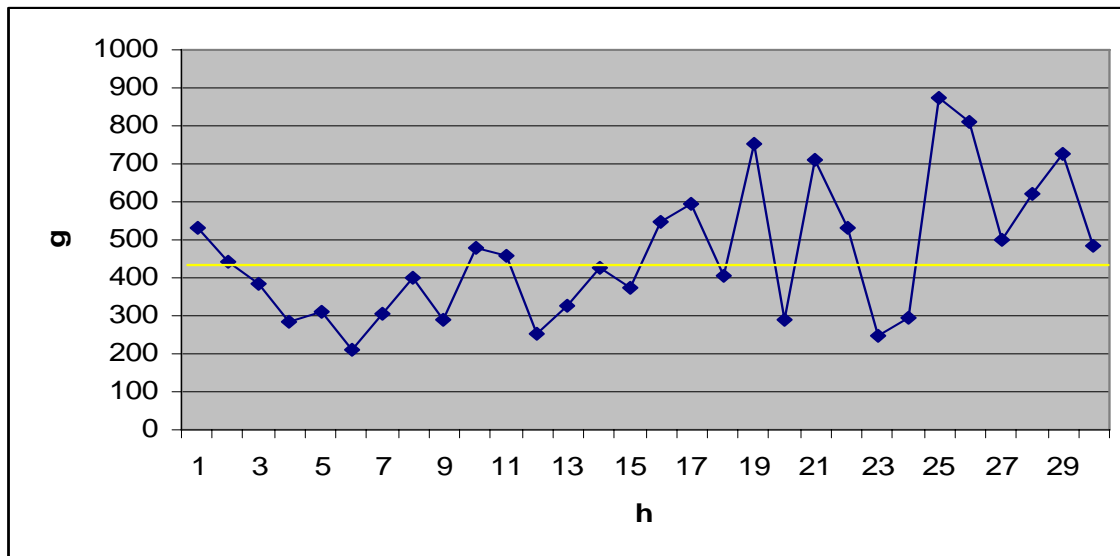


Figure 4. 18. Variogram model along the dip of the ore body (X - Z direction for Nb<sub>2</sub>O<sub>5</sub>)

The variogram models show that the spatial distribution of assay values within the ore body is random and do not follow any sort of pattern in both directions (along the thickness and dip of the ore body). There are no range and sill values, which limits the continuity and similarity of distribution of the assay values in the ore body and the variograms fit to a pure nugget effect models.

The computed variograms for grades from bore holes data for Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub> in the Kenticha deposit along the thickness and dip of the ore body shows the following observations and conclusions:-

- 1 the variograms computed resulted to a pure nugget effect models,
2. strong nugget effect (random) is observed for Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub> assay values both along the thickness and dip of the ore body,
3. nested structures have been noted along both directions,
4. there is anisotropy in grade distribution.

In conclusion, the computed variograms shows high 'nugget' component, anisotropy, and nested structures for both Ta<sub>2</sub>O<sub>5</sub> and Nb<sub>2</sub>O<sub>5</sub>.

The main problems to obtaining reasonable  $\gamma(h)$ 's could be related to the following reasons:-

- the bore holes were spaced too far apart in X - Y direction,
- the extremely erratic behavior of the mineralization and
- absence of important geological structures/lithologies controlling the spatial distribution of the mineralization within the ore body.

#### ***4.6 Neighbourhood search***

Neighborhood functions create output values for each cell location based on the value for the location and the values identified in specified neighborhood directions (ArcGIS training manual). Discarding samples from the sample drill hole and estimating the value using samples from another hole may produce good results that are even much better than expected. But, this can only be true if we have geological layers that are more or less horizontal and if the drill holes are all vertical (David, 1977).

In the study area the ore bodies dip 30° N - E direction and the bore holes are located 80m apart in X - Y direction. Therefore, it was necessary to give more emphasis to samples in the vertical direction (in the same hole) than horizontal direction. The

following figures shows the different directions of neighborhood searching performed in the study.

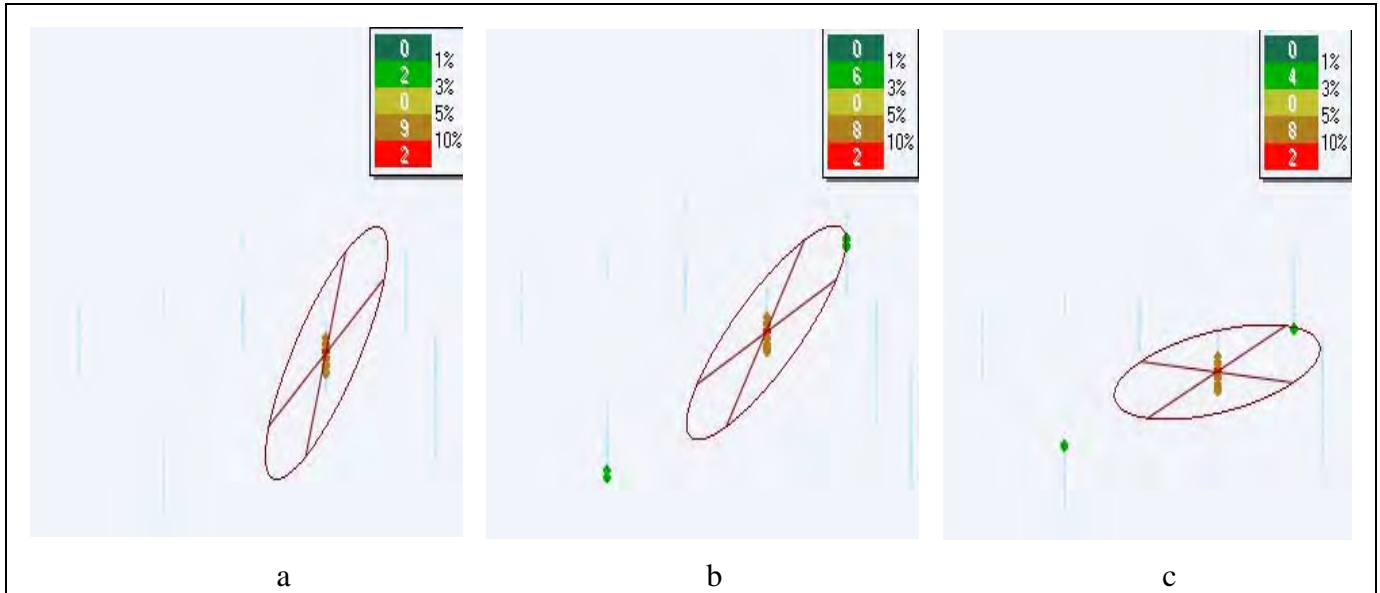


Figure 4. 19. Neighborhood search at (a) search in  $30^{\circ}$  (b) searches in  $45^{\circ}$  (c) searches in  $80^{\circ}$

There are many diagnostic statistics in cross validation which are derived when an unknown value is estimated from a known one. These statistical values are helpful to examine if the estimation procedure to be conducted with a certain variogram model and search neighborhood parameters is optimal or not. The parameters are Mean, Root-Mean-Square, Average Standard Error, Mean Standardized and Root-Mean-Square Standardized. A zero mean denotes unbiasedness in the estimation procedure used to generate errors. The Root-Mean-Square Standardized error should also be close to 1.

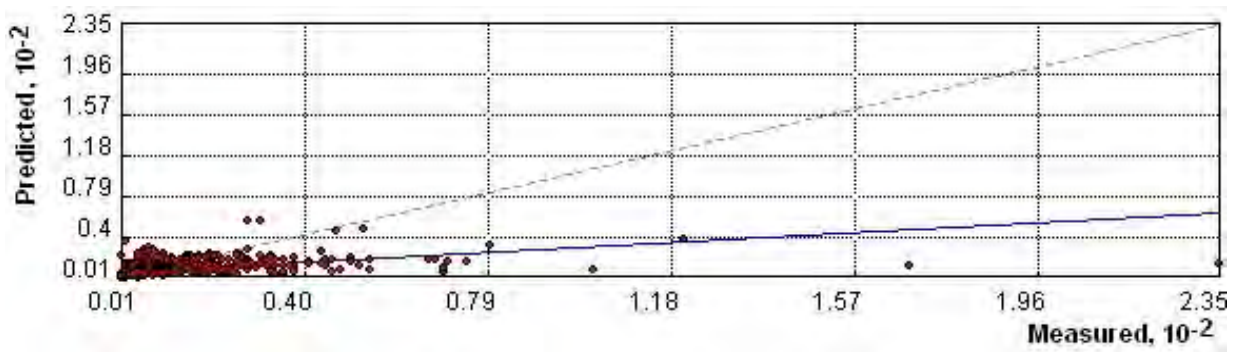


Figure 4. 20. Cross validation for  $30^{\circ}$

Three cross validations for search angle  $30^{\circ}$ ,  $45^{\circ}$  and  $80^{\circ}$  were calculated and the results are given in the following Table.

	Mean	RMS	ASE	MS	RMSS	Total Data
$30^{\circ}$	0.7254	12.05	6.751	0.1036	1.49	1016
$45^{\circ}$	0.7334	12.08	6.681	0.1025	1.556	1016
$80^{\circ}$	0.7756	12.07	6.436	0.1211	1.628	1016

Table 4. 4. Description statistics of search neighborhoods.

As can be observed from the above table, the Root-Mean-Square (RMS) and Root-Mean-Square Standardized (RMSS) errors increased with increase in degree of neighborhood selection, which implies uncertainty in estimation of unknown values, while the data involved in the estimation remain constant.

#### ***4.6 Estimation by ordinary kriging***

Once the histograms and variograms are calculated and the nature of the spatial distribution of the deposit is understood, the next step was to create grid to estimate rare-metal values using kriging. In the study, ordinary kriging was favored compared to simple or universal kriging for there was a need to comply with the reality where the global mean is usually unknown (even though the sample mean in this study is determined). The ordinary kriging variance allows determining the loss of accuracy caused by unknown true mean (Armstrong, 1998 in Lulseged, 2004).

To see the spatial distribution of the assay values clearly, six 20 m independent layers were used in X - Z directions instead of one layer only. The data above 1676 m and below 1556 m elevation were eliminated to obtain more information to make the prediction accurate.

In performing kriging, the assay values were converted to lognormal to prove whether the values follow log normality or normal distribution.

Since the ore body is dipping  $30^{\circ}$  in N - E direction kriging was performed in this dip direction. The  $30^{\circ}$  angle of inclination was favored because, in neighborhood selection, the RMS and RMSS errors were minimized in this angle when compared with the other angles for interpolation.

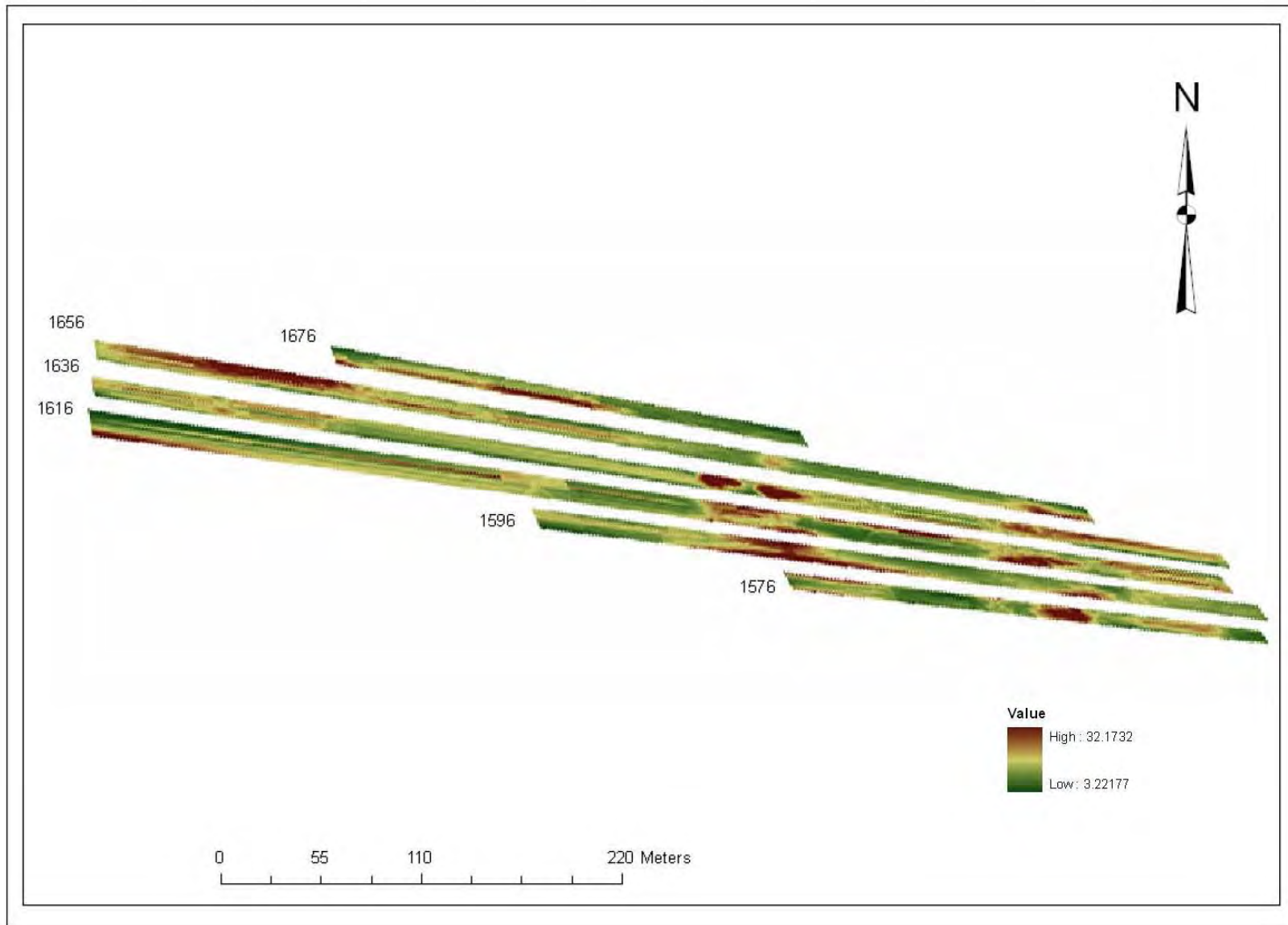


Figure 4. 21. Kriging for  $Ta_2O_5$  at  $30^\circ$  dip direction

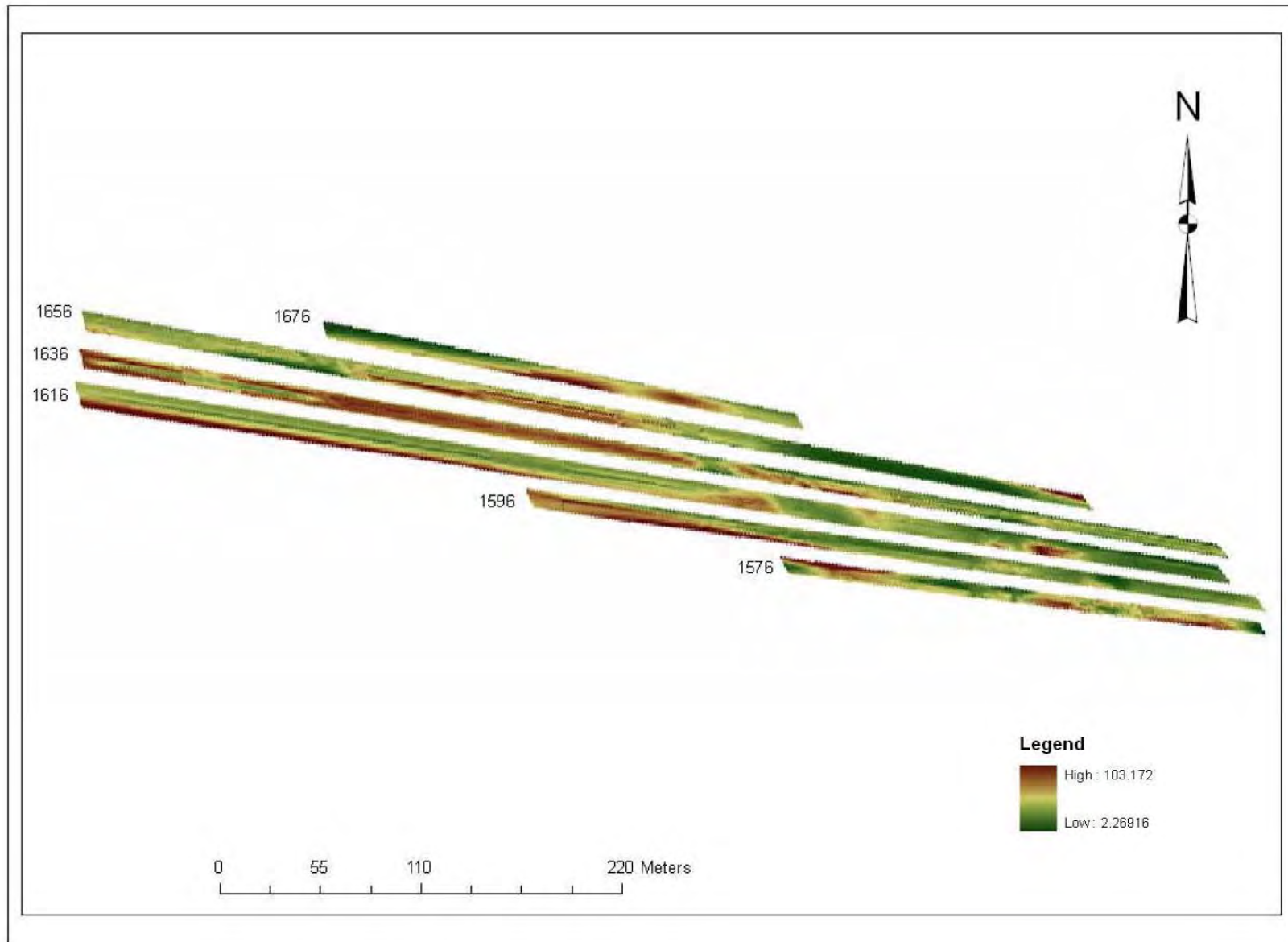


Figure 4. 22. Kriging for  $\text{Nb}_2\text{O}_5$  at  $30^\circ$  dip direction

The kriged maps at 20 m interval also confirm the random distribution nature of the assay values within the ore body at Kenticha.

The map shows the presence of rich ore-shoots, moderate, low grade sections and barren portions indicating that the assay values are not uniformly distributed all over the deposit.

In case of  $Ta_2O_5$  at a depth of 1636 m, northern part at a depth of 1656 m, and central part at a depth 1596 m and 1616m the kriged map shows the presence of high concentration of assay values, and at a depth of 1636 m, northern and central part of 1616 and central part of 1656 m, 1676m and 1576m, the map shows potential locations of mineral reserves for  $Nb_2O_5$ .

The above maps are certainly represents the reality of the nature of mineral distributions within the ore body.

The constructed kriged maps for both  $Ta_2O_5$  and  $Nb_2O_5$  shows pattern of the mineral distribution similar to the histogram and variogram analysis results obtained in the previous study as follows:

- a) the presence of nested structures along the dip of the ore body,
- b) random spatial distribution of the mineralization indicating that no control of any geological structures/lithologies.

## CHAPTER FIVE

### **5. Land use/land Cover Changes and the Impact of Mining Activities on the Environment**

#### ***5.1. Comparison of Land use - Land cover pattern and change detection in the Kenticha Belt and Locality (1986-2002)***

The Kenticha rare metal Belt is located in southern Ethiopia within the Adola gold field. The belt is long about 104 km in N-S direction and wide 10 km in E – W direction covering a total area of 1045.5 km<sup>2</sup>.

The mining activity at a pilot scale in the Kenticha area started in 1991 and has been in continuous operation for over 15 years. Currently, the mining activity is limited to the Kenticha locality within an area of 37 km<sup>2</sup>. The EMDSH.Co. is planning to expand its activities to a full scale industrial mining in the coming few years.

#### ***5.2 Description of land use / land covers categories in the study area***

##### **5.2.1 Forest land**

Forest lands are areas that are covered with natural plantations of large trees of different species. This category includes densely vegetated areas of trees such as eucalyptus, conifers, and different deciduous types. As the Kenticha area is covered with different kinds of vegetation, it can be categorized as forest.

##### **5.2.2 Bare soil**

This category includes agricultural lands and areas of the top cover cleared out for agricultural, mining, and other different purposes. The subcategories include land use for

cultivation of food crops like sorghum and maize. In the study area the indigenous people cultivate mainly maize. They cover a small part of the area since agriculture is not very common due to non-fertility of the soil.

### **5.2.3 Bare land**

This category includes non-vegetated and non-agricultural land. They include lands which were formerly agricultural but recently abandoned areas and areas which were formerly forest but left barren due to forest fire. This type of land covers large part of the study area.

### **5.2.4 Cleared land**

These are mining sites, which were formerly forest areas but altered to bare lands due to the mining activity. They include excavated land, nested dump and tailing sites, which are considered as the major environmental degraders and polluters in many mining sites.

### **5.2.5 Wood land**

Low woody plants generally below 3 m in height dominate wood lands. These include areas of immature trees like eucalyptus and conifers species in transition to forest land.

### **5.2.6 Settlements**

Urban areas range from high density, represented by a multiple unit structures of urban core, to low-density house coverage.

### ***5.3 Image interpretation and classification system***

In this study based on 112 points , interpretation and classification of land use/land cover was carried out first by composing false color composite (321 RGB) and unsupervised classification of land sat ETM+ for the year 2002 using GPS and ERDAS software.

Some additional points were taken for feature identification and based on the ground checkpoints; supervised classification was also done on the image.

For the years 1986 and 2002, a false color composite (741 RGB) and true color composite (321 RGB) were prepared and supervised classifications were conducted. Different enhancements and noise removal were also made to increase the visual interpretation and quality of the images.

### ***5.4 Image interpretation elements***

Different image interpretation elements were used to distinguish variations among features. To begin with, tone is directly related to reflectance of light from features and is a measure of the relative amount of light reflected by an object and actually recorded on the image. It was a fundamental element to distinguish features specially like water, plantation, crop type, wood lands, shrubs, grass lands and bare lands. In the false color composite of (432 RGB), vegetation appears in shades of red, urban areas are cyan blue, and soils vary from dark to light brown. Ice, snow and clouds appear white or light cyan. Coniferous trees will appear dark red than hardwoods and densely populated urban areas appear light blue.

Shape is the other interpretation element, and refers to general form, structure, and configuration or outline of an individual object. The most important factors for recognizing an object from image is to distinguish land uses like plantation, water bodies and wood lands.

Pattern refers to the spatial arrangement of objects. The repetition of certain general forms or relationships can characterize many objects, both natural and man made which aids in recognizing and interpreting land cover types like grass land, and wood land.

Size is a function of scale and is important to relate size of features to other features in the scene. Using this interpretation key, it was possible to identify temporal crops from perennial crops, plantations and water bodies.

Association is the other helpful clue in identification of features like marsh area and can be identified by associating with water bodies. Residents and towns could be also separated from bare lands by associating with roads taking into account their shapes.

Texture is the arrangement and frequency of tonal variation in particular areas of the image. Smooth textures like grass could possibly be separated from crop lands though they have similar reflectance. Moreover, water bodies can be easily separated from the surrounding features due to their smooth features. Urban areas can also be separated from bare land due to their rough texture.

Landsat ETM+ imageries of the study area for the years 1986 and 2002 with band combinations of 3, 2, 1 and 7, 4, 1 and maximum likelihood classifications with six classes are shown below in the following Figures:

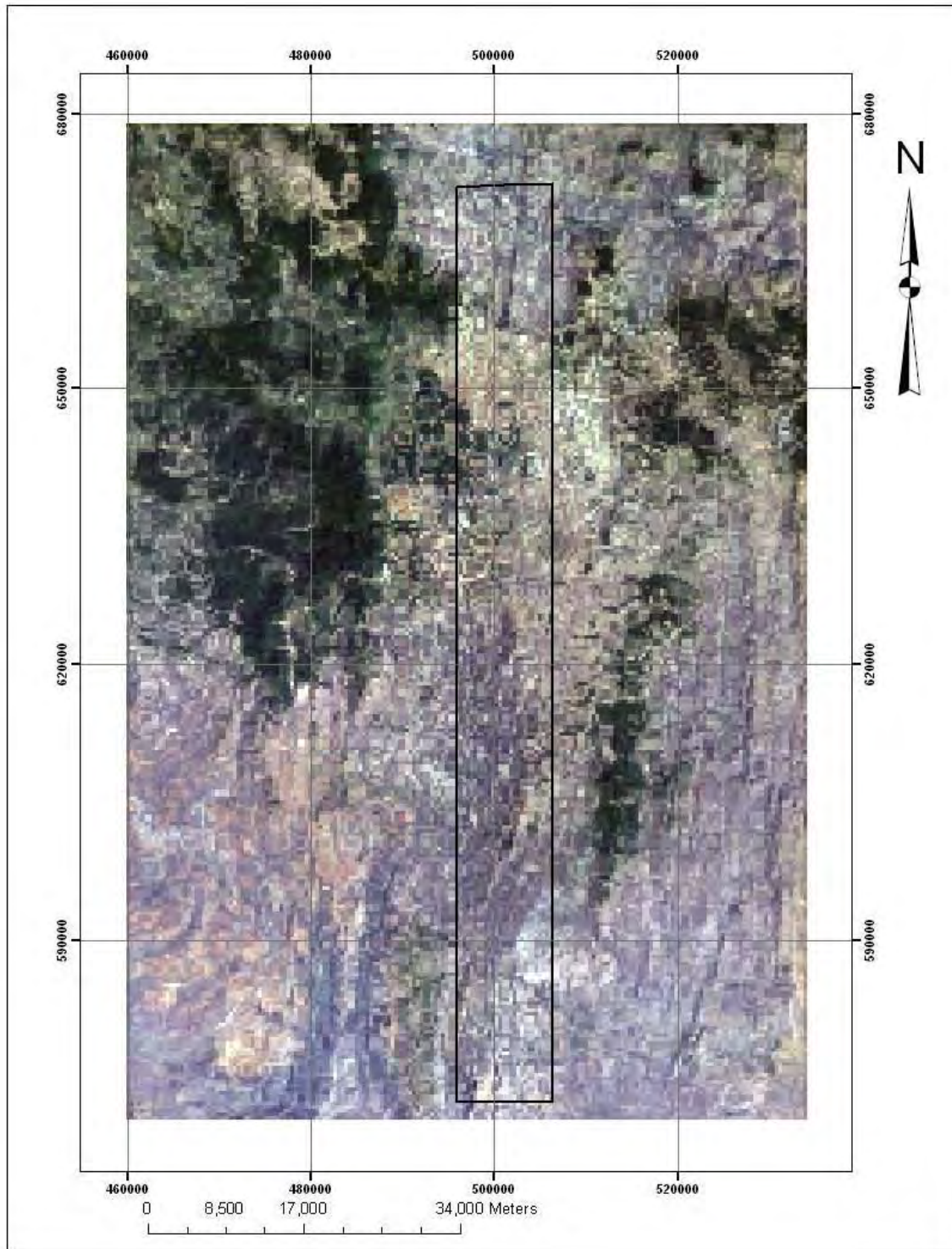


Figure 5. 1 Band 3, 2, 1 combination for the year 1986 in the Kenticha Belt

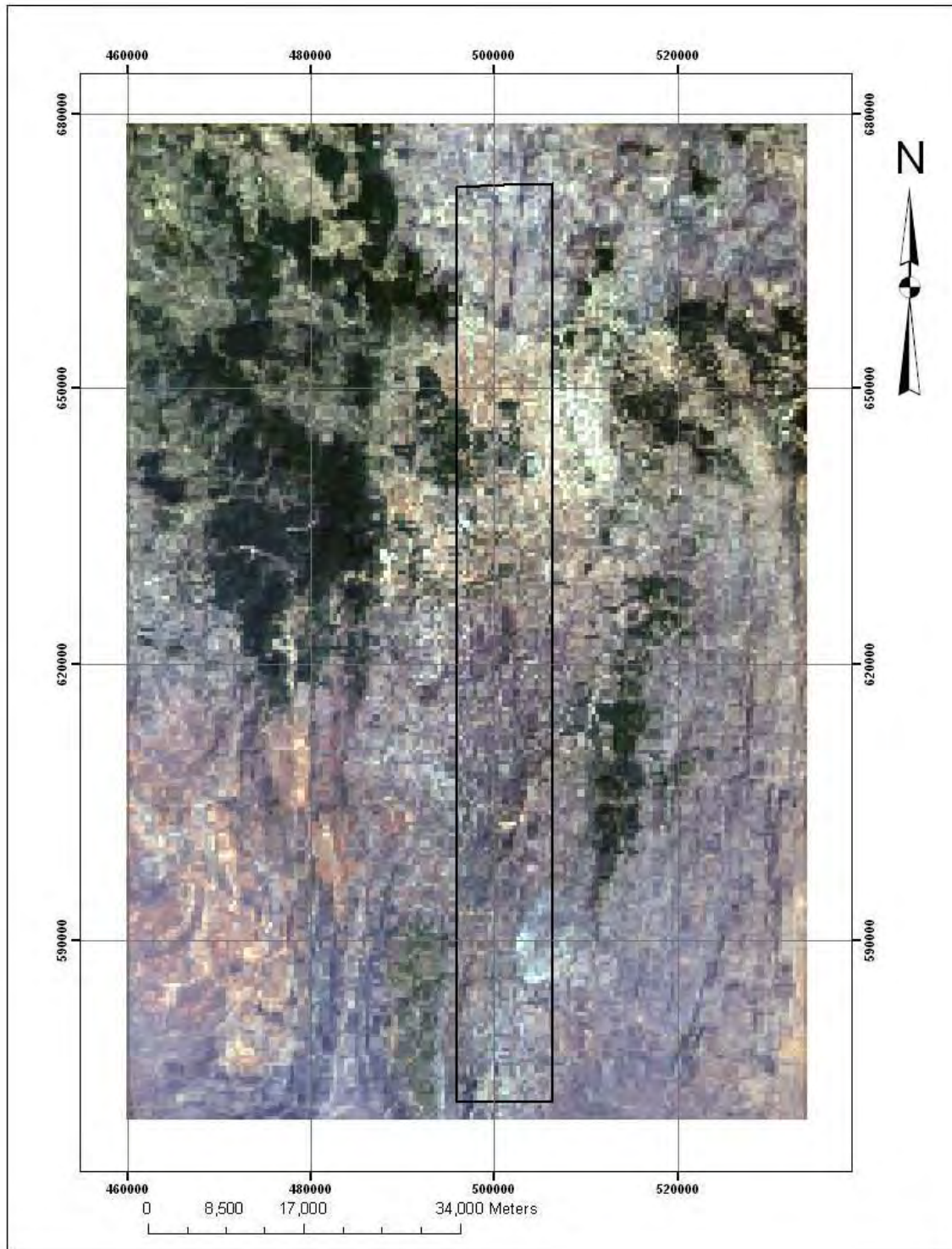


Figure 5. 2 Band 3, 2, 1 combination for the year 2002 in the Kenticha Belt

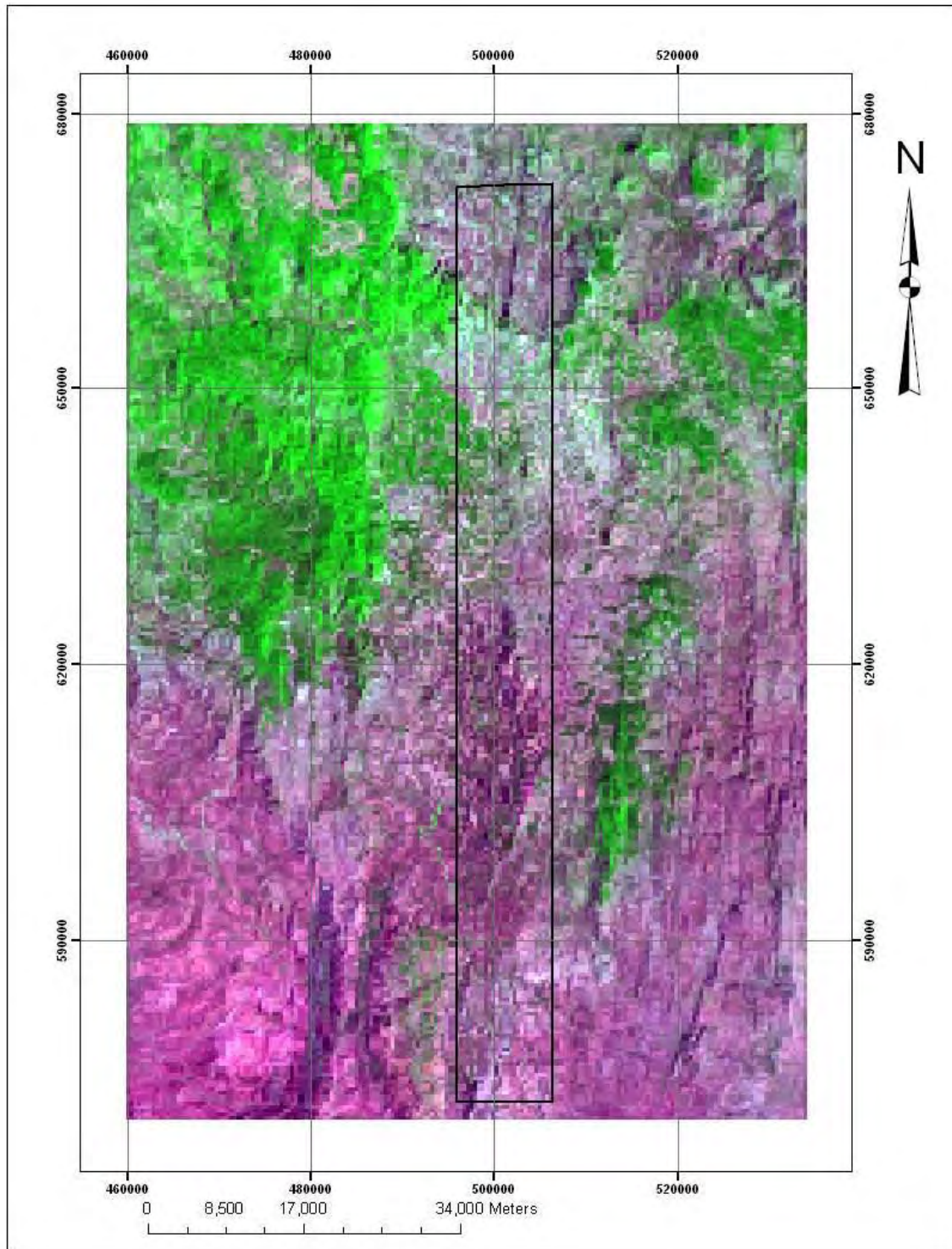


Figure 5. 3 Band 7, 4, 3. Combination for the year 1986 in the Kenticha Belt

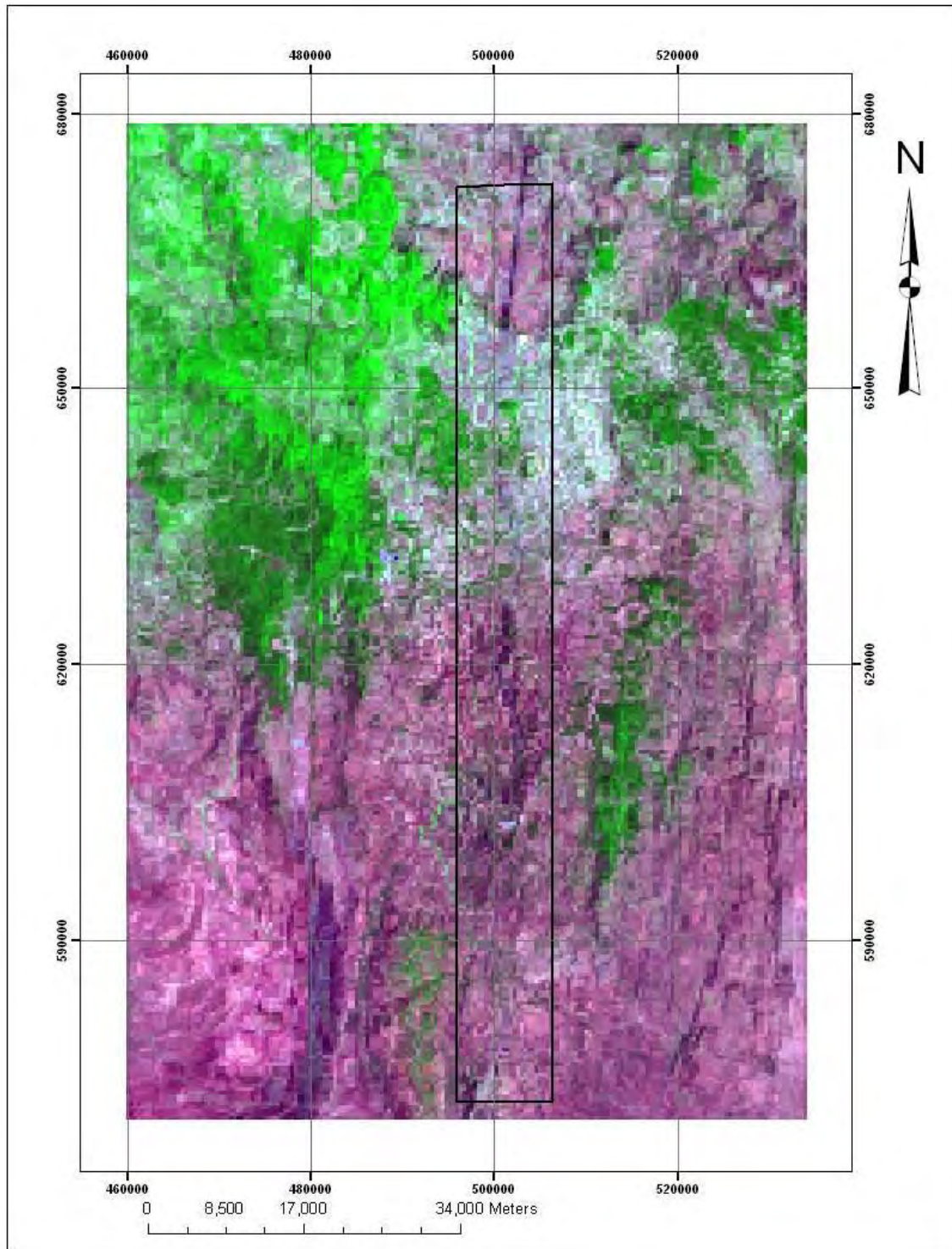


Figure 5. 4. Band 7, 4, 3 combination for the year 2002 in the Kenticha Belt

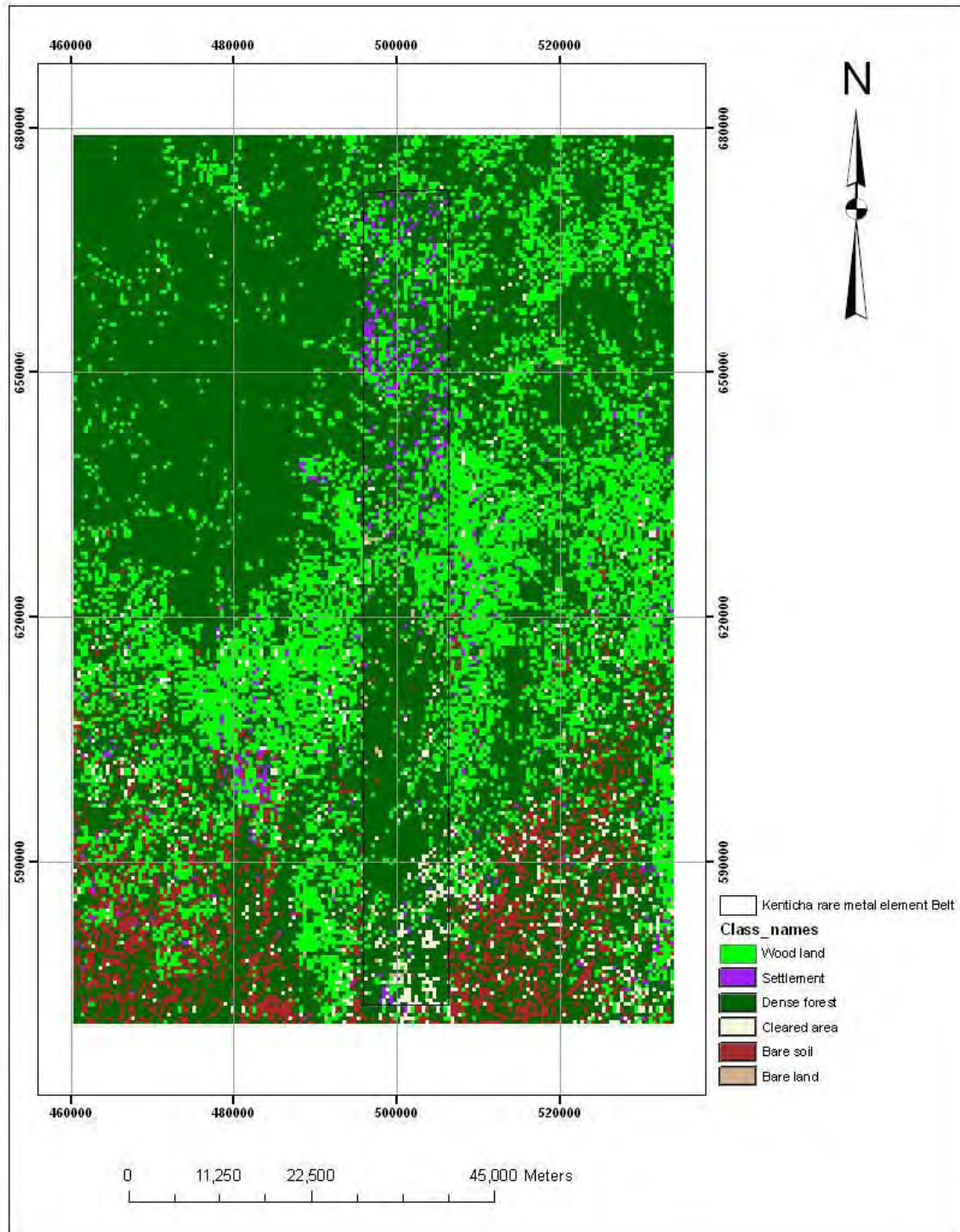


Figure 5. 5. Maximum likelihood classification of image for the year 1986 in Kenticha Belt

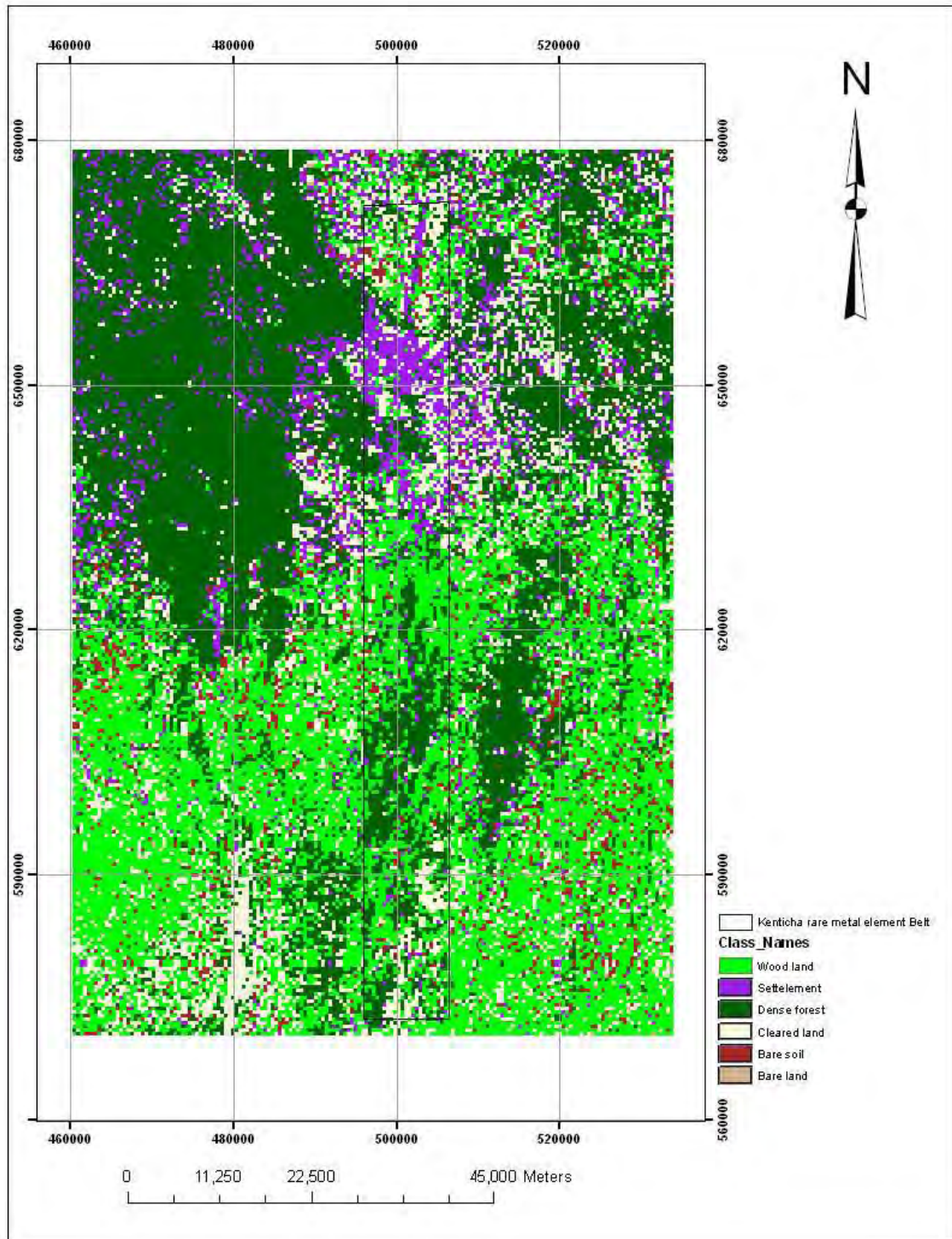


Figure 5. 6. Maximum likelihood classification of image for the year 2002 in Kenticha Belt

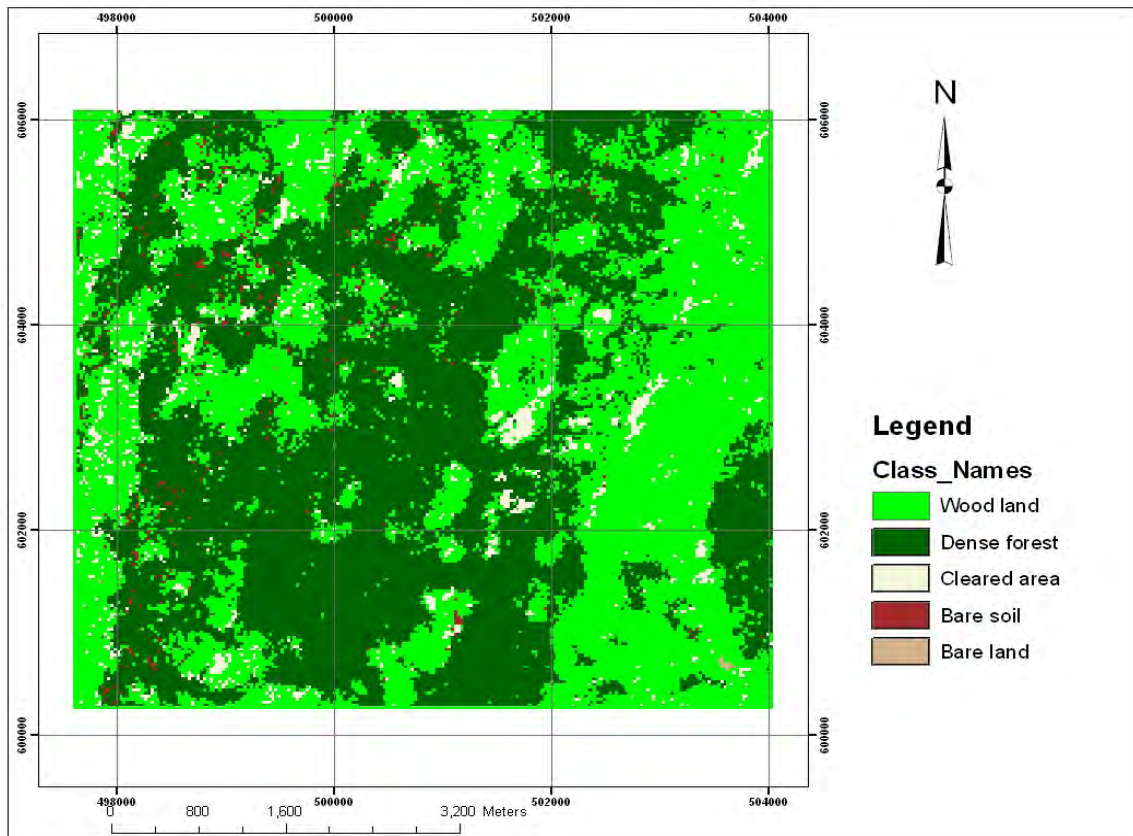


Figure 5. 7. Maximum likelihood classification of Kenticha locality for the year 1986

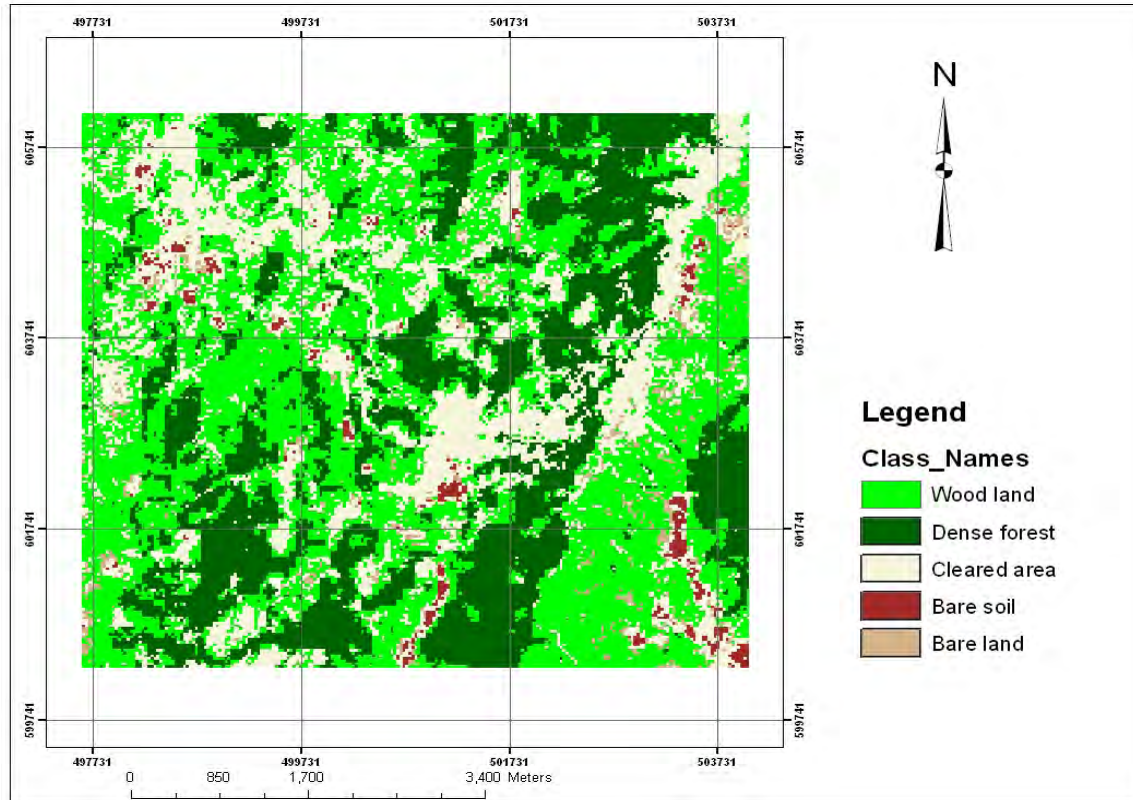


Figure 5. 8. Maximum likelihood classification of the Kenticha locality for the year 2002

## 5.5. Land use and land cover of the Kenticha Belt and Locality

### 5.5.1 Land use and land cover change of the Kenticha Belt and Locality in 1986

In the year 1986, majority of the land in the Kenticha Belt was covered by dense forest (68%) by wood land (21%) cleared area (4.2%) and by settlement, bare land and agricultural land (6.8%).

Land use/ cover	Area in km <sup>2</sup>	Area (%)
Wood land	219.5	21
Settlement	56.5	5.4
Dense forest	710.4	68.0
Cleared area	43.7	4.2
Bare land	13.5	1.3
Bare soil	1.4	0.1
<b>Total</b>	<b>1045.0</b>	<b>100%</b>

Table 5. 1. Land use /land cover class of Kenticha Belt for the year 1986.

In the same year, the land cover of the Kenticha locality were covered by, dense forest (49.3%), cleared area (3.2%), wood land (46.4%) and bare land and bare soil (1.1%). The table below shows the land use covers of the Kenticha locality where the mining activity is currently operating.

class	Area in km <sup>2</sup>	Area (%)
Wood land	17.3	46.4
Dense forest	18.4	49.3
Cleared area	1.6	3.2
Bare land	0.3	0.8
Bare soil	0.017	0.3
<b>Total</b>	<b>37.3 km<sup>2</sup></b>	<b>100 %</b>

Table 5. 2. Land use and cover class of Kenticha locality for the year 1986

### 5.5.2 Land use and land cover of the Kenticha Belt and Locality in 2002

In the year 2002 the land cover of Kenticha Belt changed to dense forest (50.5%), cleared area (15.1%), wood land (19.8%), Settlement (11.1%) and the rest 3.5% covered by bare land and bare soil.

<b>Land use / cover</b>	<b>Area in km<sup>2</sup></b>	<b>Area (%)</b>
Wood land	202.3	19.3
Settlement	116.1	11.1
Dense forest	527.4	50.5
Cleared area	157.6	15.1
Bare land	7.3	0.6
Bare soil	35.3	3.4
<b>Total</b>	<b>1045.0</b>	<b>100%</b>

Table 5. 3. Land use and cover class of Kenticha Belt for the year 2002

In the same year, land cover of Kenticha locality changed to dense forest (29%), cleared area (25%), wood land (42.3%) and bare land and bare soil 3.7%.

<b>Class</b>	<b>Area in km<sup>2</sup></b>	<b>Area (%)</b>
Wood land	15.8	42.3
Dense forest	10.8	29.0
Cleared area	9.3	25.0
Bare land	0.5	1.3
Bare soil	0.9	2.4
<b>Total</b>	<b>37.3 km<sup>2</sup></b>	<b>100 %</b>

Table 5. 4. Land use and cover class of Kenticha locality for the year 2002

## **5.6 Land use and land cover change analyses for the period 1986-2002**

The Kenticha Belt and locality both showed difference in land use land cover during the past 15 years. In order to put any change into a proper perspective, it is necessary to establish the state of the environment in the selected base year. The aerial extent of each land use/ land cover class in the different years (1986 and 2002) was analyzed to get an overview of changes in magnitude so as to justify the change analysis. The overall change analysis of the Kenticha Belt and Locality are presented below.

<b>Class</b>	<b>Year/ km<sup>2</sup></b>		<b>Changes (%)</b>	
	<b>1986 km<sup>2</sup></b>	<b>2002 km<sup>2</sup></b>	<b>change</b>	<b>change%</b>
Wood land	219.5	202.3	-17.5	-8.0
Settlement	56.5	116.1	59.6	105.5
Dense forest	710.4	527.4	-183.0	-25.7
Cleared area	43.7	157.6	137.7	259.0
Bare land	13.5	7.3	-6.2	-45.9
Bare soil	1.4	35.3	34.1	2435.7

Table 5. 5. Land use/ land cover change analysis of Kenticha Belt in the period (1986 -2002)

<b>Class</b>	<b>Years km<sup>2</sup></b>		<b>Changes</b>	
	<b>1986</b>	<b>2002</b>	<b>Change</b>	<b>Change (%)</b>
Wood land	17.3	15.8	-1.5	-8.7
Dense forest	18.4	10.8	-7.6	-41.3
Cleared area	1.6	9.3	7.7	481.3
Bare land	0.3	0.5	0.2	66.7
Bare soil	0.1	0.9	0.8	800

Table 5. 6. Land use/ land cover change analysis for Kenticha locality in the period (1986 - 2002)

As indicated in the Tables, in both cases (Kenticha Belt and Locality) a considerable amount of dense forest and wood land cover were changed to areas of cleared land, bare soil and bare land. Dense forest decreased by 25.7 % and 41.3 % in the Kenticha Belt and Locality respectively.

The amounts of land cover changes in specific land use/land cover types were also calculated. According to the statistics, a large amount of dense forest and wood land are converted to cleared area, bare soil and Settlement. The land use land cover image difference for each class of the two images is summarized in the following Table.

Class of land use/land cover in 2002 (%)	Area coverage in 1986 (%)						Row Total	Class Total
	Dense forest	Settlement	Woodland	Bare soil	Bare land			
Dense forest	41.806	6.234	17.547	41.681	6.697	99.374	100	
Settlement	12.195	38.287	16.603	5.838	3.319	99.657	100	
Woodland	30.614	15.338	43.069	41.856	57.675	95.489	100	
Cleared land	12.994	36.813	20.54	7.122	29.117	87.142	100	
Bare soil	2.379	3.32	2.199	3.503	2.7	93.323	100	
Bare land	0.011	0.009	0.042	0	0.492	100	100	
Class Total	100%	100%	100%	100%	100%			
Class Changes	58.194	61.713	56.931	96.497	99.508			
Image Difference	-51.765	158.246	56.97					

Table 5. 7. Land use Land cover difference of Keticha Belt in the period (1986 -2002)

Class of land use/land cover in 2002 (%)	Class of land use land cover in 1986 (%)					Row Total	Class Total
	Dense forest	Cleared area	Wood land	Bare land			
Dense forest	41.68	1.869	13.46	0	100	100	
Cleared area	18.871	41.351	28.518	49.138	98.312	100	
Bare soil	1.351	2.076	0.959	0	94.325	100	
Wood land	36.356	48.746	55.048	36.207	99.697	100	
Bare land	1.741	5.958	2.015	14.655	94.597	100	
Class Total	100%	100%	100%	100%			
Class Changes	58.32	58.649	44.952	85.345			
Image Difference	-52.469	80.738	73.133	905.172			

Image Difference	-52.469	80.738	73.133	905.172		
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Table 5. 8. Land use Land cover difference of Keticha Locality in the period (1986 -2002)

**Rate of land use and land cover changes**

The rate of land use / land cover change for each class was calculated as follows:-

$$\text{Rate of change (km}^2\text{/year)} = (A-B)/C$$

Where, A= recent land use / land cover in km<sup>2</sup>

B= Previous area of land use/ land cover in km<sup>2</sup>

C= Interval between year A and year B

The result of the calculated changes per year is summarized in the following Table.

Class	Year (km <sup>2</sup> )		Rate of change (km <sup>2</sup> /year)
	1986/ (km <sup>2</sup> )	2002/ (km <sup>2</sup> )	
Wood land	219.7	202.5	-1.1
Settlement	56.5	116.1	3.7
Dense forest	710.8	527.8	-11.4
Cleared area	43.9	157.6	8.6
Bare land	13.5	7.3	-0.4
Bare soil	1.4	35.5	2.1

Table 5. 9. Land use/ land cover change rate of the Kenticha Belt in the period (1986-2002)

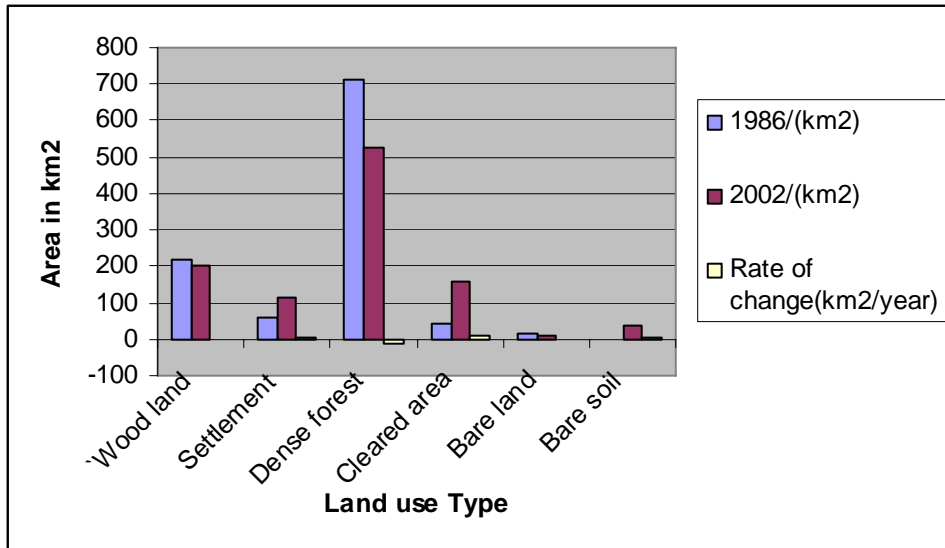


Table 5. 10. Land use/ land cover graph of the Kenticha Belt for the period (1986 and 2002)

Class	Year (km <sup>2</sup> )		Rate of change (km <sup>2</sup> /year)
	1986/ (km <sup>2</sup> )	2002/ (km <sup>2</sup> )	
Wood land	17.3	15.8	-0.1
Dense forest	18.4	10.8	-0.56
Cleared area	1.6	9.3	0.52
Bare land	0.3	0.5	0.02
Bare soil	0.1	0.9	0.06

Table 5. 11. Land use/ land cover change rate of Kenticha Locality in the period (1986-2002)

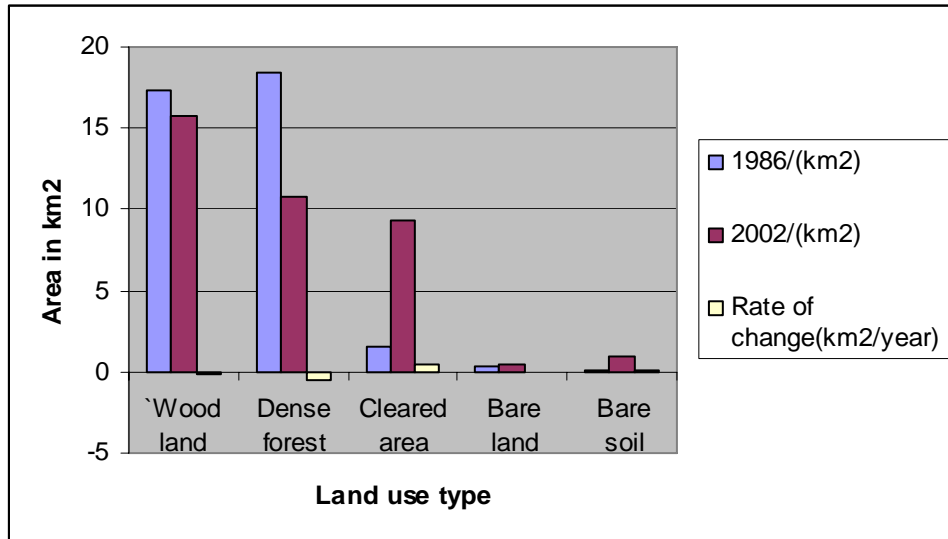


Table 5. 12. Land use/ land cover graph of the Kenticha Belt for the period (1986 and 2002)

### **5.7 NDVI (Normalized Difference Vegetation Index) analysis of the Kenticha Belt and Locality**

The differential reflectance band 3 and band 4 (Visible and near infrared) provide a means of monitoring density and vigour of green vegetation growth using the spectral reflectivity of solar radiation as shown in the figures below. Index values can range from -1.0 to 1.0, but vegetation values typically range between 0.1 and 0.7. Higher index values are associated with higher levels of healthy vegetation cover, whereas clouds and snow will cause index values near zero, making to appear the vegetation less green. The formula to calculate NDVI is the following:

$$NDVI = (NIR - VIS) / (NIR + VIS)$$

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaf gives a value close to zero. Zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. In the study, the density of the vegetation cover is shown as bright red for the densely forested areas, yellow for moderately vegetated areas and red for less vegetated and bare areas.

The images given below show the vegetation cover density of Kenticha Belt and Locality in the years 1986 and 2002 respectively.

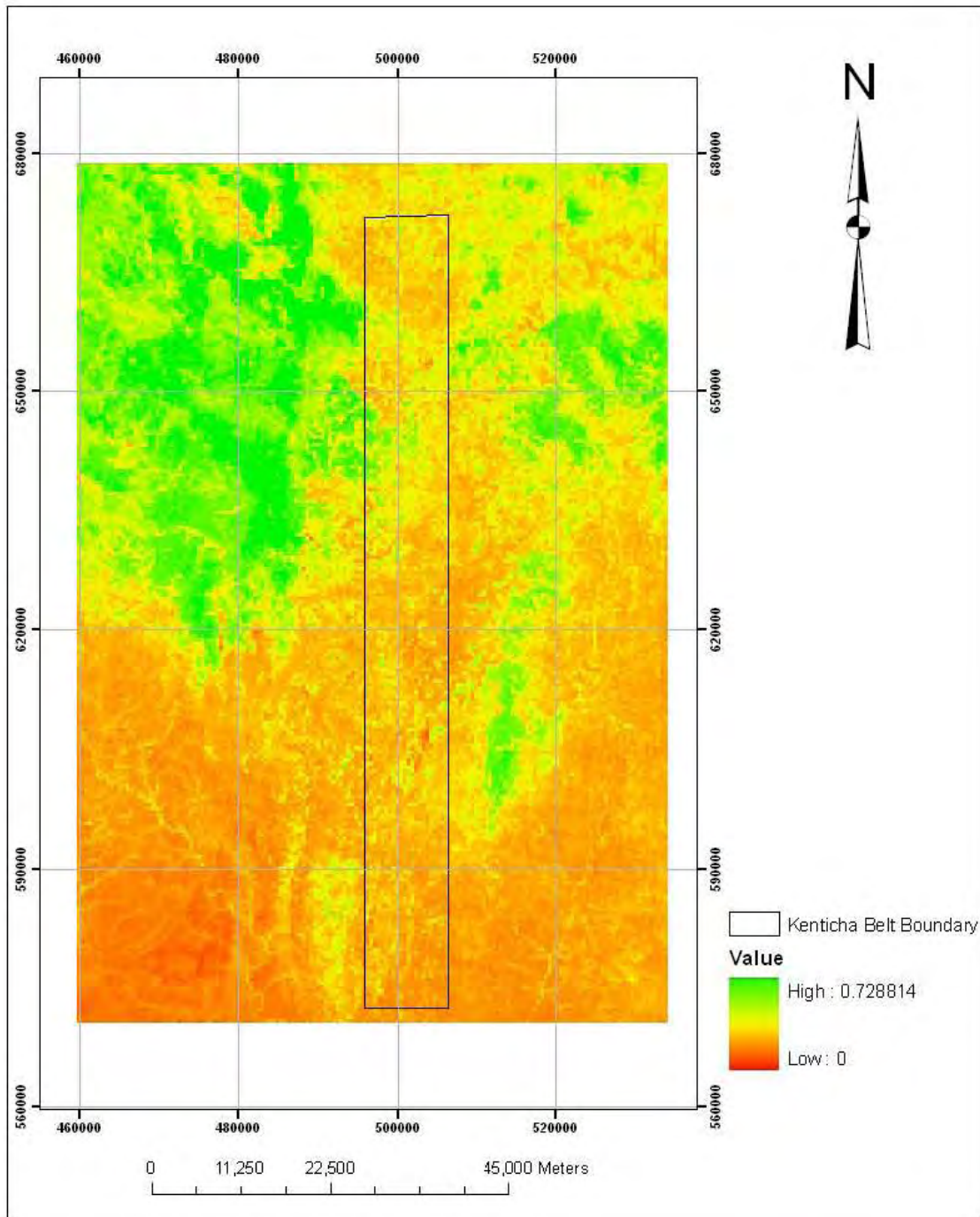


Figure 5. 9. NDVI classification of Kenticha Belt (1986)

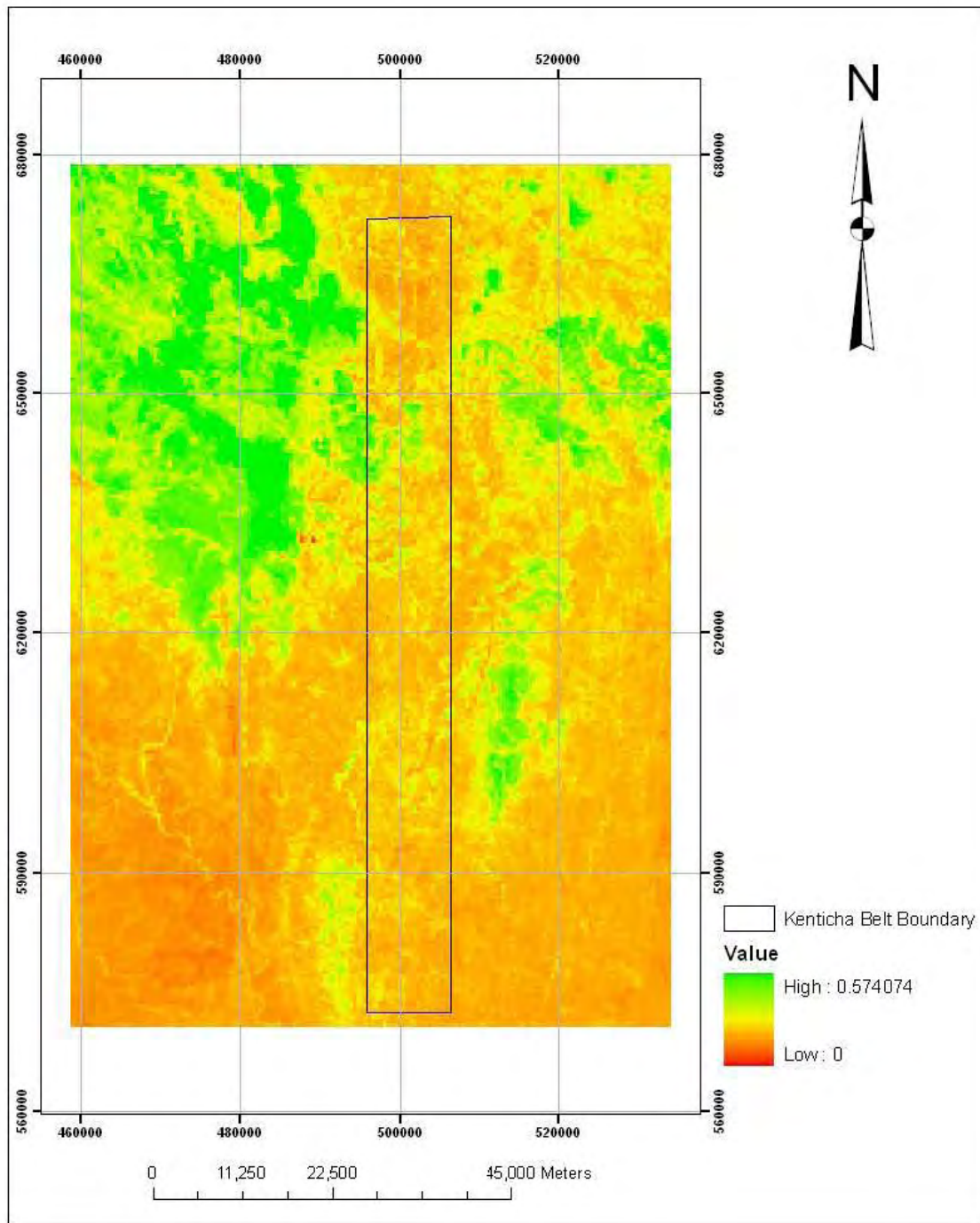


Figure 5. 10. NDVI classification of Kenticha Belt (2002)

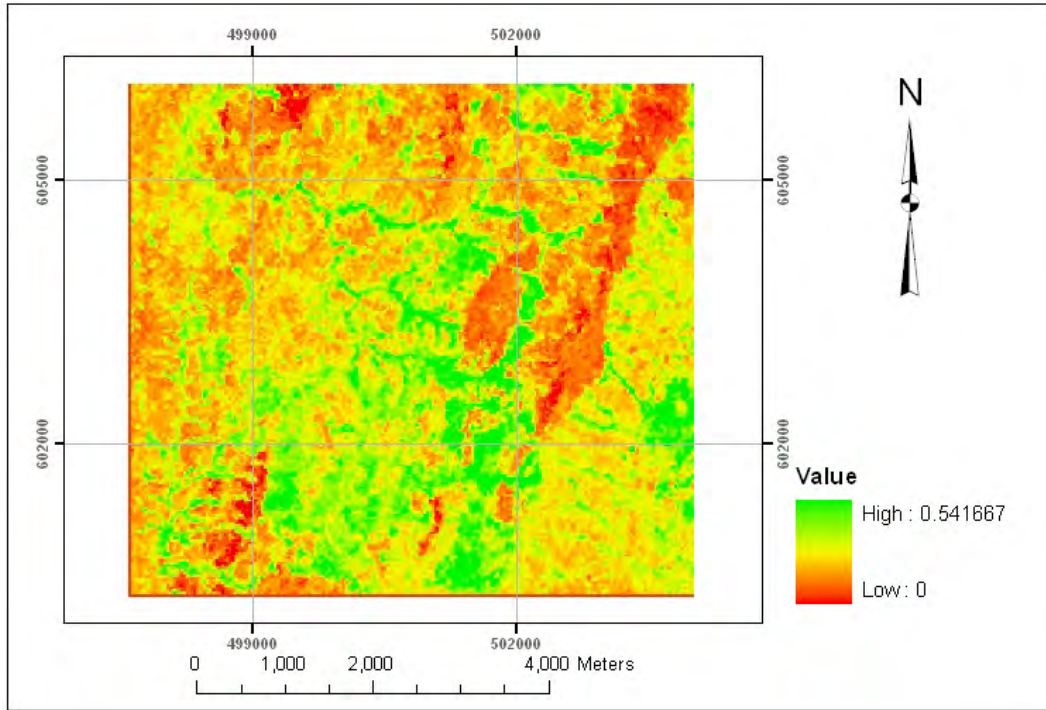


Figure 5. 11 NDVI classification of Kenticha Locality (1986)

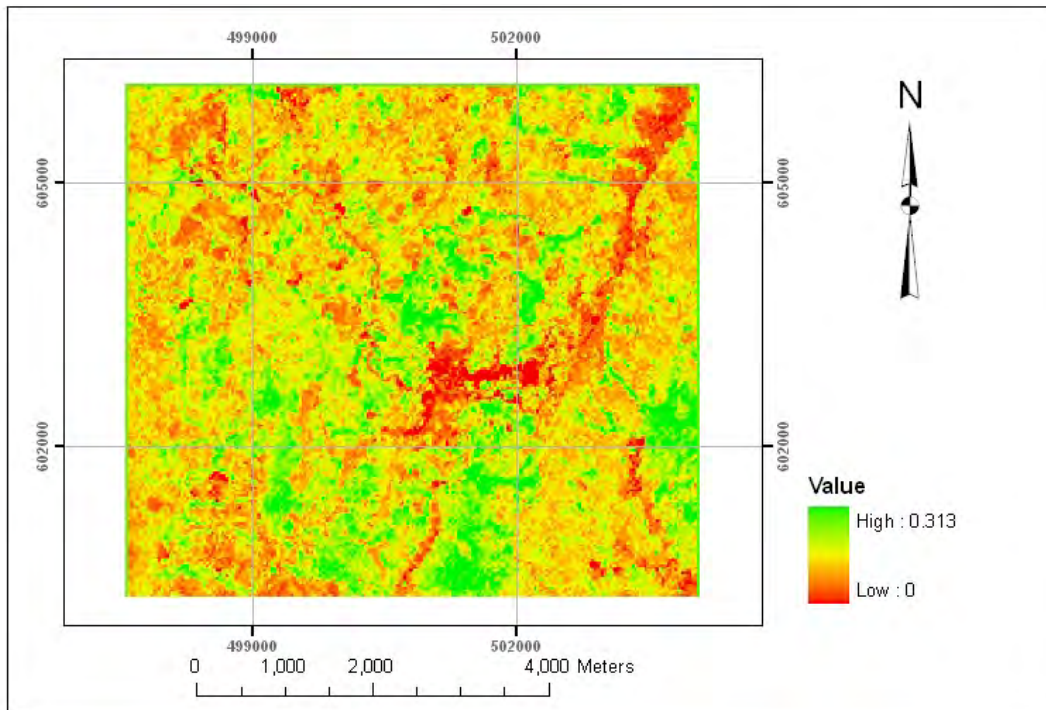


Figure 5. 12. NDVI classification of Kenticha Locality (2002)

NDVI value of Kenticha Belt changed from 0.729 in the year 1986 to 0.574 in the year 2002 with decreasing value of 0.155. Similarly the Kenticha Locality changed from 0.541 in the year 1986 to 0.313 in the year 2002 showing a value difference of 0.228. The NDVI calculation shows the vegetation cover is diminishing in time in both the Kenticha Belt and Locality; though the major index change appear around the Kenticha Locality where the mining and processing activity is taking place.

The other considerable impact occurring on the Kenticha Locality is forest fragmentation. As the NDVI maps of the two years shows, the forest cover of the area which was condensed in the year 1986 shrinks to small patches of forest covers in the year 2002 due to the mining and processing activities going on in the area.

### ***5.8. The environmental impacts***

The aim of this part of study is therefore, to asses the environmental impact from the mine and processing plant in the last 15 years in Kenticha and to recommended environmental protection scheme in the region.

Mining and mineral processing can cause serious environmental problems if not properly controlled. Based on the land use and land cover analyses performed above, the following environmental impact problems were identified with the mining and processing activities in the Kenticha tantalum mine.

The main environmental problems identified with mining and processing in Kenticha area are forest fragmentation, land degradation, deforestation, waste water, solid waste and tailings.

#### **Forest fragmentation**

Forest fragmentation occurs when large, continuous forests are converted into smaller blocks, either by roads, clearing for agriculture, urbanization, mining or other human

developments. In Kenticha Locality the continuous and dense forest cover, which was condensed in the year 1986 has been transformed to a fragmented small patches of forest covers in the year 2002, and this is because of the mining and processing activity and construction of different infrastructures for the mining plant.

### **Deforestation**

The mining activities in Kenticha locality entail removal of the vegetation cover over approximately 37 km<sup>2</sup> and modification of the topography. The pits created lower the topographic level by 100m in places. The installation of processing plant has resulted in the disappearance of vegetation cover and a change in topography. Most of the forest cover and wood land are converted to cleared land and bare land in Kenticha locality. Extensive rare metal mining has led to shrinking of land base and creation of a landscape dotted with mine spoils. The pitfalls of such activities are felt in the impairment of vegetation in the environment.

### **Land degradation**

By land degradation it is intended to imply the land cover change of the area from different types of vegetation cover to bare land and cleared lands. The deterioration begins with the removal of the vegetation cover. Once the plant cover is disturbed, soil degradation occurs in the form of accelerated water erosion, soil compaction or surface soil crusting with a resultant loss of soil fertility. Thus, badly controlled mining methods can destroy soil and living resources leaving behind barren, denuded and eroded wastelands; a process apparently taking place around the Kenticha area.

### **Wastewater**

Large volumes of waste water are produced in the processes of mining and mineral processing at Kenticha mine. Waste water streams from the pumping of working pits, process water, and water associated with the discharge of tailing can contain a number of different metals, acid or alkaline-generating materials and bacteria, which together or on

their own can cause severe pollution to farm land, rivers and drinking water if they are discharged with out prior treatment.

### **Solid waste**

By its very nature, mining produces large volumes of waste rock in the stripping and processing of metal ores. In open pits, the generation of waste through stripping can significantly exceed the production of ore.

### **Tailings**

Tailing dams or dumps are effectively a special subset of the waste dam situation. Because tailings are usually very finely ground and contain residual amounts of chemicals used in the processing operation, they are potentially a source of environmental contamination. Tailings can also be a potential source of acid drainage. Because of their physical and chemical nature, some tailings may be particularly difficult and also impossible to re-vegetation. The tailings are spread behind dams that close off the Kenticha valley. The material held back behind the dam also causes a notable change in the topography



Figure 5. 13. Kenticha Tantalum deposit with location of open pit, processing plant, waste dump and tailing dam.

## **5.9. Discussion**

For the land use/land cover change analysis, both supervised and unsupervised classification systems were employed to interpret and classify images for the year 1986-2002. The supervised classification system was preferred since it gave a better accuracy of the land use/land cover classification in both years for the change analysis.

In the Kenticha Belt, wood lands shows the largest change, declining from 2302.7 km<sup>2</sup> to 1212.5 km<sup>2</sup> resulting a 47.3% decrease. As can be observed from the images most of the wood land areas have been changed to agricultural lands and cleared areas. The cleared areas are directly related to the mining activity in the Kenticha Locality.

Urban areas show a growth from 147.6 km<sup>2</sup> to 389.1 km<sup>2</sup> with 163.6% increment. The urban areas show development around the densely forested and wood land areas resulting deforestation.

Dense forests appear to be the second most affected areas shrinking in size next to wood lands. This class shows decrease from 2086.5 km<sup>2</sup> to 1678.7 km<sup>2</sup> within the period of 1986 - 2002. The major causes of the changes were due to the expansion of urban and cleared areas related to the mining activity. The people who migrated to these areas are of the lowest economic level and very dependant on the environment for their daily requirements. Deforestation in the area is aggravated due to the expansion of urban areas, which are the fallout of mining sites around the vicinity.

Cleared areas on the other hand show an increase in coverage from 1497.7 km<sup>2</sup> to 1635.5 km<sup>2</sup>. The possible causes are clearing of vegetation for the mining activity, fire wood supply and forest fire by the farmers looking for agricultural land.

Bare land has also decreased from 65.6 km<sup>2</sup> to 43.1 km<sup>2</sup>. The possible causes could be that most of the barren lands are changed to agricultural lands since most of the barren lands are covered by agricultural land classes.

Bare soils have shown a drastic increase from the other classes changing from 25.9 km<sup>2</sup> to 1167.1 km<sup>2</sup>. As compared to the other classes most clusters of bare soils are located around the mining activity due to the removal of plants, destruction of forests and jungle, digging of holes and trenches for the mining purposes. Other causes could be an increase in the population seeking for high production of food crops from farm lands resulting an increase of agricultural lands in the area under discussion; in this relation, most of the cleared lands and part of wood lands in the year 1986 changed to agricultural lands in 2002.

Similarly in the Kenticha Locality, due to the mining activities, most parts of the locality has been converted from lush green landscape into mine spoils and excavated lands (cleared land) which are toxicated by chemicals from the tailings resulting unfavorable condition for vegetation growth. Large scale denudation of forest cover and degradation of lands are some of the conspicuous environmental implications of mining in Kenticha locality. Due to the extensive mining activity, large areas of the locality have been

altered into degraded land, creating unfavorable conditions for plant growth. The mining has also caused damages to the landscape of the area.

The change analysis of different components shows that there was a decrease in the change of dense forest and wood lands to different kind of land uses with time, in the mining sites. Dense forest and wood lands have changed from 17.3km<sup>2</sup> and 18.4km<sup>2</sup> to 15.8km<sup>2</sup> and 10.8km<sup>2</sup> resulting a 8.7 and 41.3 percentages respectively.

Cleared areas shows change from 1.6 km<sup>2</sup> to 9.2 km<sup>2</sup> resulting a 481.3% increase during the mining activity. Bare lands and bare soils have also changed from 0.3 km<sup>2</sup> to 0.5 km<sup>2</sup> and 0.17 km<sup>2</sup> to 0.9 km<sup>2</sup> resulting 66.3 % and 800 % increases respectively, due to excavation of pits (for mining waste and ore materials), installation of processing plant and construction of a tailing dam, cleared the vegetation changing the landscape of the area.

Calculation of vegetation cover by NDVI also confirmed that, the forest coverage has shown a considerable decrease in coverage and density from 0.729-0.547 in Kenticha Belt for the following reasons:-

- a. firing forest seeking for agricultural land,
- b. fast increase of population,
- c. intensive placer extraction activities with in the belt by the local people for their survival.

In kenticha locality, the forest shows a considerable decrease in coverage and density from 0.541-0.313 in Kenticha Locality due to construction of infrastructures such as mining holes in the ground as land is excavated to extract the ore and remove waste, tailing dam, roads, resident and office buildings, fast growth of settlement around the mine areas are the major causes of the damages in the locality. The forest areas were also fragmented to small patches of forest covers and appear as non vegetated areas.

## CHAPTER SIX

### 6. Conclusion and Recommendation

The statistical studies conducted on the Kenticha mine dataset shows a positively skewed and asymmetrical distribution of the assay values with mixed type population and multimodal frequency distributions.

The experimental variograms computed along the thickness of the ore body clearly displays a pure nugget effect. This means that no regionalization exists (at least along the thickness of the ore body). It implies that the grade distribution is random, and therefore the best way to treat the population is that of the gaussian laws (normal or lognormal random distribution).

The accumulation (product of the mean grade by the thickness) is seen along the line of the bore holes, i.e. along the dip of the ore body, in a direction perpendicular to that of the previous semi-variogram. The variogram along this direction shows behaviour similar to that of the variograms computed along the direction of the thickness of the ore body.

Since the number of the data (one for each bore hole) is much less than that of the previous variograms, this variogram is less reliable in its layer lags. However, the first lags (the most reliable) confirm the pure nugget effect. Thus, at least along two of the three spatial directions, we can accept the random nature of the grade distribution.

The computed variogram models also proved the random nature of the distribution, the presence of nested structures and anisotropy in grade distribution.

The computed kriged maps at 20 m intervals also revealed the presence of rich ore-shoots, moderate, low- grade sections and barren portions indicating that the assay values are not uniformly distributed all over the ore body.

The geomathematical techniques provide some insight into the behaviors of mineralized zones of the Kenticha tantalite deposit and provide means of predicting the localization and probability of ore-shoots within the deposit.

This study was a first-ever attempt to use various computer techniques for processing large volume of mine samples data from the Ethiopian Mineral Development Share Co. mine.

It appears from the environmental impacts studies of the Kenticha mine project that five main domains are to be subjects of particular care for protecting the environment affected by the mining operation: land degradation, deforestation, erosion, wastewater and tailing dam.

Though currently mine in Kenticha Locality is operating at a pilot plant scale, the impact of the mining activity on the environment is considerable; the apprehension is the effect will get much worse by the time the project grows to its full capacity. When the mine operates its activity at industrial scale, the impact might result for undesirable damages therefore, the most effective, least expensive and quickest means must be identified and urgently implemented to preserve the environment, or at least to minimize the undesirable damage to it within the region.

However, In the Kenticha locality the predictable effects that the mining operation will have on the various environmental parameters during the course of the project are limited in terms of geographical area and the time. Most of the impacts will cease as soon as the site is closed.

The installation of processing a plant has resulted in social and economic impacts due to the creation of new jobs; social facilities (clinic, schools, church etc.) are an important growth and infrastructural development. Better health care, economic benefit to the local population is results of the Kenticha tantalum mine development.

The Kenticha mine guarantees an economic development in the region, both through its own activities and also through the fabric of commercial exchange that it generate.

However, the mine only has a 15 year life, based on the production and capacity of the processing plant. Thus it is necessary; in order to avoid a sudden halt to activities in the area at the end of the project, to feed the mine with ore from other mineralized areas within a 30 to 50 km radius of the site. Furthermore, a large exploration programme is necessary to ensure the complement. This exploration programme should be carried out over the next five years, so as to enable a smooth transition between the different supply sources.

### **Recommendation**

Like all other geological problems, ore search also depends very much on the understanding of the geological controls of ore localization. Therefore, geomathematical methods do not have much value when applied in isolation, but provide a lot of extra strength to exploration and mining when used in conjunction with geological methods.

Remedial measures suggested by this study to reduce the impact:

- The use of slope protection devices from runoff is essential (e.g. lined, longitudinal ditches).
- To diminish the quantity of runoff water reaching the tailings pond, diversion ditches should be dug around the dam perimeter.
- Diverting the surface water around the storage area.
- Draining the dumps.
- Planting the dumps to increase their stability, reduce erosion, and diminish the landscape impact.
- Once the site has been remodeled, the surface should be covered with humble soil preserved from the original stripping and a vegetation programme for the whole area should be undertaken.
- Re-vegetation should be accomplished by transplanting and by seeding local species. Re-vegetation will be used to accomplish the following: help stabilize easily eroded slopes improve the aesthetics of the area, increase evapo-transpiration so that a minimum percentage of precipitation enters to runoff cycle.

- Waste water from mining and mineral processing complexes can be treated in two ways: it can be reused to reduce the discharge of waste water to the environment, or it can be discharged to the environment once levels of contaminants have been reduced to meet the state discharge.
- Restoration of the mined area to the desired condition will include landscaping, re-vegetation and stabilization. In order to minimize the topographic impact of the mines partial infill should be carried out (using waste materials) so that certain parts of the mine will be restored before the end of the project.
- In order to minimize the topographic impact of the mines, partial infill should be carried.

The remedial measures suggested by this study to reduce the impact are to be adapted to the site and ore processing plant. The measures suggested by the study are compatible with the mining operation, provided they are programmed simultaneously.

The rehabilitation of ecosystems, degraded by the mining activity in Kenticha mine, should aim to restore natural ecosystems rather than generate artificial one (e.g agriculture) where reclamation activity should begin from the outset of the project and be phased across the lifetime of the mine.

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