Validating Landscape Heterogeneity Mapped by Hyper –Temporal NDVI Images through Line – Transect Data

Rishan Araya Berhe

February, 2010

Validating Landscape Heterogeneity Mapped by Hyper –Temporal NDVI Images through Line – Transect Data

By

Rishan Araya Berhe

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: Natural Resources Management

Thesis Assessment Board

Prof. Dr. Ir. E.M.A. Smaling (Chair), NRS Department, ITC, The Netherlands
Dr. B.G.J.S. Sonneveld (External Examiner) University of Amsterdam
Dr. Ir. C.A.J.M. de Bie (Supervisor), NRS Department, ITC, The Netherlands

Supervisors

Dr. Ir. C.A.J.M. de Bie (1st Supervisor), NRS Department, ITC, The Netherlands
Prof. Dr. A.K. Andrew Skidmore (2nd Supervisor), NRS Department, ITC, The Netherlands

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

Landscape heterogeneity mapped using hyper-temporal NDVI images can give efficient, reliable and effective information at national and regional level for sustainable development plans. The main objective of this study was to validate landscape heterogeneity mapped using hyper temporal NDVI images though transect sampling method. SPOT-vegetation NDVI image data layers for ten years (April 1998 – March 2007) were stacked and classified using ISODATA; of which optimum number of classes was identified. All the classified images up to the best classified classes were superimposed on top of each other to produce the landscape heterogeneity map. Data was collected from transects that were placed randomly in each survey site. High resolution Google images were digitized and described by using lookup table created using field data. Cover percentages of each pixel was estimated by crossing digitized map with NDVI classes. Finally, estimated cover percents of each cover type, NDVI value extracted from stacked image and boundary heterogeneity value extracted from landscape heterogeneity map were plotted for visual analysis.

Using stepwise least squares dummy variable regression method NDVI classes were tested for their significant differences in each survey site. This research found that NDVI classes in the heterogeneity map have significant differences using cover percentages of transects. Strong boundaries were also validated using linear regression analysis between the heterogeneity value of pixels and tree cover percentages in transects. Tree cover percent was the main indicative parameter for strong boundaries between map units. Mainly NDVI classes having strong boundaries were found significantly different using tree cover percentages. Landscape heterogeneity map is found powerful to explain the landscape heterogeneity.

DEDICATION

This thesis is dedicated to my family, who give me encouragement and supports to pursue my goals.

Acknowledgements

First of all I would like to express my heart fill thank to almighty God, the most gracious and merciful, who gave his guidance, will and strength to successfully accomplish my study.

I would like to express my sincere gratitude to the government of Netherlands through the Netherlands program (Nuffic) for granting me this opportunity to study for a Master of Science degree. I am gratitude to my employer Ministry of Mines and Energy and Ethiopian Rural Energy Development and Promotion Centre for providing me this opportunity.

I feel great pleasure and honour to express my sincere and heart full thanks to my first supervisor Dr. Ir. C.A.J.M. de Bie for his constant supervision, invaluable guidance and encouragement throughout this research period. Grateful acknowledgement is made for concerted technical guidance and wise counselling received from my second supervisor Prof. Dr. A.K. Andrew Skidmore.

I would like to express my spatial thanks to Mr. Atkilt Girma who gave me full support, advice and guide during the field work and throughout my research. I would like to extend my thanks to Mr. Amjad Ali who always had time for me and give me regular advice during my research. I am indebted to the honourable course director Dr. Michael Weir program director of NRM for being our father throughout the studies. Especial thanks are extending to all staff and faculty members of NRM department for their help throughout my study in ITC. I am grateful to all my friends and colleagues in ITC for their unending kindness and active support throughout my MSC.

I would like to extend my thanks to all people and institutions who help me during the field work.

This study would not have been possible without constant and valuable support from my family particularly my lovely husband Mr. Nigussu Damtew who always was behind me encouraging me and feeling my hopes to get successful results. Thanks to my daughters Mekedelawit and Yordanos, and my sons Yonatan and Tewodros for their constant stimulation and for showing me the sense of our life. Special thanks also extend to my grandmother Mrs. Abrhet Beraki who preys day and night for my successful completion of this research and for the whole of my life.

In the end I would like to cordially thank my parents, brothers, sisters and my family for their support but with an extra sense of gratitude. May God bless all of us!

Table of contents

List of figures

List of Tables

Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
ETM	Enhanced Thematic Mapper
ISODATA	Interactive Self-Organizing Data Analysis Technique
NDVI	Normalized Difference Vegetation Index
SPOT 2	System Pour l’Observation de la Terre 2
SPOT 4	System Pour l’Observation de la Terre 4

1. Introduction

1.1. Background

Land use/cover mapping is useful for natural resources planning and management of different land uses as spatial planning issues at national, regional and global scales. Accurate and up to date spatial information is essential for proper planning and monitoring activities.

Traditionally, various mapping techniques have been used by different researchers, planners and other professionals. Many methods are based on ground surveys only, which are not cost and time effective. Moreover, their applicability to a wide range of area such as at a regional or global is not feasible and realistic. A set of methods have emerged to resolve this problem among which mapping techniques using remotely sensed images is gaining a wide acceptance in recent years.

A variety of remotely sensed images and remote sensing techniques are used for mapping, monitoring and evaluation of vegetation cover, forest biomass estimation (Gonzallez-Alono, *et al.,* 2006), to discriminate between species and to detect certain biochemical properties in plants (Cho et al., 2007).

Among these remote sensing techniques, use of the Normalized Difference Vegetation Index (NDVI) is an important technique. Many studies have confirmed that the derived NDVI index provides effective measure of photo synthetically active biomass (JUSTICE *et al.,* 1985; Sarkar and Kafatos, 2004; De Bie *et al.,* 2008). Because it enables to discriminate vegetation from other non vegetation land cover types such as settlement, bare soil etc. It is an index that takes into account the sharp increase of vegetation reflectance in the red and near infrared region of the electromagnetic energy (EM) spectrum. Moreover, NDVI is mathematically defined as the difference between near infrared and red region reflectance divided by their sum. It can be derived from hyper-spectral, multispectral and hyper-temporal images that operate in the aforementioned EM regions (De Bie, *et al.,* 2008).

De Bie, *et al.*, (2008) explained the suitability of hyper-temporal SPOT-NDVI images to study crop phenologies in the agricultural sector which can be used for production estimation and early warning.

The earth surface is characterised by a landscape mosaic which is a complex of natural and human managed patches that vary in size, shape and arrangements (De Vries et al., 1998). Such information on the heterogeneity of the Landscape is also important for understanding the structure, function and change in time (Turner and Gardner, 1991).

“Landscape” generally refers to the landform of the land surface of the earth (Turner and Gardner, 1991). “Heterogeneity” refers to the variation of vegetation and land cover within the landscape. "Landscape heterogeneity" thus refers to the spatial distribution of vegetation on the surface within an area. It can be labelled as "land cover heterogeneity". "Boundary strength" refers to the arrangement of change in land cover between adjacent land units.

During the mapping of hyper temporal NDVI images into map units representing NDVI clusters heterogeneity within and between units can simultaneously be captured. The need to evaluate such a heterogeneity map, defined through mapping of hyper temporal NDVI images forms the motivation of this research.

The aim of this research is, therefore, to map the heterogeneity of the landscape and to investigate the landscape heterogeneity map through the line-transect theory in which the map is thoroughly tested based on field data. The conceptual logical framework diagram of this research is shown in Figure 1-1.

This research is conducted in Ethiopia, where extreme variability in cover and environmental (climate, soil, vegetation, altitude) occurs. This gives good opportunity to evaluate both the hyper temporal NDVI map and the heterogeneity map in depth.

1.2. Research problem

Mapping technology is a traditional technique that can help to understand and represent the real world through maps. In Ethiopia we lack accurate spatial information on vegetation types and their distribution. The type and distribution of vegetation varies extremely due to latitude, environmental factors (climate, soil, geology, topography and elevation), and human activities. Mapping these has been very difficult using a onetime image analysis multi-spectral images like (E)TM's etc. Time series hyper-temporal NDVI images (at a 10 day interval) is expected to give better results: (1) It contains of the greenness at the beginning and end of seasons (phenology), and (2) it contains the amount of greenness and their differences between vegetation types over a longer and reliable period of time.

FAO has been mentioning that the renewable resources of the African countries have come under severe strain and the lack of information was the major limitation for proper planning, development and management of natural resources. In response the organization propose a project Africover to establish a digital geo-referenced database on land cover and geographic referential for the whole of Africa (FAO, 1998).

Therefore, this research could help the efforts made by FAO. Mapping using hyper-temporal NDVI images analysis could give a better result than present date mapping techniques. However, the capability of obtaining landscape heterogeneity information from hyper-temporal NDVI analysis techniques has never been tested.

1.3. Objective, Research Questions and Hypothesis

1.3.1. Objective

The main objective of this study is to evaluate the hyper-temporal NDVI image analysis capability to capture landscape heterogeneity through assessment with field observations collected using line-transect sampling.

1.3.1.1. Specific objectives

The first specific objective is to assess the relative similarity of land cover within NDVI map units and to assess the relative differences of land cover between units through comparing of the landscape heterogeneity map with field data.

The second specific objective is to assess boundary strengths between NDVI map units as reported in the landscape heterogeneity map with field data.

1.3.2. Research Questions

Assuming that landscape heterogeneity can be mapped through hyper-temporal NDVI images:

1. Are land cover data collected from the same NDVI class relatively similar and are they relatively different between NDVI classes?
2. Is it possible to assess the boundary strength between units of the NDVI map using transect data and with field data?

1.3.3. Hypothesis

Hypotheses have been formulated based on the two research questions.

$H1_0$: NDVI classes or map units within the survey area don't have significant differences.

$H1_1$: NDVI class or map units within the survey area have significant differences at least using one type of cover percent.

$H2_0$: There is no significant relationship between tree cover percentages and boundary heterogeneity of pixels in transect.

$H2_1$: There is significant relationship between cover percentages and boundary heterogeneity of pixels in transect if there is strong boundary between classes in transect.

1.4. Research Logical Framework

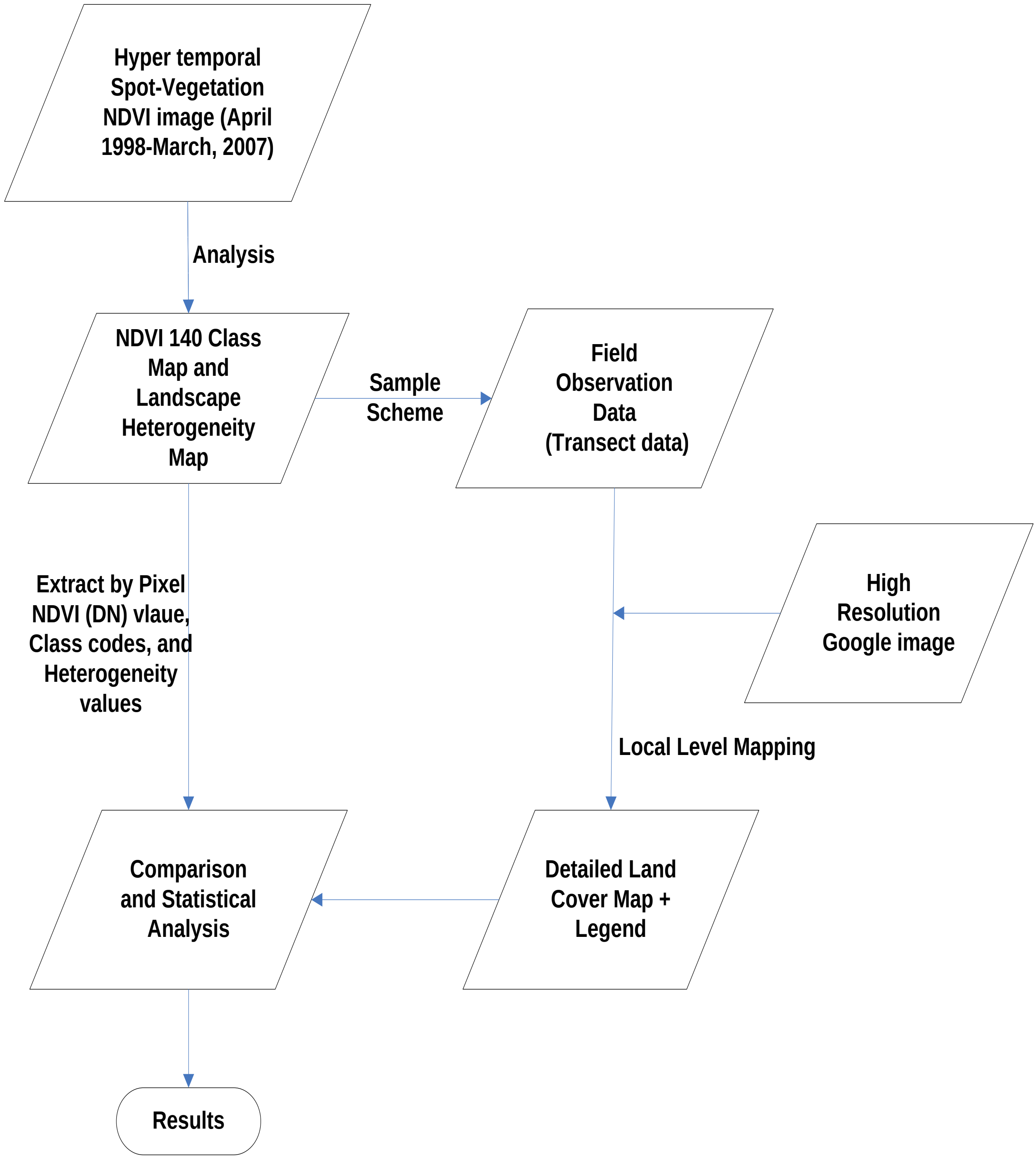


Figure 1-1 Conceptual Frameworks

2. Material and Methods

2.1. Materials

2.1.1. Study area

Ethiopia is a country located in the north-eastern part of Africa, in area known as the Horn of Africa between 3^0 N (Moyale town) -15^0 N (Badme town), 33^0 E (Akobo town) - 48^0 E (East Oromia Regional state). It is bordered by Eritrea in North-east, Somalia and Djibouti in East, Kenya in South and Sudan in West. It has an area of 1,127,127km2. Landscape of the country is dominated by mountainous and heterogeneous diversity.

This mountainous landscape of the country has extreme variability in land cover and environmental conditions with ranges of elevation from 124 m below sea level to 4525 m above sea level. It has areas with both uni-modal and bimodal rainfall (Fekadu Bekele, 2004) with large extent of soil types (Miressa Duffera and Robarge, 1999; Nyssen et al., 2008).

Based on the Ethiopian history website about 85% of natural forest has been cleared particularly in the northern part of the country for cultivation as well as settlement. In some parts of the country there were rehabilitation activities by replanting trees especially *Eucalyptus spp* and *Opuntia spp*.

The specific survey study areas were Metema, which labelled as 1 in Figure 2-1, Gerbe Guracha as 2, Sululta as 4 and Sheno. These survey sites were selected base on several criterions such as variability accessibility/uniformity. Due to lack of time during the field work data from Sheno site was not collected. Therefore, further analysis of the study was carried on the three sites (See Figure 2-1).

- **Metema Survey (Site-1)**

Metema survey site is located in the North-west part of the country near boarder to Sudan between $12^0$26’ - $11^0$60’N, and $36^0$11’ - $36^0$45’E. It covers about 60 km^2. This area is characterised by warm tropics and semi-arid climate. Vegetation cover is also unique. The dominant tree species of the area are Black Cumin (Black Boswellia), Ethiopian Frankincense (Boswellia), Stone wort (chara), Acacia Nilotica (Chibha), Combretum Molle (Key Abalo), Maesa lanceolata (Kelawanza) and Ximenia Americana (Enkoy). The major shrub types are Gramda and Ziziphus Mauritania (Gaba or Kurkura). Sesame, Sorghum, Eragrostis Abyssinica (Teff), and Maize as well as Cotton are also the major cultivated crops. During the wet season, the area is completely covered by vegetation. The mountain slope sides are dominantly covered by deciduous trees and the flat areas are dominated by shrubs as well as herb and tall spiky grasses. Almost all the trees and partly shrubs are shed their leaves during the hot season. Very few evergreen trees and shrubs are found in this site. As comparing to the other sites, this site has the least settlement and cultivated area coverage. As it was indicated in Table 2-1 elevation of this site is between 750 – 950m above sea level.

- **Gerbe Guracha (Site-4)**

Gerbe Guracha survey site is located in the centre part of the country between $9^0$33' - $10^0$6'N, and $38^0$7' - $38^0$4'E. It covers 60km^2. Unlike the Metema site land cover is dominated by settlement and agricultural activities as well as swampy or marsh areas with dense grass. The small hills are used for settlement and agricultural purposes. Most of the swampy areas are used as grass producing areas for animal feed. Wheat, Barley, Teff and Maize are the major cultivated crops. Eucalyptus and Quercus ilex L. tree patches are found associated with settlements. Compared to the other sites this site is the list in tree cover, almost there is no forest cover within the whole area. As it was indicated in the Table2-1 elevation range of this site is 2500 -2550 above sea level.

- **Sululta (Site-2)**

Sululta survey site is located near the capital city of the country, between 9^0 N - $9^0$32'N, and $38^0$29' - $39^0$1'E. It covers 60km^2. The land cover of this area is also characterised by settlement areas, forest, bare land and agricultural activities as well as an extensive swampy or marshland areas with dense grass. As shown in the Table 2-1, elevation range is from 2500 – 2650m above sea level. Similarly, the Eucalyptus tree patch is also associated with settlements. But unlike the Gerbe Guracha site this site has forests which are owned by the government. Especially near the capital city mountains are covered by forest of Eucalyptus, Quercus ilex L and Podocarpus gracilior.

2.1.2. Software Used

ArcGIS 9.3 was used for map preparation, geo-referencing, digitizing, composition and data analysis. Erdas Imagine was used for different image processing activities. Microsoft offices such as Access, word and Excel as well as SPSS were used for analysis and reporting. Arcpad using Ipaq was also used for navigation and to identify plots within transects during the field work.

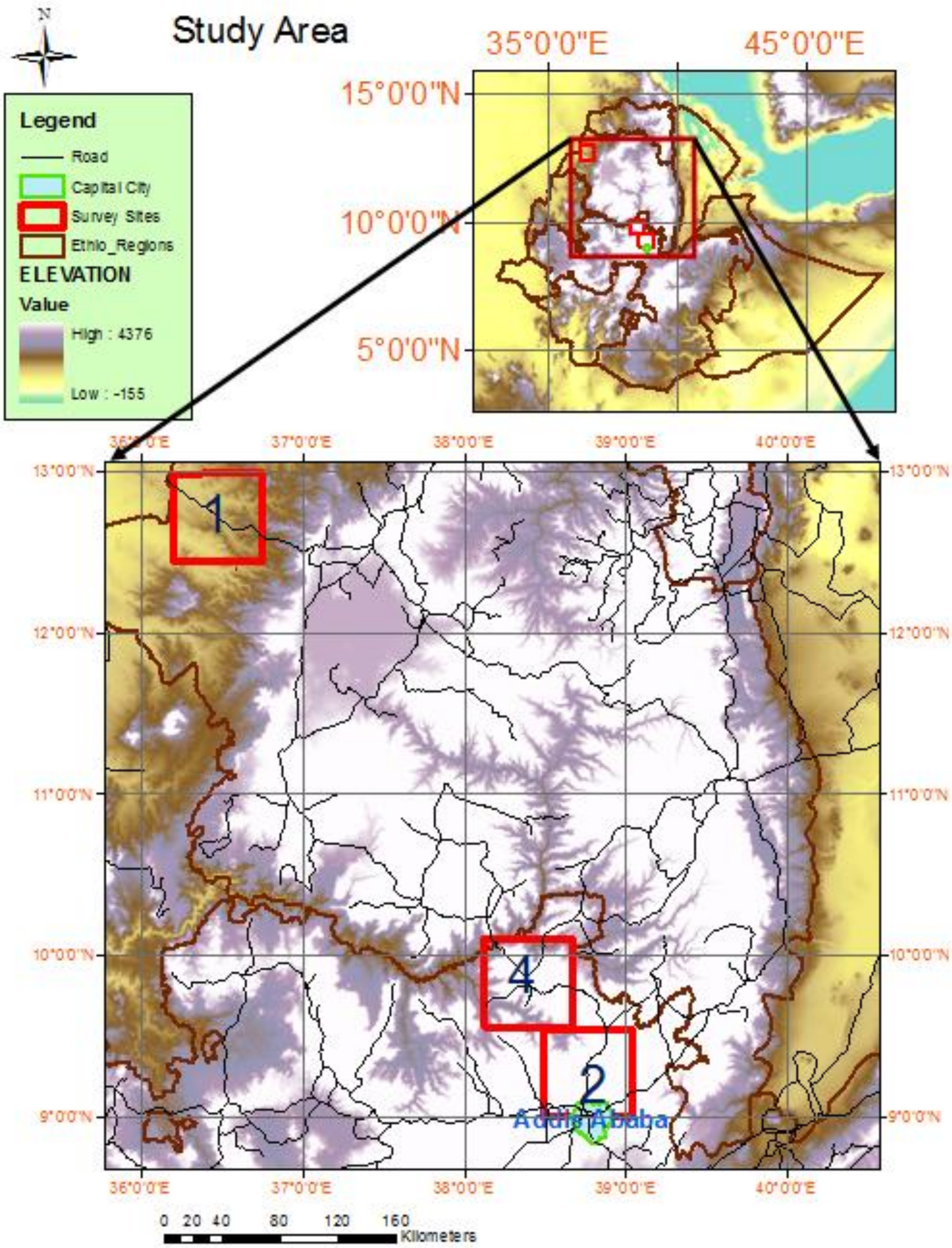


Figure 2-1 Study Area and the Survey Sites: 1=Metema, 2=Sululta, 4=Gerbe Guracha

2.2. Research Methods

2.2.1. Methodological Flowchart

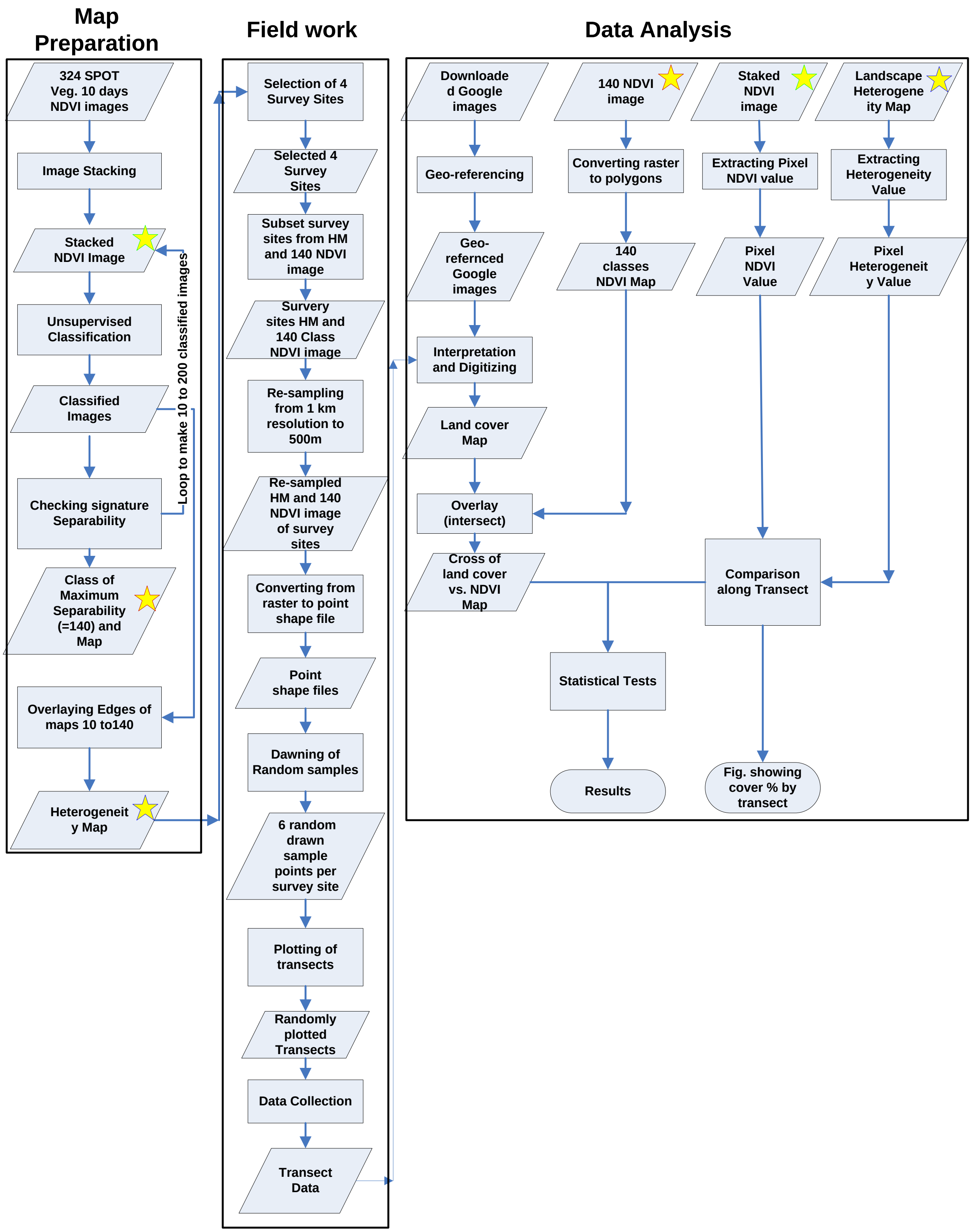


Figure 2-2 Research Methodology

2.3. Map preparation

Map preparation was processed using a methodology developed by De Bie et al., 2008 (See Figure 2-2).

The first step was stacking. 324 SPOT-Vegetation NDVI decadal images (contains each the maximum pixel value of 10 daily NDVI images) from April 1998 to March 2007 were stacked (Atkilt and De Bie, personal communication).

Unsupervised classification of the stacked images was conducted using ISODATA in ERDAS. The unsupervised classification was done with a maximum of 50 iterations in order to get higher accuracy; the convergence threshold was set at 1. The numbers of classes varied from 10 to 200; 191 maps were thus produced of which one must be considered as “best”.

After generating the maps, their signature files were used to identify the best map. The average and minimum separatebility indices were calculated using the divergence method. Then the average and minimum divergence values were plotted to identify the class having the best value for both average and minimum divergence. Finally, the 140 class image and NDVI cluster signature was chosen for further analysis (See Figure 2-3).

Then all classified images starting from 10 up to chosen 140 class were overlaid on top of each other to produce the heterogeneity map.

Table 2-1 Survey area Sites characteristics

Id	**Characteristics**	**Site 1 (Metema)**	**Site 2 (Sululta)**	**Site 3 (Sheno)**	**Site 4 (Gerbe Guracha)**
1	Elevation	780-950	2500-2650	2750-2850	2500-2550
2	NDVI Classes with area > 100km^2	123, 124	104, 114	92, 98, 114	106, 108, 109
3	LU/LC	Bush Shrub grassland	Open shrubland	Intensive cultivation	Intensive cultivation
4	Soils	Haplic Luvisols, Eurtic Vertisols	Vertic cambisols, Chromic Luvisols	Lithic Leptosols, Vertic cambisols	Eutric Vertisols, Rendzic Leptosols
5	Climate	Warm tropics semi-arid	Cold tropics arid	Cold tropics arid	worm/moderately cool tropics sub humid
6	LGP (days)	150-179	150-179	150-179	240-269

2.1. Field Work

Pre-field work

The hyper-temporal NDVI heterogeneity map that was produced covered the whole country. Since time and budget for the research was limited, it was necessary to make a selection of survey areas on the basis of mainly logistical criteria. Four smaller survey sites of 60X60km were selected based on their accessibility and variability/uniformity. One of the criteria was elevation. Elevation of the selected survey sites varied from 780m up to 2850m. Table 2-1 reports selected characteristics of the 4 sites.

Of the survey sites the heterogeneity map and 140 classes of NDVI map were clipped using the Erdas software (See Figures 2-3, 2-4 and 2.5).

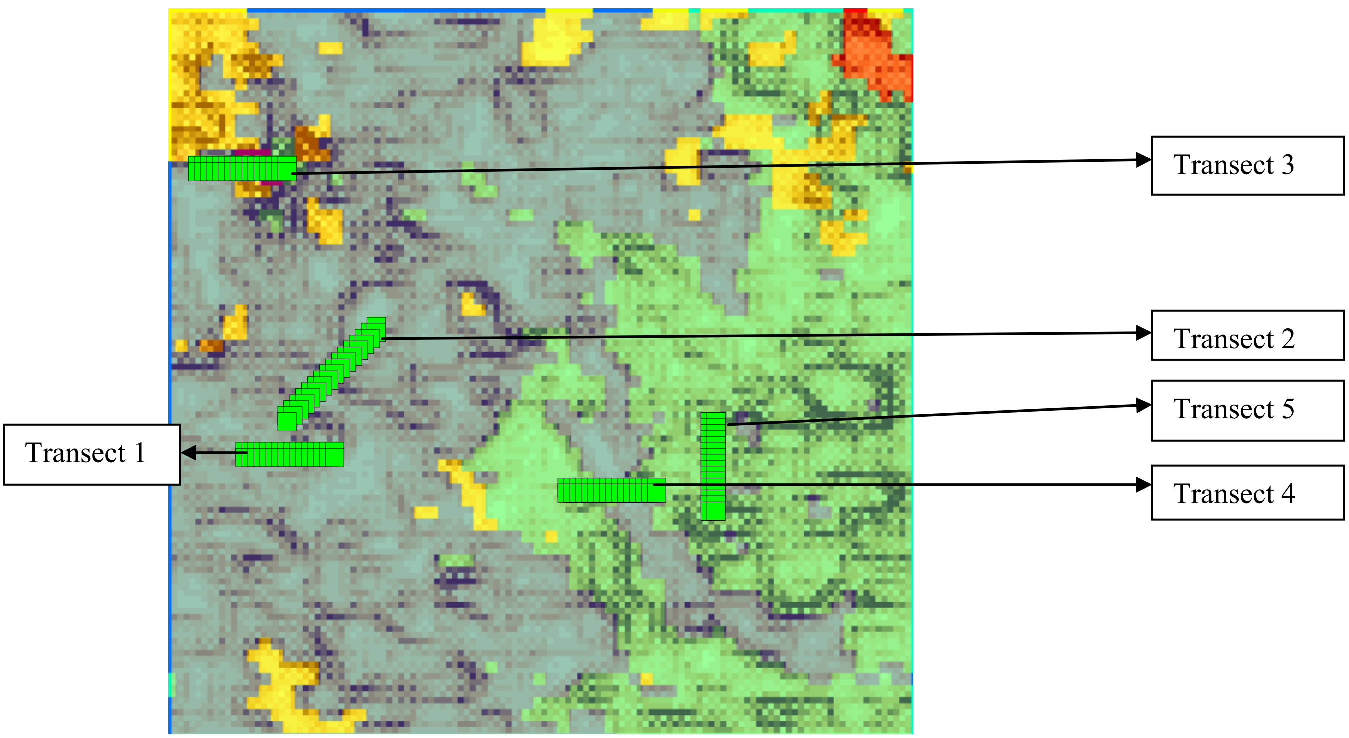


Figure 2-3 Metema Site Landscape Heterogeneity map with NDVI 140 class and five transects at scale of 4km

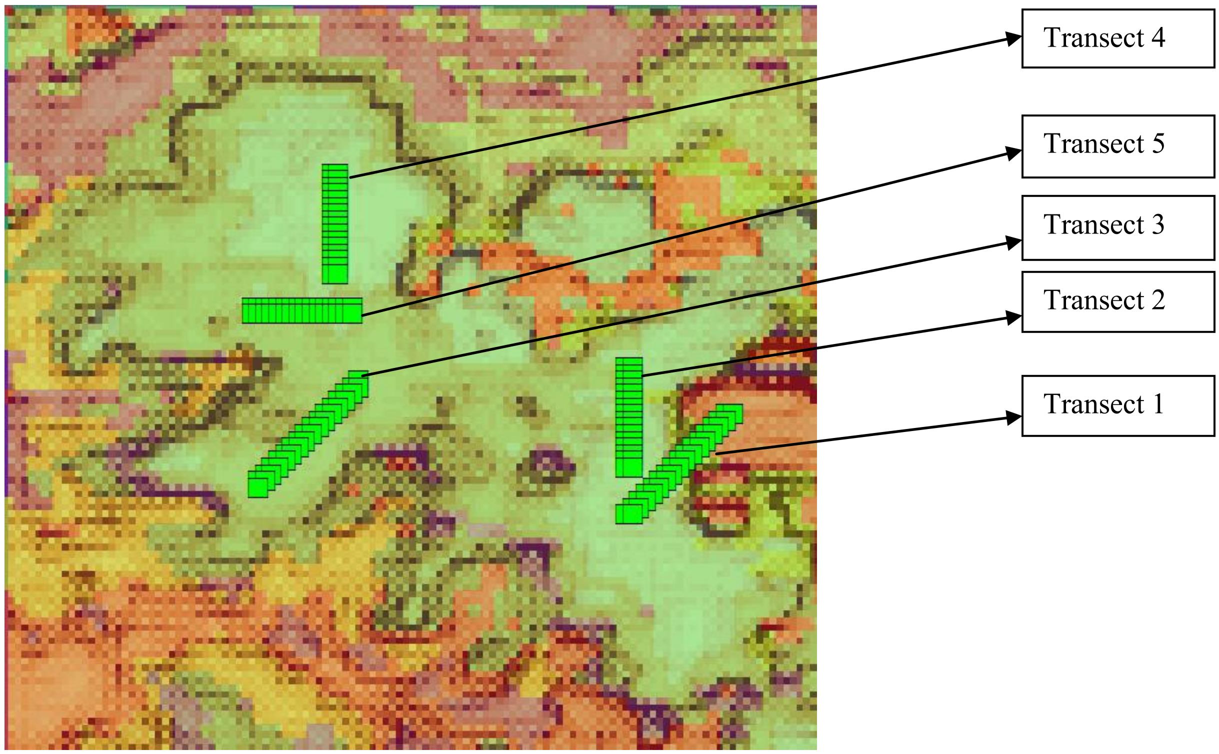


Figure 2-4 **Gerbe Guracha Site Landscape Heterogeneity map with NDVI 140 classes and five transects at scale of 4km**

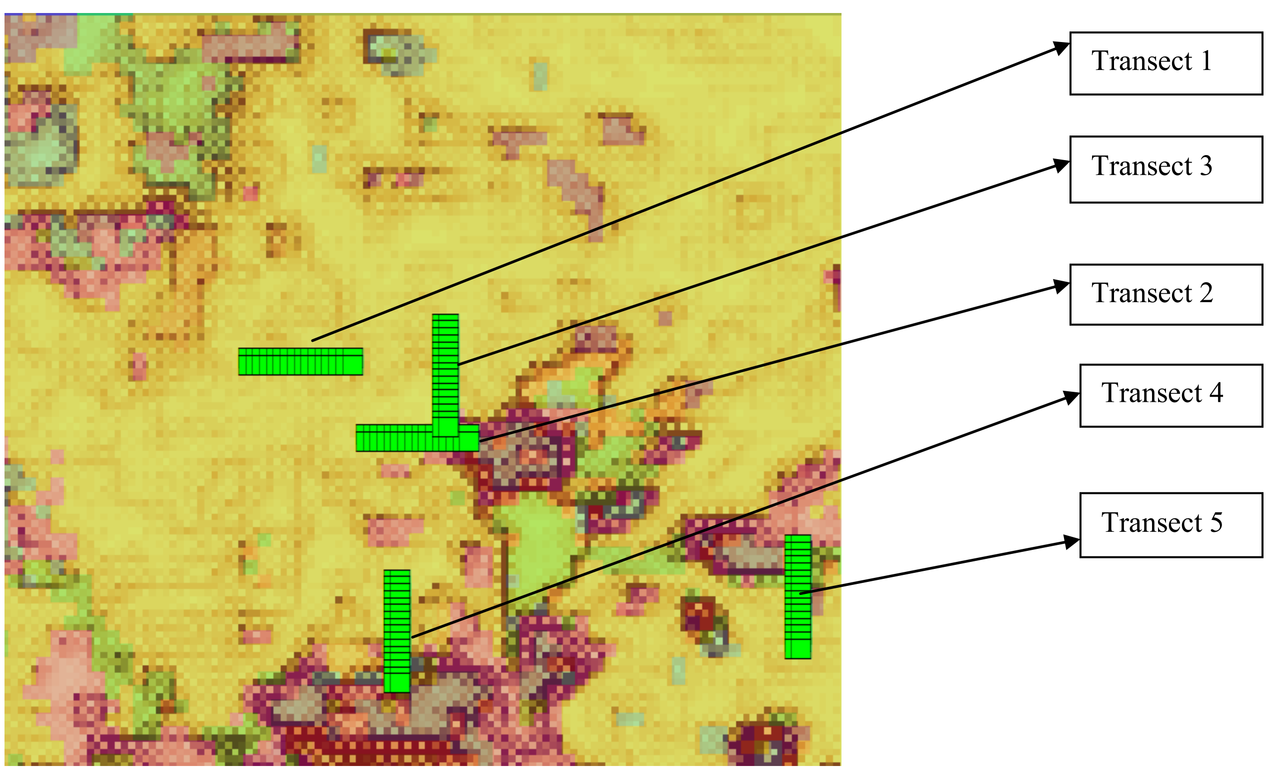


Figure 2-5 **Sululta Site Landscape Heterogeneity map with NDVI 140 class and five transects at scale of 4km**

Data had to be collected to represent a 1x1km SPOT-VGT pixel that was the lowest representation. Collection of data from an area of 1 km^2 was not possible. Therefore, the heterogeneity and NDVI maps of 1km resolution were re-sampled to $500m^2$ in Erdas software.

The raster maps were converted to point shape file in Erdas.

Random sampling method was used to locate transect line (Liquan Zhang et al., 2004) from the point shape file. Six sample points were drawn randomly for each survey site using Arc GIS.

Transects were placed randomly in each survey site. The length of each transect line were 8kms. In each transect there were 32 plots in two directions, which were the centres of each resample image pixels. Sample plot area size was 30mX30m and placed 500m apart from each other (see Figure 2-3, 2-4 and 2-5).

With the allocated time it was possible to collect data from only three sites. The types of data collected were land cover percentage per species, diameter at breast height (DBH) of trees, number of trees per species, average height per species, cover association and time and duration of greenness (phenology beginning and ending) (See Appendix A).

2.2. Data Analysis

- **Data organization**

After field work data was organized by creating Database in Access software and entered into a database.

- **Digitization, Geo-referencing and Interpretation**

The 60 x $60m^2$ area data that has been collected from the field work was not enough for further analysis since it couldn't cover the area of a pixel in the map unit (1x1km). Therefore, Google high resolution image covering only the sampled transects were downloaded from the Google image site (SPOT2 and 4 10m panchromatic, Digital Glob Quick Bird 2.4m resolution, Geo Eye 1.65m resolution) vary from 2004 up to 2008.

Google high resolution images that cover transects were downloaded, geo-referenced (2m resolution) and then map unit interpretation was done. On screen digitization was carried out in ArcGIS to delineate areas having similar characteristics of the high resolution Google images.

The visual interpretation was done using image characteristics of the image such as feature tone, pattern, shape, size, shadow texture and association (Feranec, 1999).

Digitized polygons were described using the field observation data collected from 32 plots of per transect, located 30X30m at 500m distance. Digitized polygons of the same class were assumed to have similar cover specifications.

By NDVI pixel (1x1km) the area of each digitized polygon was estimated by crossing the two maps in Arc GIS.

The attributes of the crossed images were transferred to Excel software. Land cover percentages were calculated for each pixel.

- **Data Extraction**

On the other hand NDVI value was extracted for pixels within transects from the layer of the stacked images using Erdas. The layer was selected by plotting annual average NDVI value generated from stacked image and comparing the gradient of the classes within transect. Whenever there is gradual gradient in the graph it indicates clear differences in the profiles of NDVI value of the classes. This implies a clear spatial stratification and presents distinct units that show considerable homogeneity (De Bie, *et al.*, 2008).

Landscape heterogeneity value of the boundaries of pixels was calculated by moving widow average technique averaging of edges neighbouring by pixels (average of 8 neighbours) using Erdas. Pixel boundary heterogeneity value of the pixels were extracted from the heterogeneity map for the same pixels of transects using Erdas.

Therefore, it was possible to compare cover percent, pixel NDVI value and heterogeneity value of the pixel in the map along transect by plotting their value in a graph.

- **Statistical Analysis**

Two types of statistical analysis were carried out to find relationship for validating field data and the fraction of NDVI class in a transect pixel. The first analysis focused on identification of significant differences between NDVI classes of map units in the survey area. The second analysis was focused on the identification of boundary strength or length between the map units.

Analysis has been done to find the relationship and test significance differences between the NDVI classes. Stepwise least squares dummy variable regression analyses were carried out for NDVI classes as dummy independent variables within the survey area and their cover percentages as dependent variable in SPSS 16.0 (Field, 2005). This test was used to test the 1st hypothesis “NDVI class or map units have significant differences” using their cover types. The analysis was run based on presence/ absence of NDVI class in a particular pixel of transect at 95% confidence level.

Analysis using linear regression analysis was also performed between heterogeneity of pixels boundary and the land cover percentages to find the relationship and to validate the strength of boundary of a pixel in transect. The heterogeneity value of boundaries of a pixel and differences in NDVI classes in pixels were also executed to validate the strength of boundaries of NDVI classes between pixels along transect at 95% confidence level.

Both tests were used to test the second hypothesis that says 'there is significant relation between tree cover percentages and heterogeneity value of a pixels within transect if there is strong boundary'.

3. Results

The results covered the whole methodological approach processes of the research.

3.1. Map preparation

SPOT Vegetation 10 days composite of ten years decadal NDVI images at 1-km resolution from April 1998 to March 2007 were stacked in Erdas. The stacked image was become one composite image consists of 324 layers. This stacked image was the first result of the mapping process.

The stacked image layers as one image was classified using An Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering algorithm of Erdas-Imagine software (ERDAS, 2003). Unsupervised classification was run with pre-defined number of classes starting from 10 to 200 by setting the maximum number of iterations to 50 and convergence threshold to 1. Unsupervised classification indicates to the without interference or guidance of experts or additional data were used in the process of classification.

The classified image results were checked for their separability using divergence statistical measures of distance between generated clusters signatures. As it was indicated in Figure 3-1

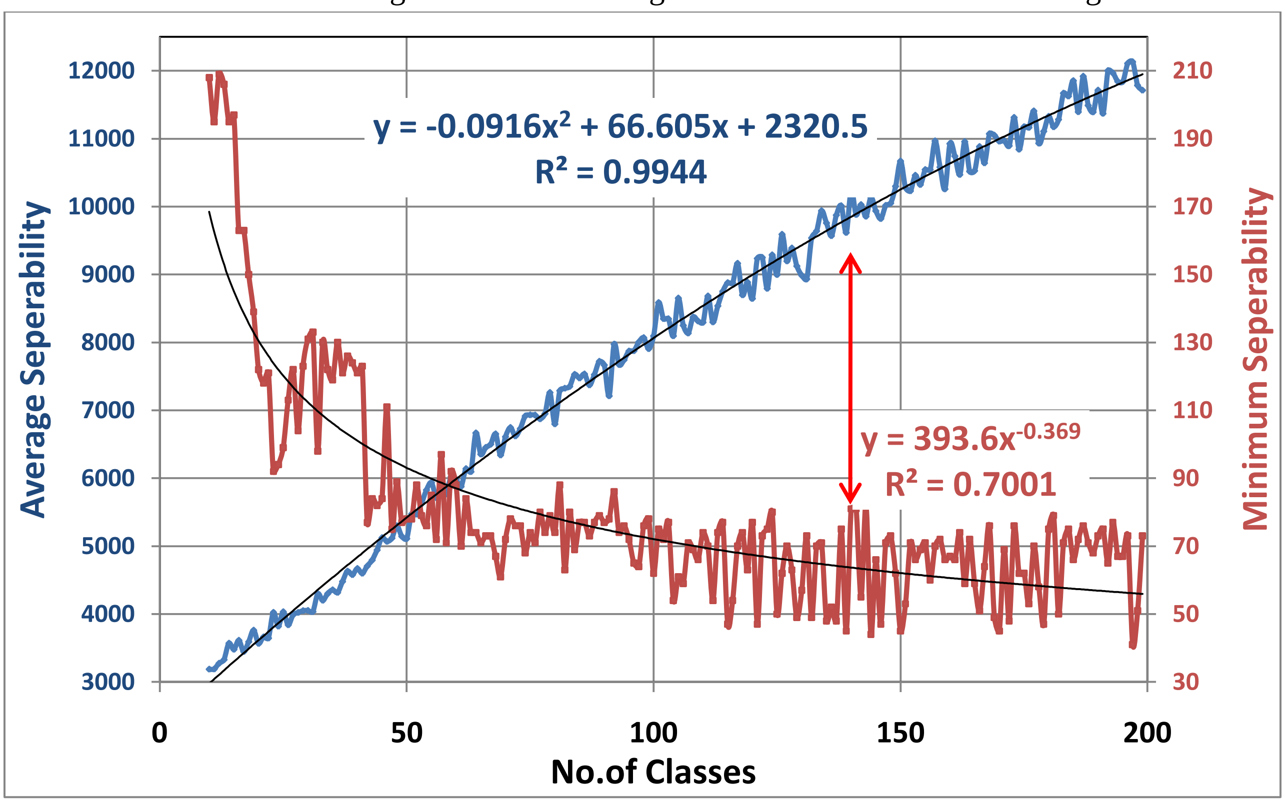


Figure 3-1 Divergence Statistics (Avg. and Min.) to identify the optimum number of classes

generated clusters signatures were plotted and finally the classified image and NDVI cluster signature of "140 class", a map which has both maximum (minimum and average) divergence statistics was chosen which was indicated by red line and considered as optimum separable class.

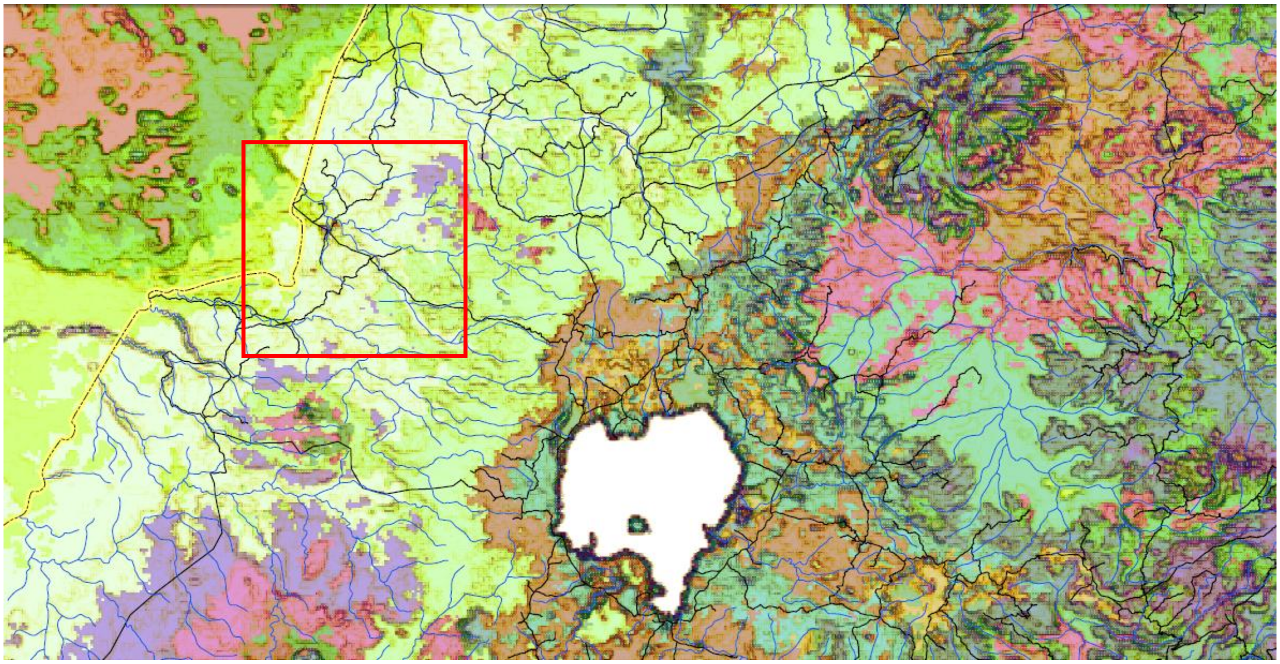


Figure 3-2 Metema Area: NDVI Class Map + the Boundary-strength Map (brown).

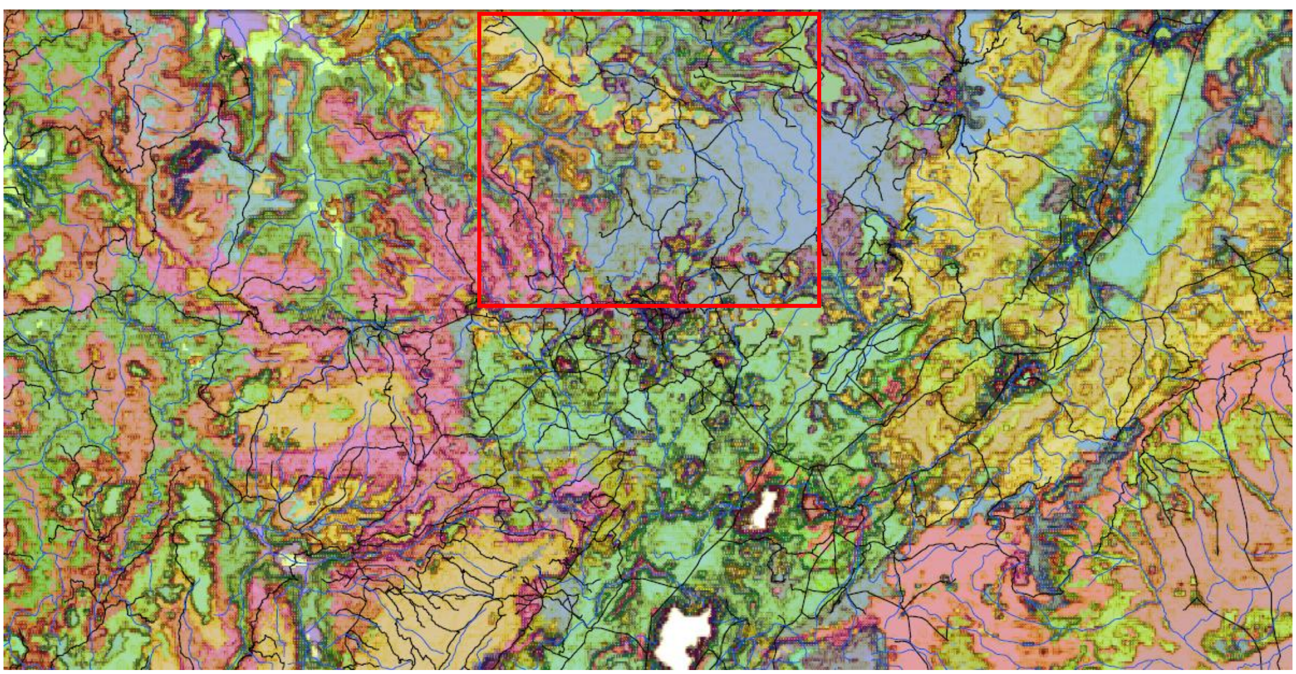


Figure 3-3 Gerbe Guracha and Sululta Areas: NDVI Class Map + the Boundary-strength Map (brown).

To know the purity of each class, all maps having 10 to 140 classes (the chosen class) were overlaid on top of each other and by pixel edge the count that a boundary between NDVI classes occurred was counted (sum of 10-140 classes) to assess the relative strength of each boundary; accordingly a boundary strength map was constructed (Figure 3-2 and 3-3). Wherever there are sharp boundaries of the classes, they coincide and produce a thick line. Wherever there are no clear boundaries (fuzzy), they do not show any thick line. Boundaries also occur within the units of the 140 classes map indicating heterogeneity. Accordingly, the heterogeneity map was produced.

3.2. Analysis

3.2.1. Result Comparison

For comparison cover percentages: that were calculated from digitized polygons, NDVI (DN) value: that were extracted from stacked image layers, NDVI classes: that were extracted from NDVI map and boundary heterogeneity values: that were extracted from heterogeneity map of pixels for each transect were plotted in a graph. All transects within survey site are displayed as follows.

- **Metema Site transects**

Annual average of NDVI generated from stacked image for classes 111, 115, 122, 123 and 124 that are found in transects 1, 2 and 3 of the Metema site were plotted to identify NDVI value that can differentiate all the classes. As indicated in Figure 3-4 the area between the two lines is an area where all NDVI classes have distinctive value of NDVI. Therefore, NDVI value for those transects was extracted from resent layer of 22 (layer of 3rd decadal image of October, 2006) which is denoted as 310 in the stacked image.

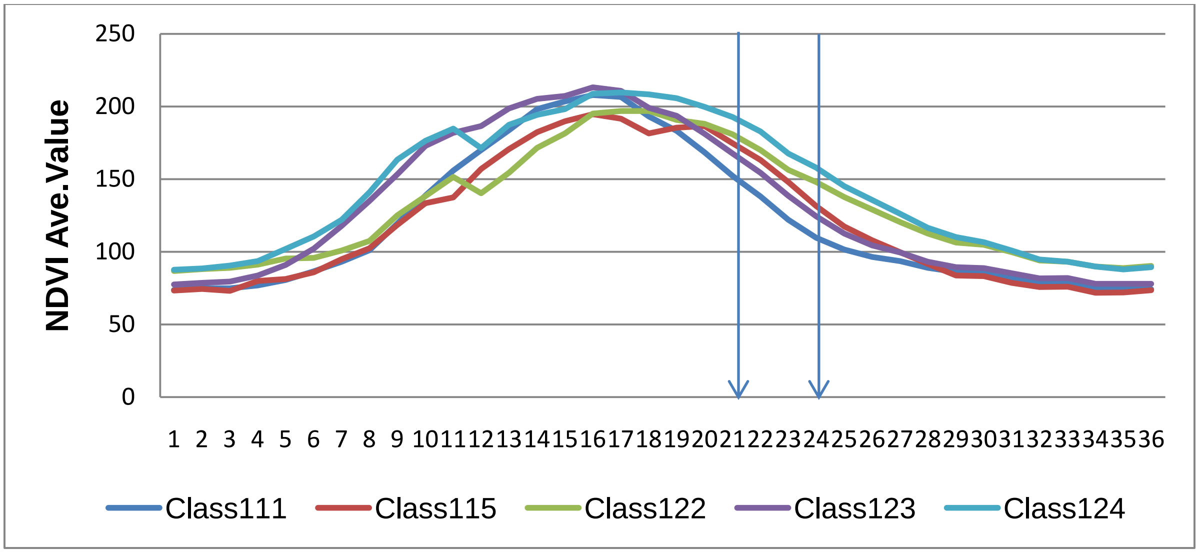


Figure 3-4 Average NDVI value generated from stacked image for classes found in Metema site 1, 2 and 3 transects the two perpendicular lines are denoting the area where all NDVI classes have distinctive value of NDVI

➢ Transect 1

From field observation, this transect begins from flat area which was covered by dominant shrub mixed with trees as well as spiky and tall grass and agricultural fields. In the middle it characterised by mountain and huge valley which was dominantly covered by big trees and agricultural areas. At the top of the mountain shrubs, grass, trees and agricultural fields were the dominant covers. Figure 3-5 shows the high resolution image of transect 1 and it was digitized into four classes (See Appendix C).

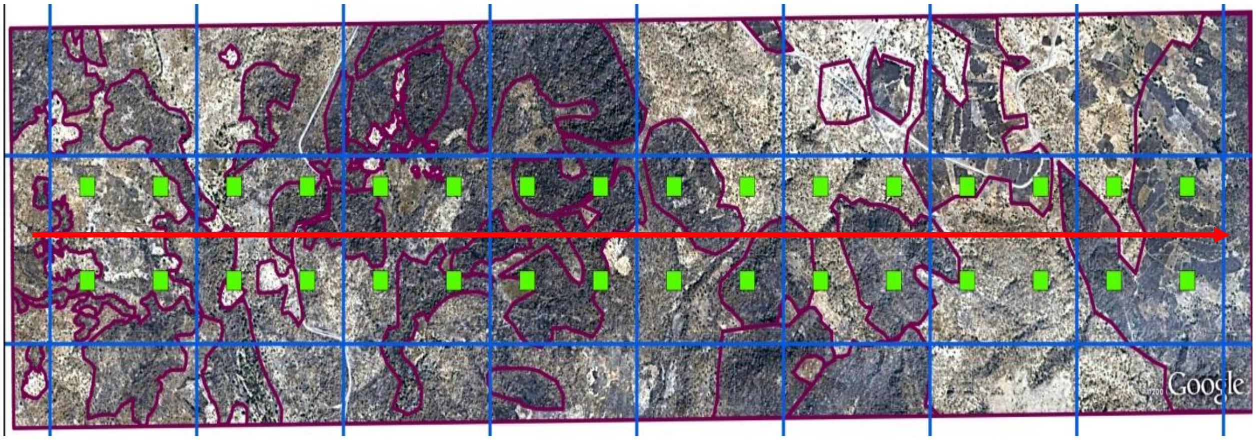


Figure 3-5 Metema Site Transect 1 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample site

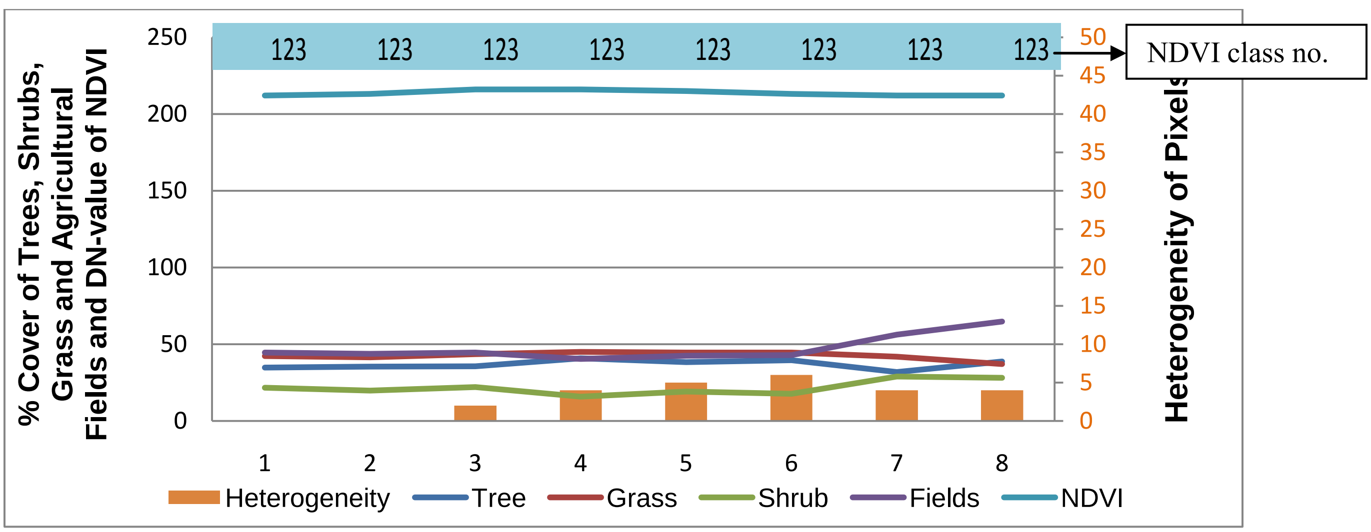


Figure 3-6 Pixel Cover %, NDIVI value and pixel boundaries heterogeneity value as well as NDVI class of pixels of Metema site transect 1

As it is clearly indicated in Figure 3-6, all the pixels are in map unit or NDVI class 123. Agricultural fields, grass and trees cover were the main covers of transect 1. Tree cover percent line and grass cover percent line tends to have same pattern with NDVI DN value line (See Appendix B).

To find the relationship between cover percentages and heterogeneity value within the transect regression analysis were performed for each cover type percents, average of tree, grass and shrub cover percents as well as average of all the cover percentages and heterogeneity value of boundaries of pixels of transect 1. The results for each cover percentages were not significant (See Table3.1). The mean cover percent of tree, grass and shrub was significant (Figure 3-7). This implies that the heterogeneity value was the results of all cover percentages instead of one cover type in transect 1.

Table 3-1 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 1 of Metema Site (d.f. = 7)

Cover Type	Tree	Grass	Shrub	Field	Average of tree, grass & shrub	Average of all covers
R square	26	6	0.3	2	**63**	9
P-Value %	20	60	90	80	**2**	50

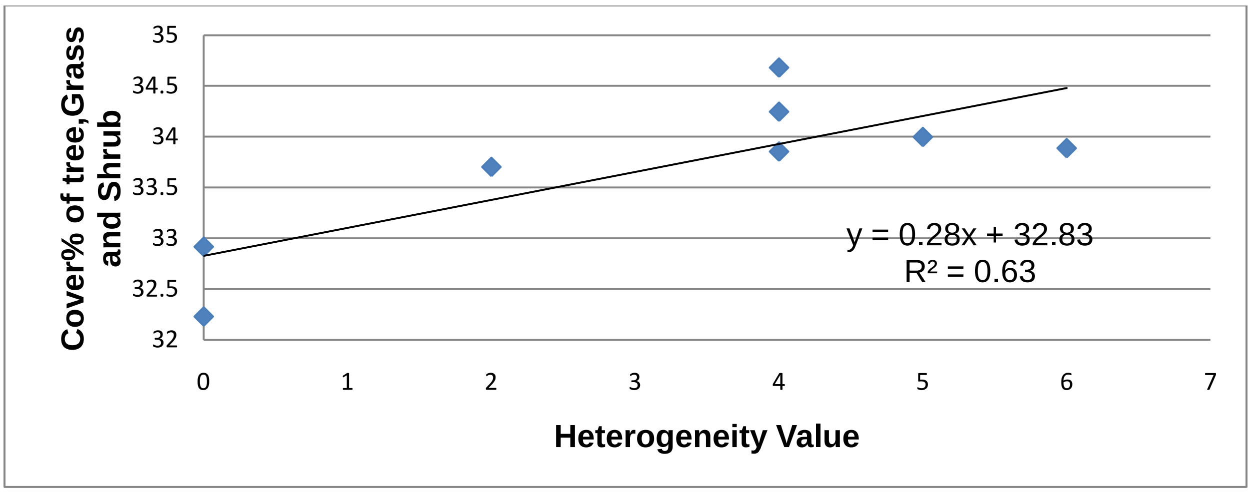


Figure 3-7 Regression Analysis result for average cover % of Tree, Grass and shrub and heterogeneity value of boundary of pixels (1X1km) for transect 1 of Metema site.

- **Transect 2**

As it was observed in the field, transect started from moderately flat area, covered by big trees, shrubs, spiky and tall grasses. This is followed by hill with mix of big trees and agriculture as well as grass covers. In the middle there were mix of settlement with agriculture as well as shrub, tree and grass. Towards the end of transect there was a mix of cover of trees, shrubs, agricultural fields and grass. In Figure 3-8 high resolution image of transect 2 of Metema site was indicated.

It was digitized into 8 classes (See Appendix C). Red line indicates the transect line and direction.

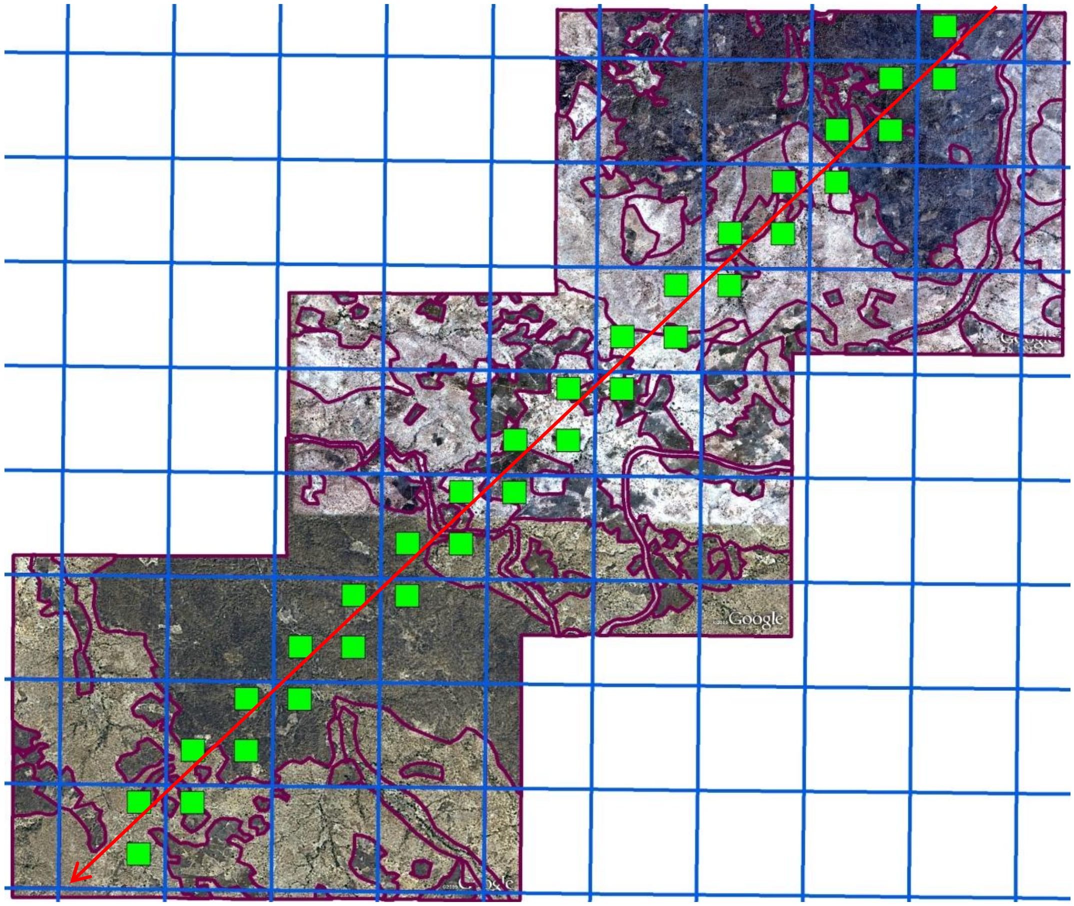


Figure 3-8 Metema Site Transect 2 digitized high resolution image (2m), with boundaries of NDVI pixel input layers; ■ are the sampled sites

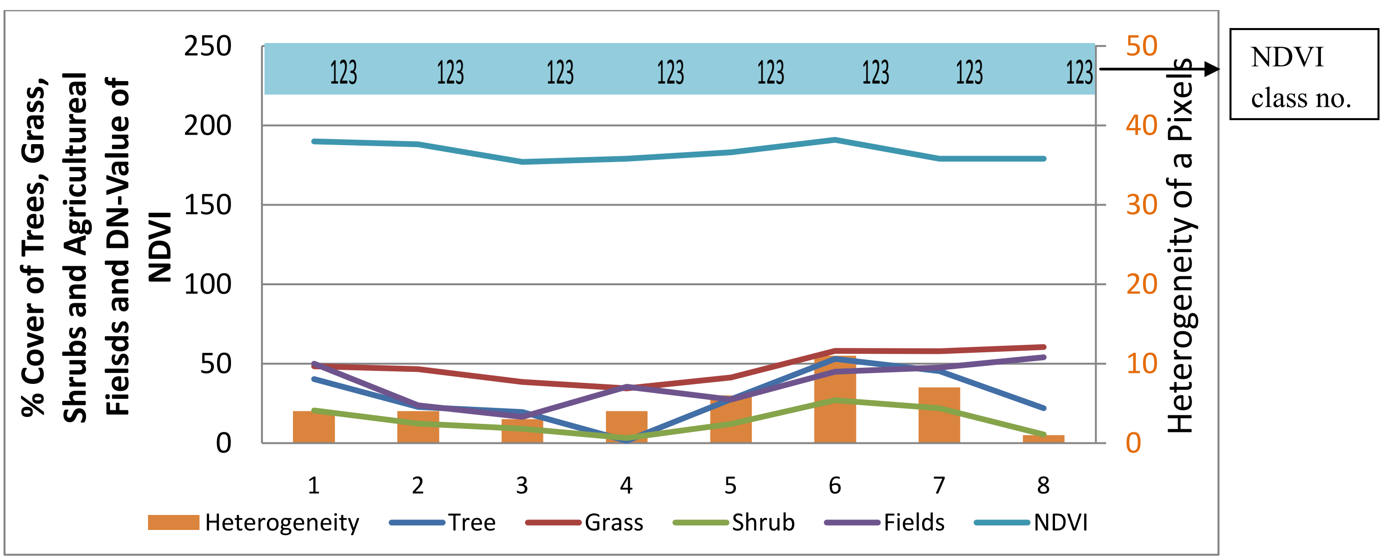


Figure 3-9 Pixel Cover %, NDVI and heterogeneity value as well as NDVI class no. for Metema site transect 2

As it is indicated in Figure 3-9 the dominant cover types of transect 2, which is within NDVI class 123, was shown as grass followed by agricultural fields. Tree cover percent was higher in the begining and ending pixels but not higher than grass percentages. Shrub was the least of all cover types in all pixels. The trend of the cover percentages was tending to have similar pattern with NDVI curve (See Appendix B).

Analysis was done to find the relationship between cover percentages and heterogeneity values of pixels in transect 2 of Metema site. Test results show that there is significant relationship between shrub cover percentages and heterogeneity value of pixels (See Figure 3-10). All other tests were not significant (See Table 3-2).

Table 3-2 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 2 of Metema Site (d.f. = 7)

Cover Type	Tree	Grass	Shrub	Field	Mean of tree, grass & shrub	Average of all covers
R square	**49**	8	**63**	1	43	30
P-Value %	**5**	50	**1**	80	7	20

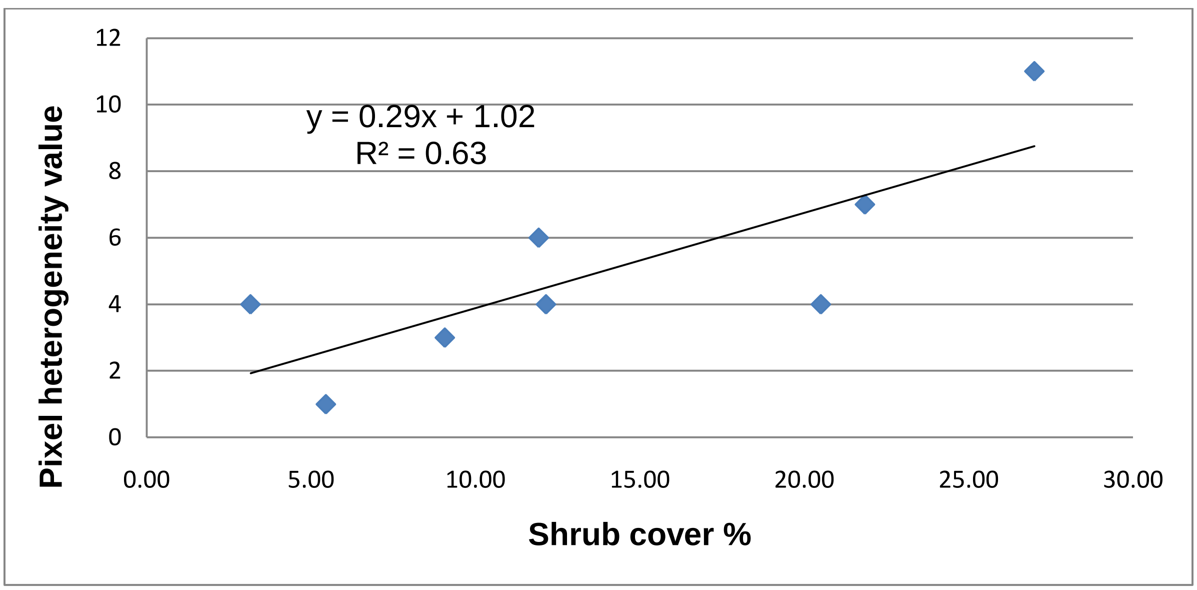


Figure 3-10 Regression analysis result for shrub cover and heterogeneity value of boundary of pixels (1X1km) for transect 2 of Metema site.

- **Transect 3**

As it was observed in the field, at the beginning of transect there were dominant cover of trees, shrub and grass with agricultural field mix. In the middle there were settlements with trees and agricultural fields. Towards the end there was a river with high cover of trees and grass. In

Figure 3-11 digitized Google image of transect 3 was shown and it was digitized into 6 classes (See Appendix C). Red line in the image indicates the line and direction of transect.

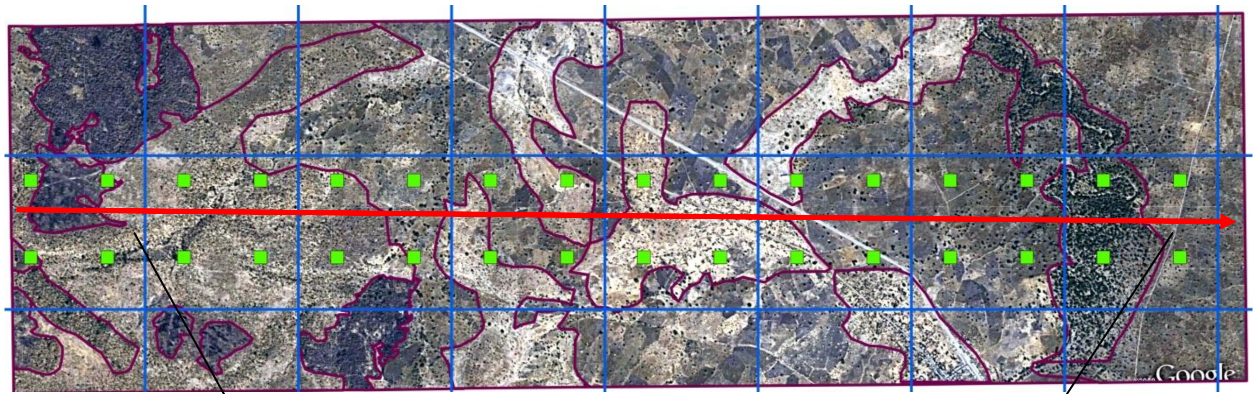


Figure 3-11 Metema Site Transect 3 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

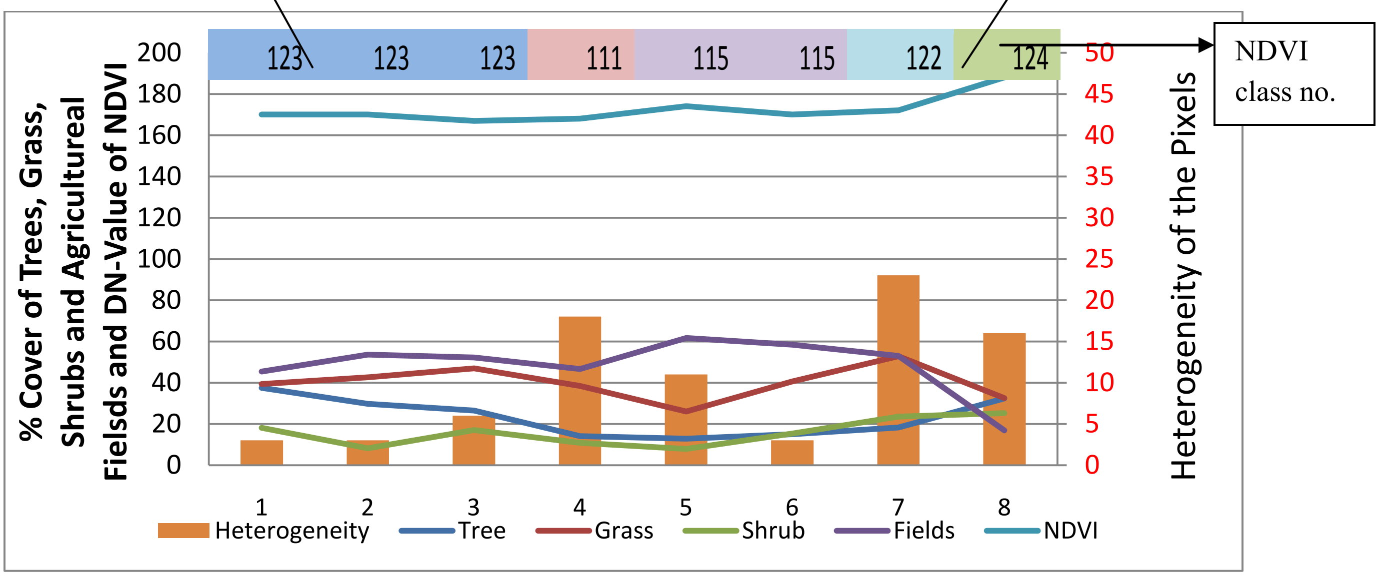


Figure 3-12 Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class no. for Metema site transect 3.

The graph in Figure 3-12 shows the trend in transect 3 of Metema site. This transect were demonstrated characteristics of five NDVI classes or map units. NDVI class 123 was characterized by uniform distribution of cover types such as high cover of agricultural field and grasses, relatively medium tree cover and low cover of shrub. Whereas NDVI class 111 was characterised relatively high cover of agricultural fields and grasses but less than NDVI class 123 and NDVI class 115 as well as less tree and shrub cover. NDVI Class 115 also indicated having low cover of tree and shrubs but high and medium cover of agricultural fields and grasses respectively. NDVI class 122 is also having both high cover of agricultural fields and grass but low cover percentages of tree and shrub cover. Finally, NDVI class 124 is dominated by tree cover which was followed by grass and shrub but low cover of agricultural fields. The high heterogeneity value of pixel 4 and 7 which are in NDVI class 111 and 122 were supported by changing in tree cover as well as NDVI value (See Appendix B).

Table 3-3 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 3 of Metema Site (d.f. = 8)

Cover Type	Tree	Grass	Shrub	Field	Mean of tree, grass & shrub	Average of all covers
R square	22	4	0	0	3	6
P-Value %	20	50	90	90	70	50

To find relationship between cover percentages and heterogeneity values of pixels in transect 3 regression analyses for cover percentages and heterogeneity value of pixels were performed. There is relationship between tree cover and heterogeneity value of pixels but, it is not significant (See Figure 3-13). Even though there is high heterogeneity value between pixels that can indicate strong boundary between the NDVI classes it could not validated.

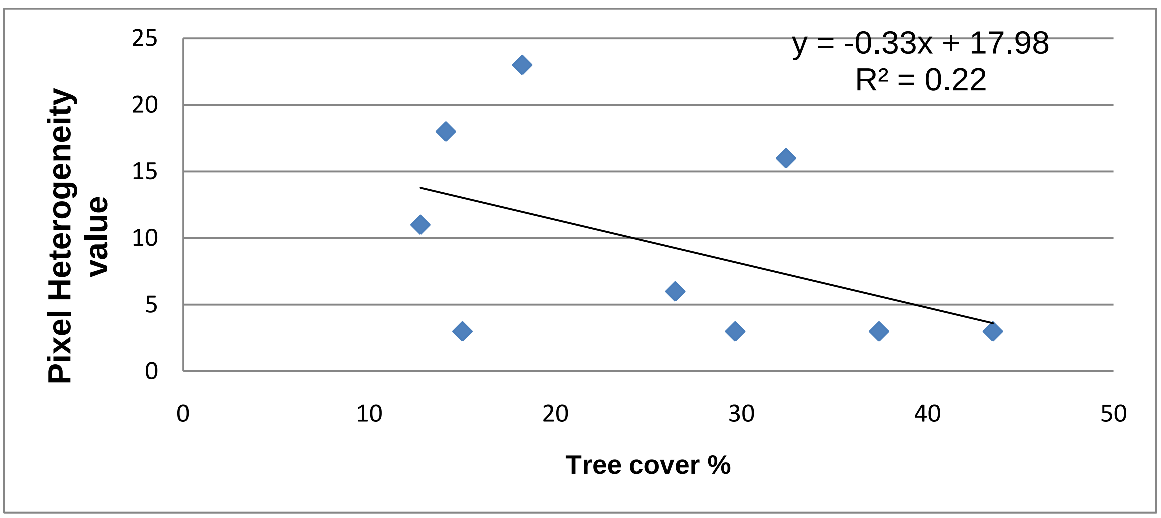


Figure 3-13 Regression analysis result of tree covers percent and boundary heterogeneity of pixels

To find relationship between if difference in NDVI class in pixels in transect with heterogeneity value of pixels in transect 3 regression analysis was performed. As seen in Figure 3-12 the differences in class in pixels are significantly related with heterogeneity value of boundary of the pixels of transect 3. The explained variability was 74%, where $f_{(1,8)}$=20 ($P<0.05$). The change of NDVI class in pixels was associated with the heterogeneity value change in transect. Therefore, this result validates the strong boundary between the NDVI classes within transect 3. This implies that the changes in classes in pixels are because of true change in heterogeneity value.

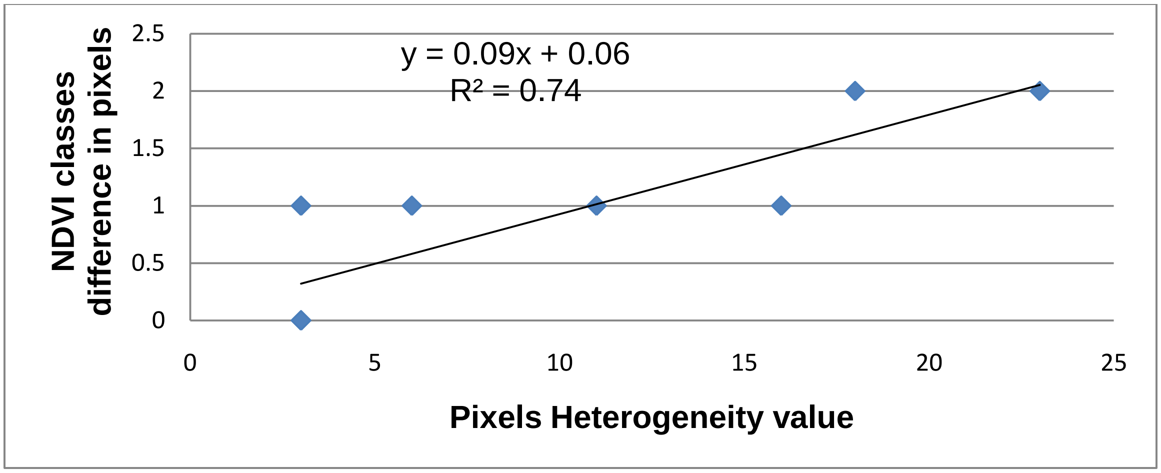


Figure 3-14 Regression analysis result between differences in class in the pixels and boundary heterogeneity of pixels of transect 3 Metema site

➢ **Transect 4**

Figure 3-15 shows annual average NDVI generated from stacked image for classes 123 and 124 of transect 4 and 5 of Metema site. As seen in the graph the classes were overlapped on the range of layer from 6 up to 12 and 16 up to 18. Therefore, it was possible to extract NDVI value from all layers except the above range. NDVI value for transect 4 and 5 were extracted from 3rd decade of November 2006.

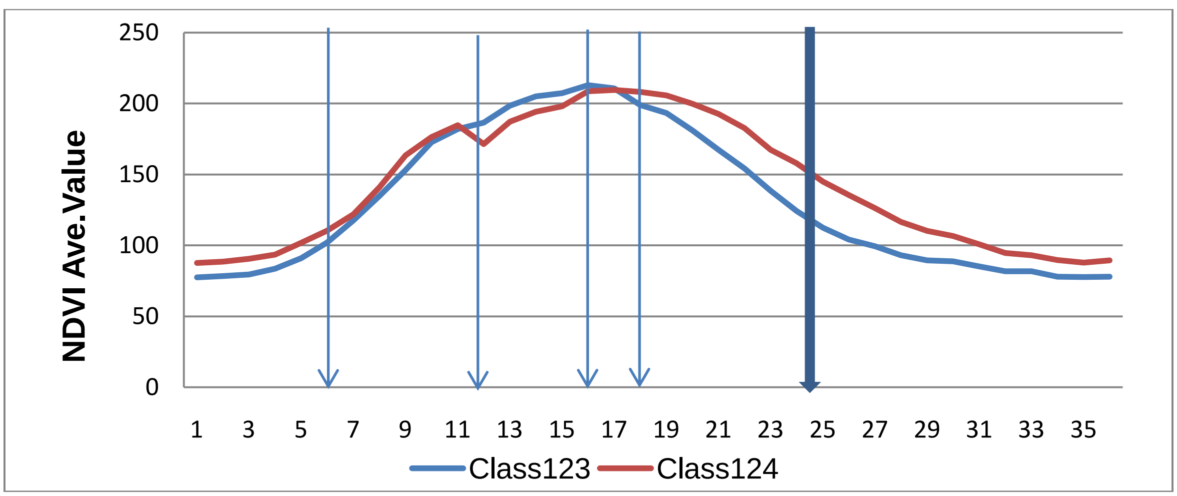


Figure 3-15 Average NDVI value generated from stacked image for classes found in Metema site 4 and 5 transects

Based on field observation, it starts from high mountains covered by big trees with grass. In the flat area shrub with grass trees as well as agricultural field were the main covers. This is followed by river junction with high cover of trees and grass. The river goes along transect line up to the end. In Figure 3-16, Google image of transect 4 of Metema site was displayed. It was digitized in to 6 classes (See Appendix C). The red line in the image indicates the line and direction of transect.

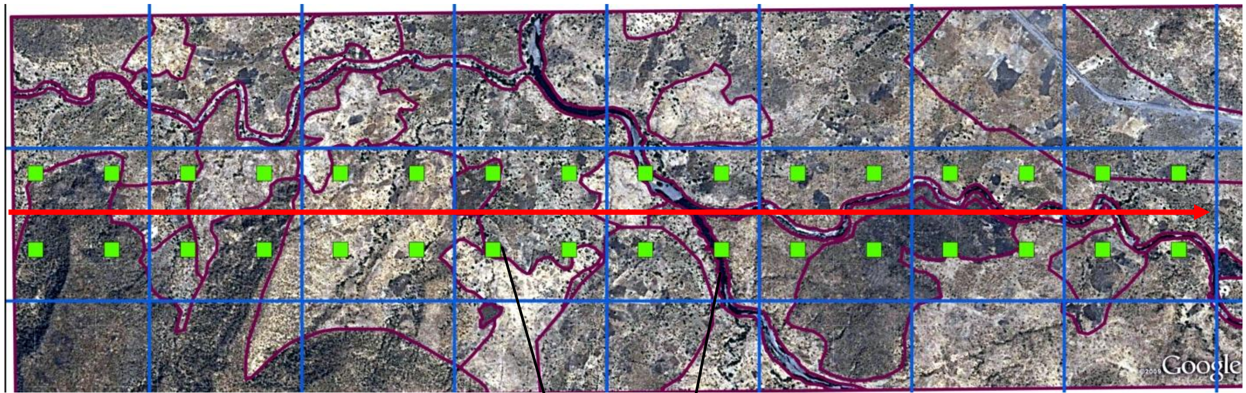


Figure 3-16 Metema Site Transect 4 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

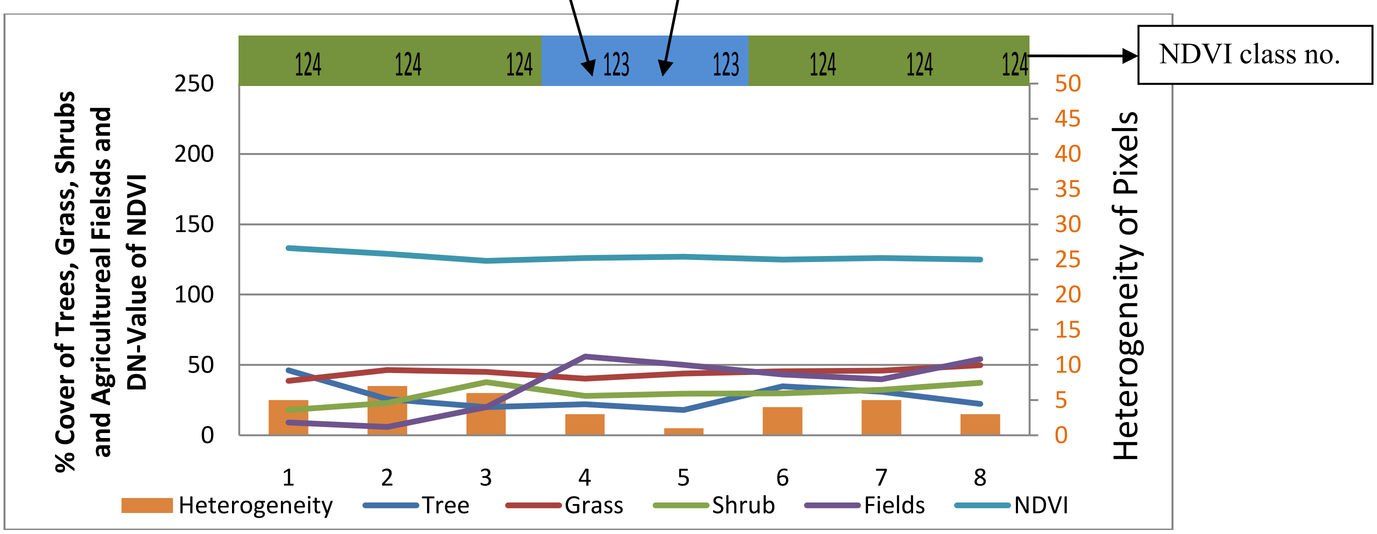


Figure 3-17 Pixel Cover %, NDIVI value and heterogeneity value of pixels boundaries as well as NDVI class No. for Metema site transect 4

In Figure 3-17, cover percentages, NDVI value and heterogeneity values of boundaries of pixels in Metema site of transect 4 were plotted. It is clearly indicated in the graph that NDVI class 123 pixels were dominated by agricultural fields and NDVI class 124 pixels were dominated by grass. NDVI class 124 pixels tend to have higher tree cover percentage than NDVI class 123 pixels. Plus, it tends to follow the trends of boundary heterogeneity value of pixels(See Appendix B)..

To find relationship between cover percentages and heterogeneity value of pixels, regression analysis was performed for all cover percentages, mean value of tree, grass and shrub covers and boundary heterogeneity value of pixels of transect 4. It was displayed in Table 3-4 that agriculture field and average cover percentage of all covers have significantly related with boundary heterogeneity value of pixels of transect 4 (See Figure 3-18).

Table 3-4 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 4 of Metema Site (d.f. = 7)

Cover Type	Tree	Grass	Shrub	Field	Average of tree, grass & shrub	Average of all covers
R square	5	11	13	**77**	4	**60**
P-Value %	58	38	34	**2**	59	**1**

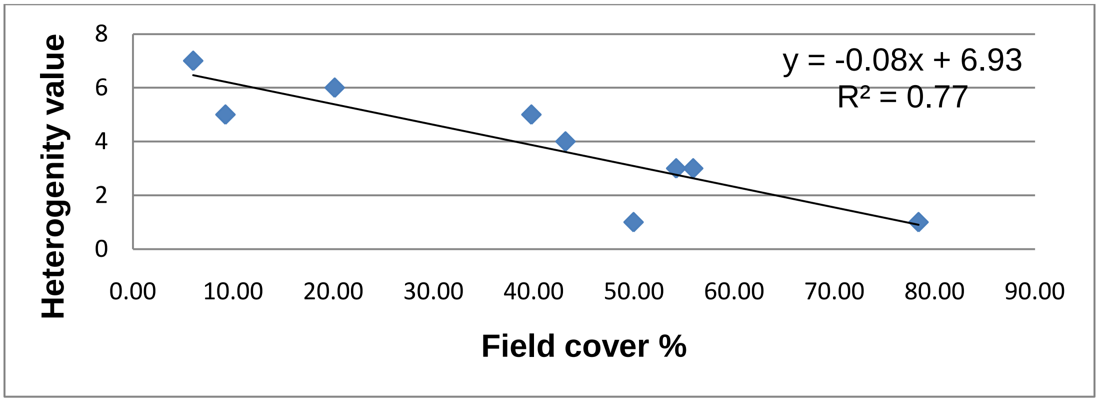


Figure 3-18 Regression between cover percentages of agricultural fields and boundary heterogeneity value of pixels in transect 4

To find relationship between if deference in NDVI class in pixels with heterogeneity value of pixels regression analysis was carried out for differences in NDVI class in pixels and heterogeneity value for pixels in transect 4 of Metema site. The result shows that there was no relation between these two variables at all (See Figure 19). This implies that there is no any strong boundary in transect 4.

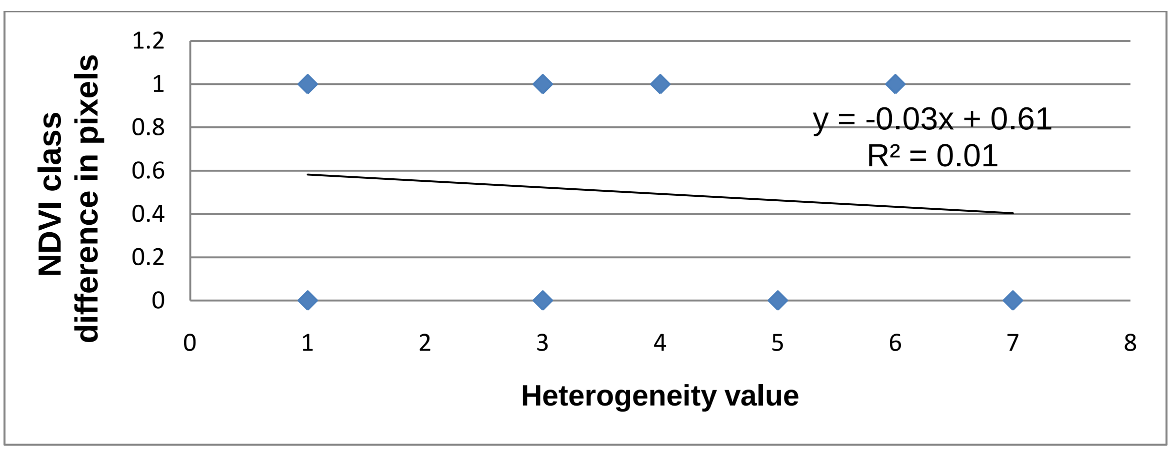


Figure 3-19 Regression analysis between differences in class in the pixels and boundary heterogeneity of pixels of transect 4 Metema site

- **Transect 5**

As observed in the field, transect 5 begins from the other side of the mountain. The mountain sides are covered by big trees and grasses, but the top steep slope of the mountain is bare. The middle part was covered by trees, grass and agricultural fields. Towards the end, there was a river where tree was dominant. In Figure 3-19 digitized image of transect 5 in Metama site was exhibited. It was digitized into 8 classes (See Appendix C). The red line in the image indicates the line and direction of transect.

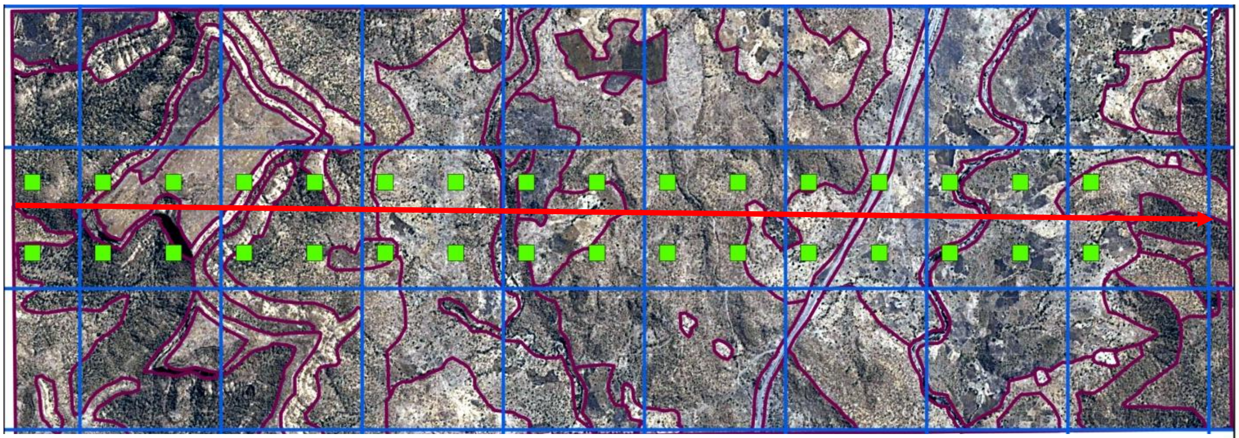


Figure 3-20 Metema Site Transect 5 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

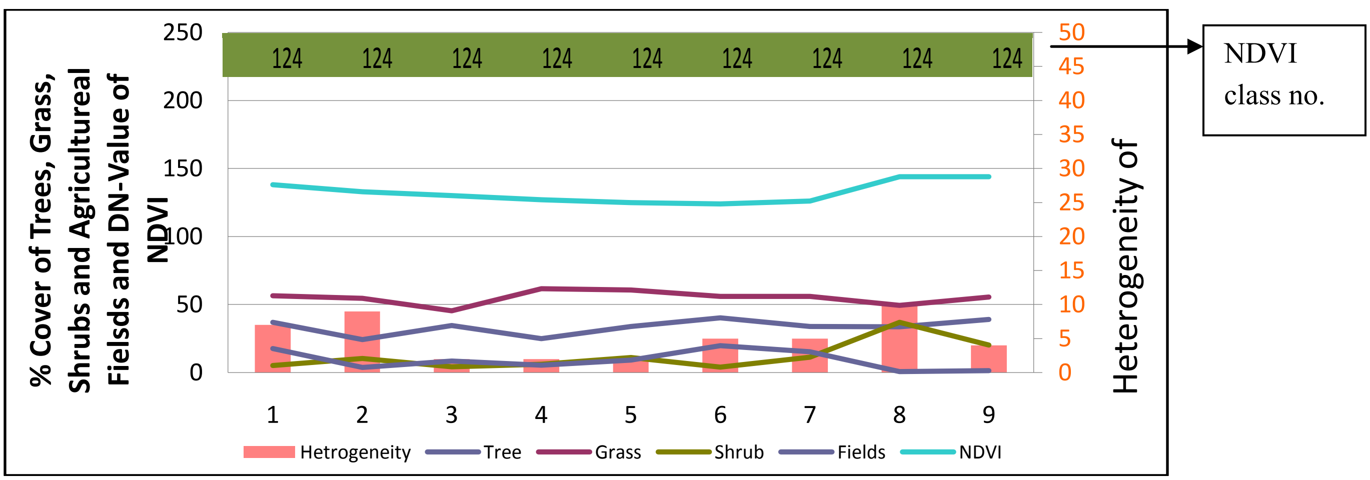


Figure 3-21 Pixel Cover %, DN value of NDVI and heterogeneity value as well as NDVI class no. for Metama site transect 5

As shown in Figure 3-20 all the pixels of transect 5 of Metama site are in the NDVI class 124 and dominated by grass cover percentage followed by tree cover. Shrub and agricultural fields were very low (See Appendix B).

To find relationship between cover percentages and heterogeneity value of the pixels and to test significance of relationship regression analysis for transect 5 of Metema site were performed. All the results were not significant (See Table 3-5).

Table 3-5 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 5 of Metema Site (d.f. = 8)

Cover Type	Tree	Grass	Shrub	Field	Average of tree, grass & shrub	Average of all covers
R square	1	8	30	2	11	3
P-Value %	80	45	13	71	39	64

- **Statistical analysis for Metema site to test significant differences between NDVI classes**

To find the relationship between NDVI classes and their cover percentages in Metema site and to test significant differences between NDVI classes, stepwise least square dummy variable regression analysis was executed for NDVI classes as dummy independent variable and their estimated cover percentage of pixels as dependent variable. The analyses were performed for tree, grass, shrub and agricultural field cover types.

- **Tree and grass as dependent variable**

Using tree and grass cover percentages from the field data NDVI class 115 was significantly different from all other NDVI classes in the site having explained variability of R^2 10.5% and 9.4% respectively (For detail See Appendix D). It has significantly less tree and grass cover percentages then all other NDVI classes in the site (Table 3-6 and Table 3-7).

Table 3-6 Result of regression analysis between NDVI classes using Tree cover % of pixels for Metema site

NDVI class	Coefficients	t	Sig.
constant	31	20	0.000
115	-17	-2	0.019

Table 3-7 Result of regression analysis between NDVI classes using Grass cover % of pixels for Metema site

NDVI class	Coefficients	t	Sig.
Constant	46	37	0.000
115	-13	-2	0.026

- **Field as dependent variable**

NDVI class 124 was significantly different from all other NDVI classes using agricultural field cover percentages having explained variability of R^2 38.8% (See Appendix D). It has less agricultural fields cover percentages than all other NDVI classes in the site (See Table 3-8).

Table 3-8 Result of regression analysis between NDVI classes using Field cover % of pixels for Metema site

NDVI class	Coefficients	t	Sig.
constant	46	14	0.000
124	-25	-5	0.000

- **G/Guracha Site Transects**

As it was indicated in Figure 3-22, average NDVI value of classes generated from the stacked image in transect 1 of Gerbe Guracha site were plotted. The arrow line indicates a layer which has gradual gradient and it was taken as clear separation. No.12 layer was denoted as 300 in the stacked image represents 2nd decade of July 2006. NDVI value was extracted from this particular layer for transect 1, 3 and 4.

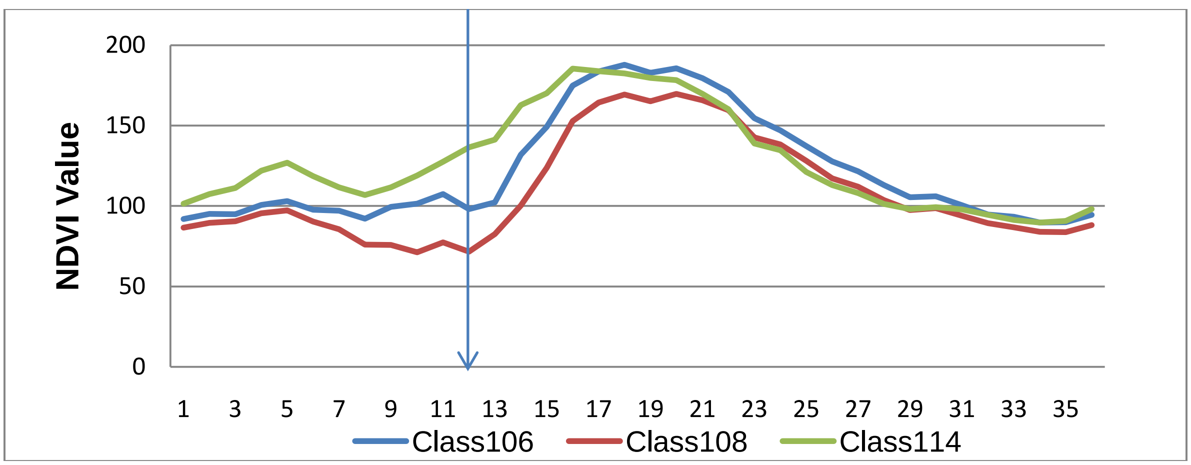


Figure 3-22 Average NDVI value generated from stacked image for classes found in Gerbe Guracha site transect 1

- **Transect 1**

As observed during the field work, transect1 begins with massive grass cover within marsh area and agricultural fields. This was followed with agricultural fields and some settlements. Gradually the transect goes though a mountain which was characterised by shrub bare and a few trees as well as agricultural fields. In Figure 3-23 partial Google image of transect 1 of 5 pixels was shown. It was digitized into five classes (See Appendix C). Due to the unclarity of Google image during downloading, it was not possible to use full transect image.

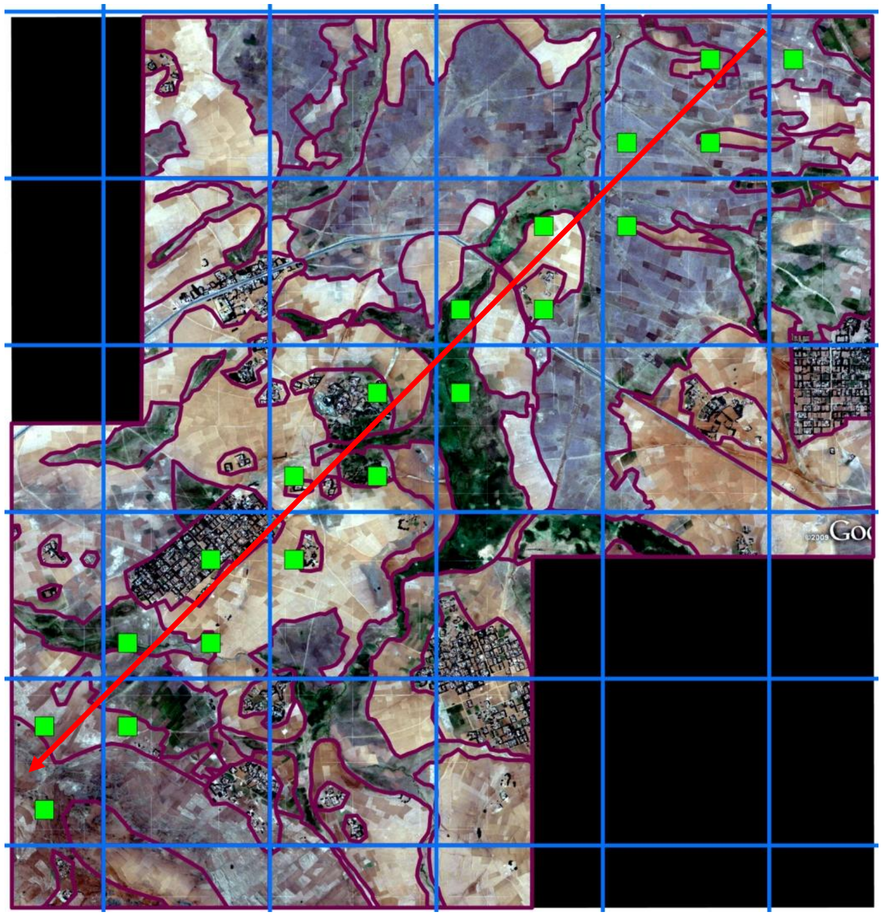


Figure 3-23 Gerbe Guracha Site Transect 1 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

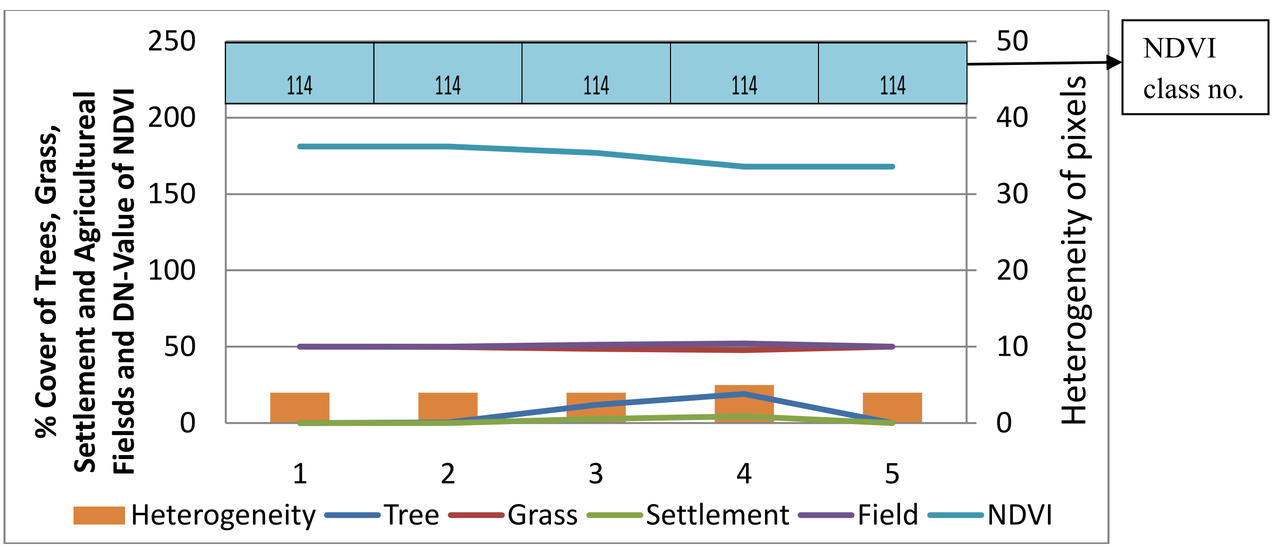


Figure 3-24 Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class no. for Gerbe Guracha site transect 1

As it was indicated in Figure 3-24, all the pixels of transect 1 are in map unit or NDVI class 114 and dominated by grass and agricultural field cover. Tree and settlements cover percentage are very few (See Appendix B).

Table 3-9 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 1 of Gerbe Guracha Site (d.f.=4)

Cover Type	Tree	Grass	Settlement	Field	Average of tree & grass	Average of all covers
R square	66	66	66	66	66	66
P-Value %	9	9	9	9	9	9

To find significant relationship between cover percentages and boundary heterogeneity value of pixels and to test the boundary strength in transect 1 regression analysis was performed. The result shows that there is relationship, but it was not significant (See Table 3-9).

- **Transect 3**

Based on field observation, at the beginning the area was flat and was covered partly with agricultural fields and marsh area with grass. This was followed by small hills covered by settlements with few Eucalyptus trees as well as agricultural fields. Generally, low lands were covered by marsh lands with tall grass, areas outside the marsh area was covered by agricultural fields and small hills were also covered by mixes of few Eucalyptus trees associated with settlements and agricultural fields. Digitized Google image of transect 3 of Gerbe Guracha site is visualized in Figure 3-25. It was digitized in to 4 classes (See Appendix C).

In Figure 3-26, cover percentages, NDVI value and heterogeneity value of pixels in the Gerbe Guracha transect 3 was indicated. All the pixels were within NDVI class 106. This class was characterised by high cover percent of settlement, followed by grass cover (See Appendix B).

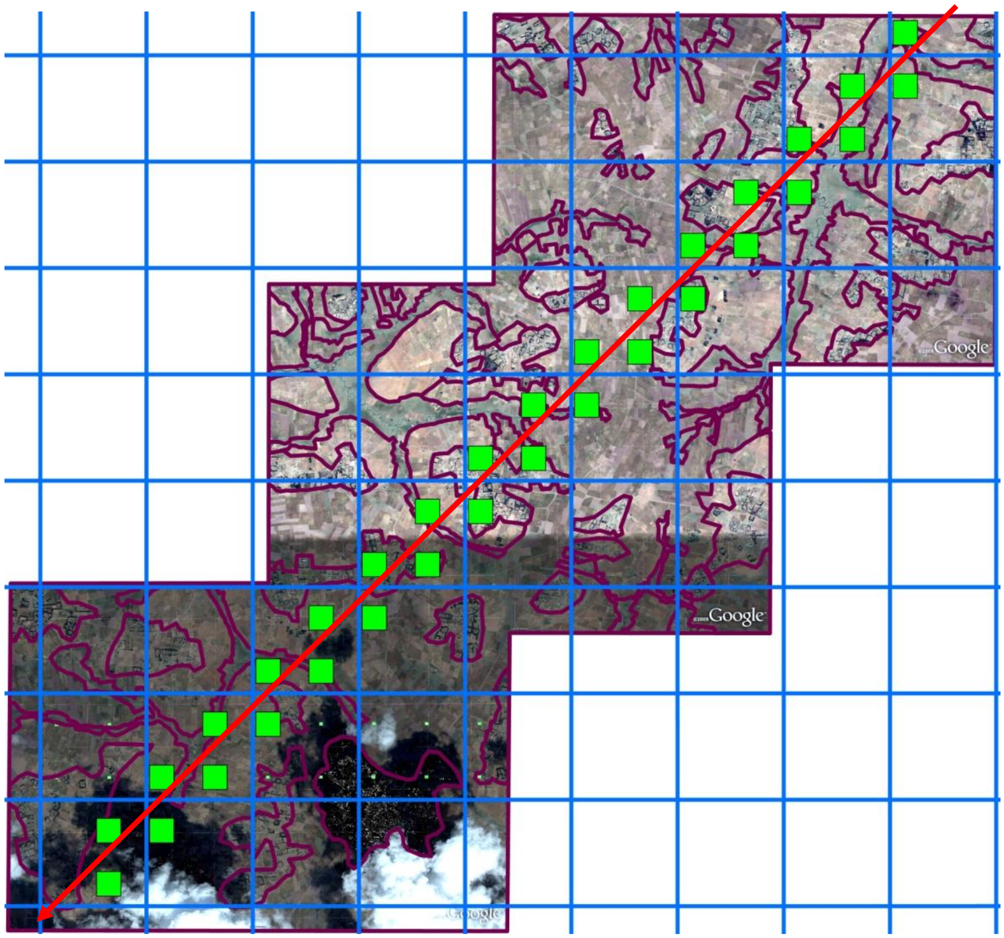


Figure 3-25 **Gerbe Guracha Site Transect 3 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites**

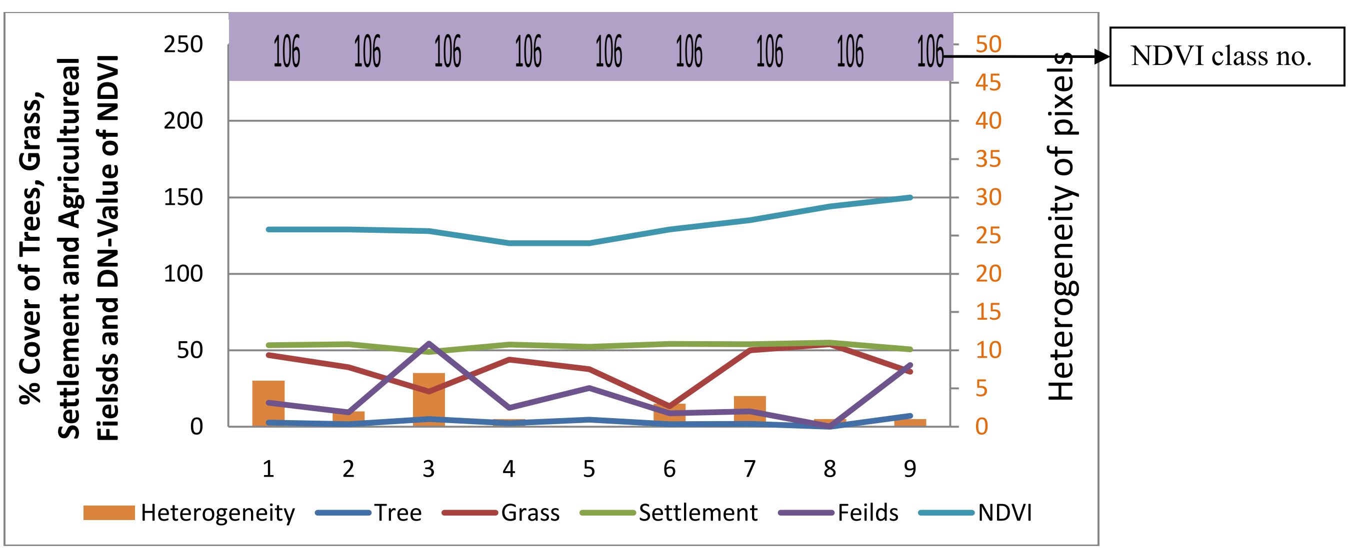


Figure 3-26 **Pixel Cover %, NDIVI value and boundary heterogeneity value as well as NDVI class for Gerbe Guracha site transect 3**

To find relationship between cover percentages and heterogeneity value of pixels and to test boundary strength regression analysis was executed for each cover percentages, average of tree and grass covers as well as average of all cover percentages and heterogeneity value of pixels for transect 3 of Metema site. For all tests there was no relation between the cover types and the heterogeneity value (See Table 3-10). It implies there was no strong boundary in transect 3.

Table 3-10 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 3 of Gerbe Guracha Site (d.f.=8)

Cover Type	Tree	Grass	Settlement	Field	Mean of tree & grass	Average of all cover percentages
R square	0	6	13	13	6	1
P-Value %	90	53	34	34	53	80

- **Transect 4**

Based on the field observation, transect was covered with vast agricultural fields, grass and settlements with a few Eucalyptus trees as well as bare land around settlements. In Figure 3-27, digitized Google image of transect 4 of Gerbe Guracha site is displayed. It was digitized in to 4 classes (See Appendix C). Red line in the image indicates the line and direction of transect.

In Figure 3-28, cover percent of each pixel in transect 4 of Gerbe Guracha site was indicated. Pixels of this transect were within 108 NDVI class. Generally this class was characterised by maximum agricultural field cover followed by grass but very less cover of trees and settlement. As a result in all pixels it has a very low NDVI value. The complete drop of NDVI in pixel 1 and 4 could be associated with availability of extensive marsh area and bare land in these pixels (See Appendix B).

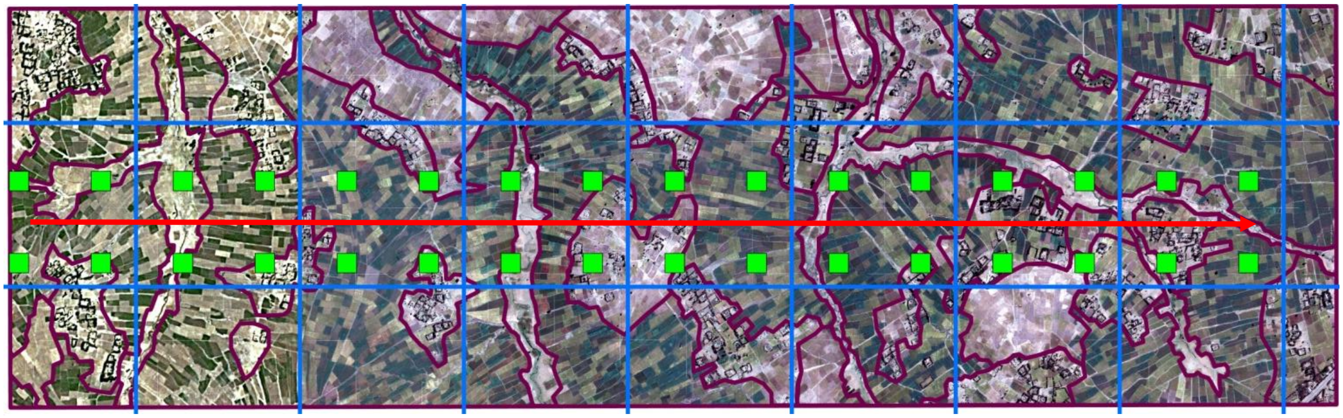


Figure 3-27 Gerbe Guracha Site Transect 4 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

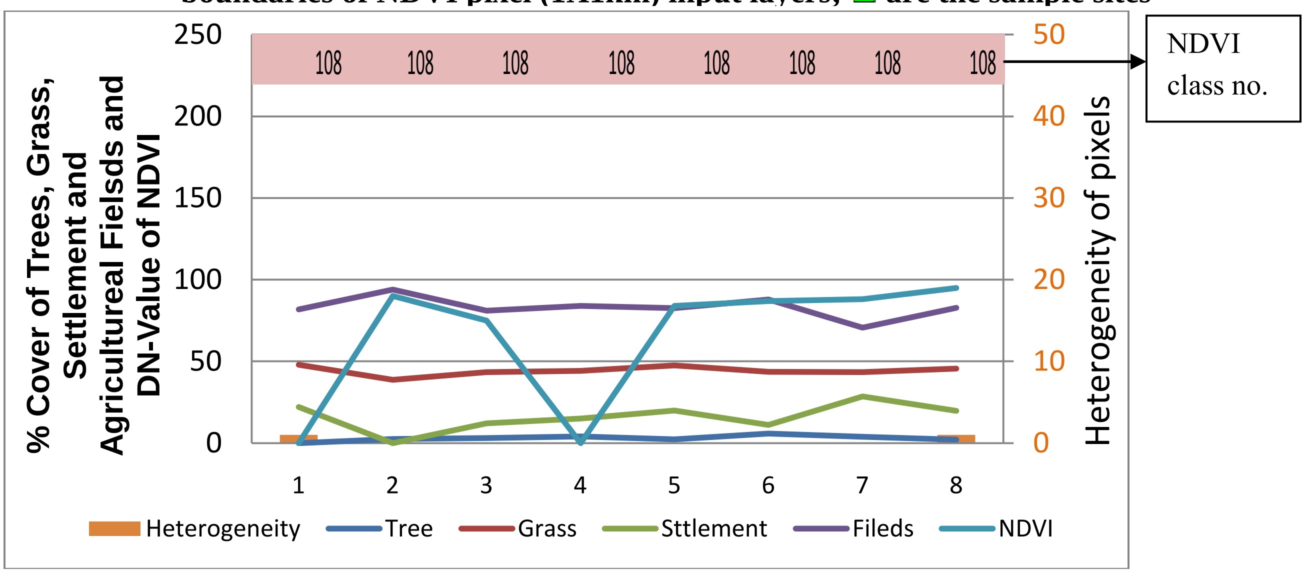


Figure 3-28 Pixel Cover %, NDIVI value and boundary heterogeneity value as well as NDVI class for Gerbe Guracha site transect 4

To fine relationship between cover percentages and boundary heterogeneity value of pixels in transect 4 of Metema site, regression analysis was performed for each cover type, average of tree and grass, average of all cover types and boundaries heterogeneity of pixels. All tests were insignificant (see Table 3-11). It implies that there was no strong boundary in transect 4.

Table 3-11 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 4 of Gerbe Guracha Site (d.f.=7)

Cover Type	Tree	Grass	Settlement	Field	Mean of tree & grass	Average of all covers
R square	21	26	30	1	6	21
P-Value %	21	16	65	83	53	21

- **Transect 5**

Annual average NDVI generated from stacked image for classes 106 and 108 of transect 5 of Gerbe Guracha site were plotted in graph shown in Figure 3-29. The gradual gradient in the graph was indicted by line and DN value for transect was taken from layer no.10 which is denoted by 298 in the stacked image represented for 3rd decade of June 2006.

Figure 3-29 Average NDVI value generated from stacked image for classes found in Gerbe Guracha site transect 5

Based on field observation, transect starts with agricultural field and settlements with few Eucalyptus trees. This was followed by bare land and an extensive marsh grass land. In the middle, there was an extensive agricultural field. At the end, there were settlement with Eucalyptus trees and agricultural fields. In Figure 3-30, digitized Google image of transect 5 in Gerbe Guracha site was displayed. It was digitized into four classes (See Appendix C).

Transect 5 pixels were laid on two NDVI or map units namely NDVI 106 and 108. In Figure 3-31, it was indicated that pixels in NDVI class 106 were having higher grass and settlement cover as well as NDVI (Turner and Gardner) value than NDVI class 108. NDVI class 108 was dominantly covered by agricultural fields and relatively very low cover of tree and shrub (See Appendix B)..

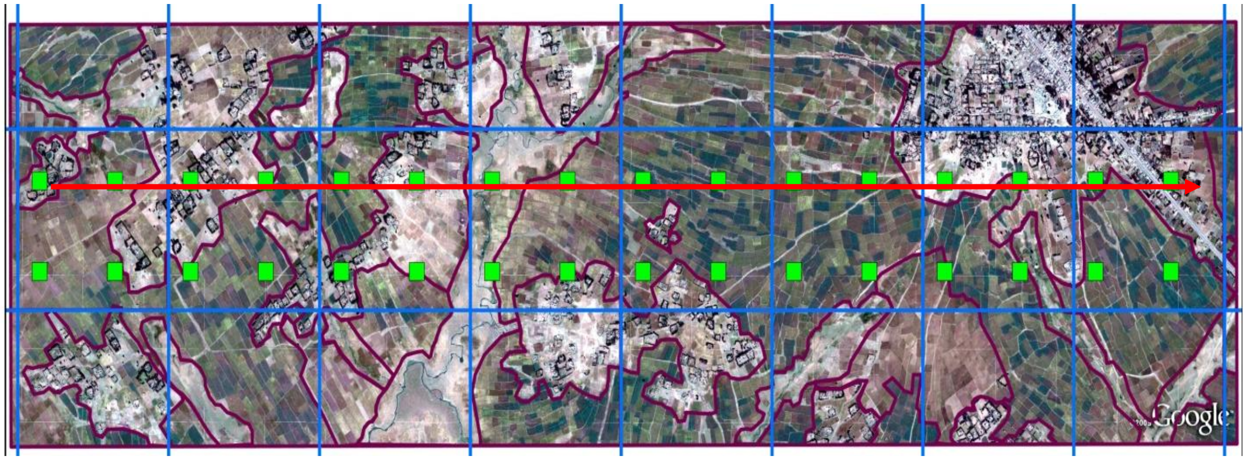


Figure 3-30 Gerbe Guracha Site Transect 5 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

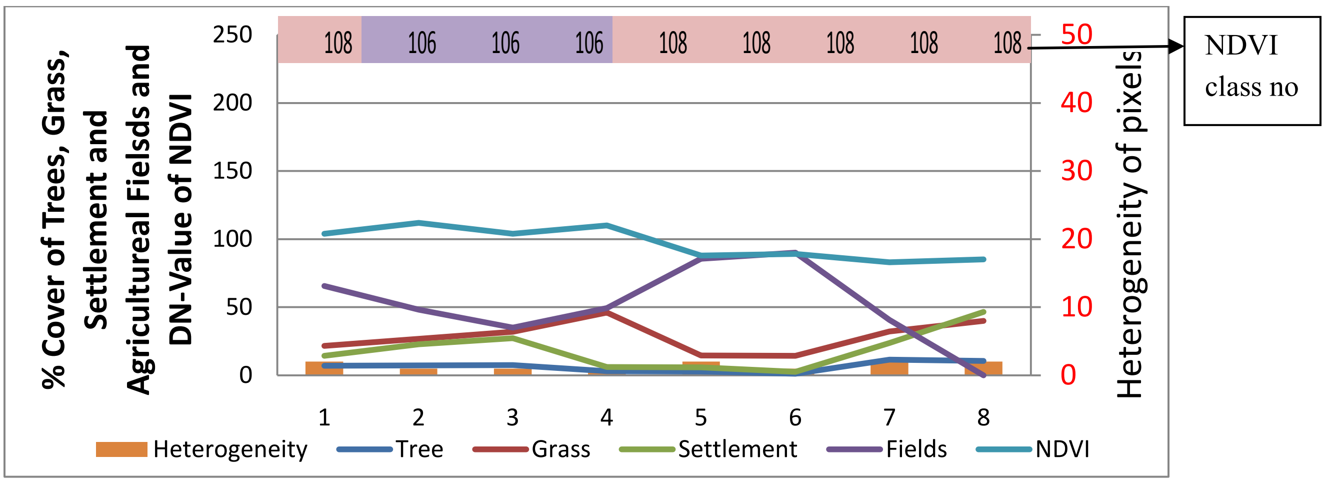


Figure 3-31 Pixel Cover %, NDIVI value and boundary heterogeneity value as well as NDVI class No. for Gerbe Guracha site transect 5

Table 3-12 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 5 of Gerbe Guracha Site (d.f.=7)

Cover Type	Tree	Grass	Settlement	Field	Average of tree & grass	Average of all covers
R square	1	2	8	2	1	5
P-Value %	80	80	50	70	80	50

To find relationship between cover percentages and heterogeneity value of pixels in transect 5 of Gerbe Guracha site regression analysis were performed for each cover percentages, average of tree and grass and overall average of cover percentages and boundary heterogeneity value of pixels. The results for all tests were shown that there were no relationship between covers and boundary heterogeneity values of the pixels of transect 5 (See Table 3-12). This implies as there is no strong boundary in transect 5.

- **Statistical analysis for Gerbe Guracha site to find significant difference between NDVI classes**

To find relationship between NDVI classes and cover percentages and to test their significant differences between each other stepwise least square dummy variable regression analyses were executed in SPSS 16.0. NDVI classes 114, 106 and 108 which are found within Gerbe Guracha site were tested. The test results for each cover percentages reported as follows:

  - **Tree cover percent as dependent variable**

Analysis to find relationship between NDVI class and their cover percentages using tree cover percent to test their differences in this site was not significant. This implies that all the NDVI classes do not have significant differences with regard to tree cover percentages.

  - **Grass cover percentage as dependent variable**

In the analysis using grass as dependent variable, it was found that NDVI class 114 was significant different from all other NDVI classes of the site having explained variability of R^2 12% (detail See Appendix E). This implies that NDVI class 114 had much more grass than others (See Table 3.13).

Table 3-13 Results of regression analysis between NDVI Classes of Gerbe Guracha Site Using Grass cover %

NDVI class	Coefficients	t	Sig.
Constant	37	17	0.000
114	11	2	0.032

  - **Settlement cover percentage as dependent variable**

Analysis was done to find relationship using settlement cover percentages and to test significant differences between NDVI classes. Results indicate that NDVI class 106 and 114 were significantly different from NDVI class 108 having explained variability of R^2 60.9% (For detail See Appendix E). This can be interpreted as NDVI class 106 has more settlement cover and NDVI class 114 has less settlement cover than NDVI class 108 (See Table 3-14).

Table 3-14 Results of regression analysis between NDVI Classes of Gerbe Guracha Site Using Settlement cover %

NDVI class	Coefficients	t	Sig.
Constant	16	4	0.000
106	27	5	0.000
114	-15	-2	0.034

- **Fields Cover percentage as dependent variable**.

Analysis was done to find significant relationship and differences between NDVI classes using fields cover percentage. NDVI class 106 and 108 were found significantly different from NDVI class 114 having explained variability of R^2 52% (for detail See Appendix E). This implies that NDVI class 106 has less agricultural field cover and NDVI class 108 has much more cover percentage than NDVI class 114 (See Table 3-15).

Table 3-15 Results of regression Analysis between NDVI Classes of Gerbe Guracha Site Using Agricultural Fields cover %

NDVI class	Coefficients	t	Sig.
Constant	50	5	0.000
106	-25	-2	0.032
108	23	2	0.041

- **Sululta Site Transects**

Annual average NDVI generated from stacked image for classes 104, 109, 114 and 132 of transect 2 of Sululta site was plotted in a graph in Figure 3-32. As seen in the graph, the gradual gradient is located between the two lines. Therefore, NDVI was extracted from no.30 which was denoted in the stacked image as 318 represented 3rd decade of January, 2007 for transect 1, 2 and 3.

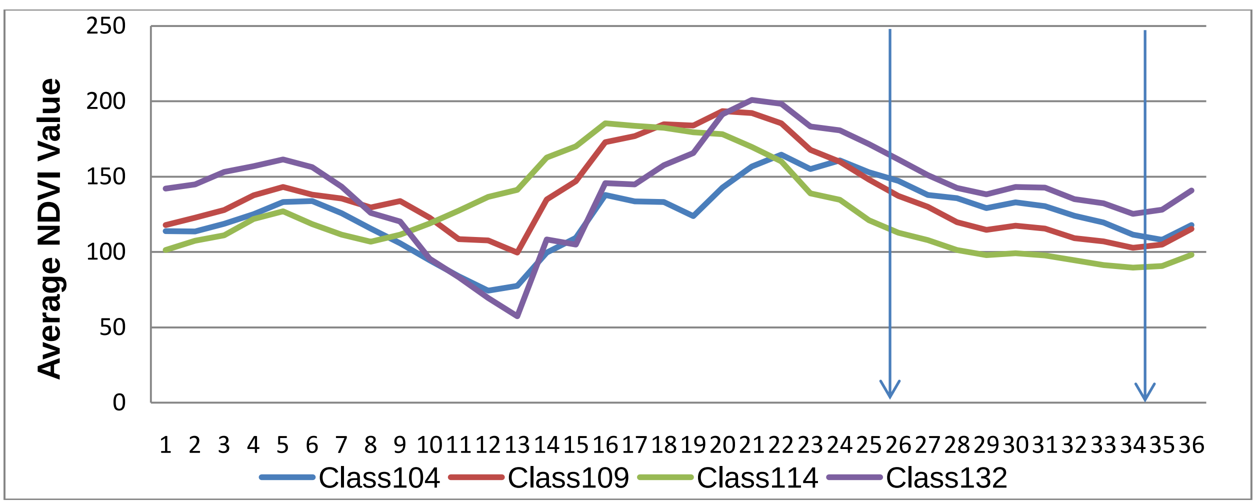


Figure 3-32 Average NDVI value generated from stacked image for classes found in Sululta site transect 1 and 2

- **Transect 1**

Based on field observation, transect starts with extensive flat area of grass and agricultural fields as well as few settlements. This was followed by an area dominated by agricultural fields. In the middle of transect, there were hills with few tree patches and settlements. Towards the end, mix of agricultural fields and grass lands near the river was the main cover. In Figure 3-33, digitized image of Sululta site transect1 was displayed. It was digitized into four classes (See Appendix C).

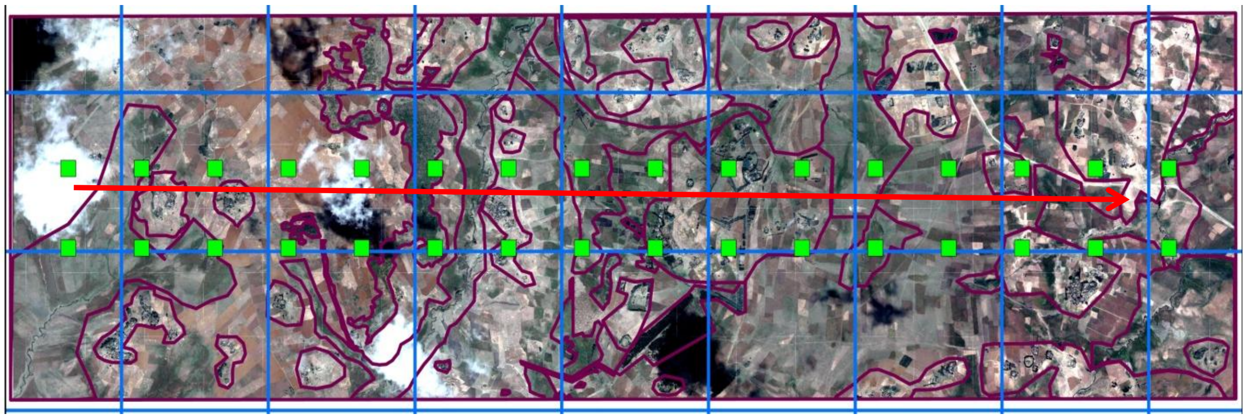


Figure 3-33 Sululta Site Transect 1 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

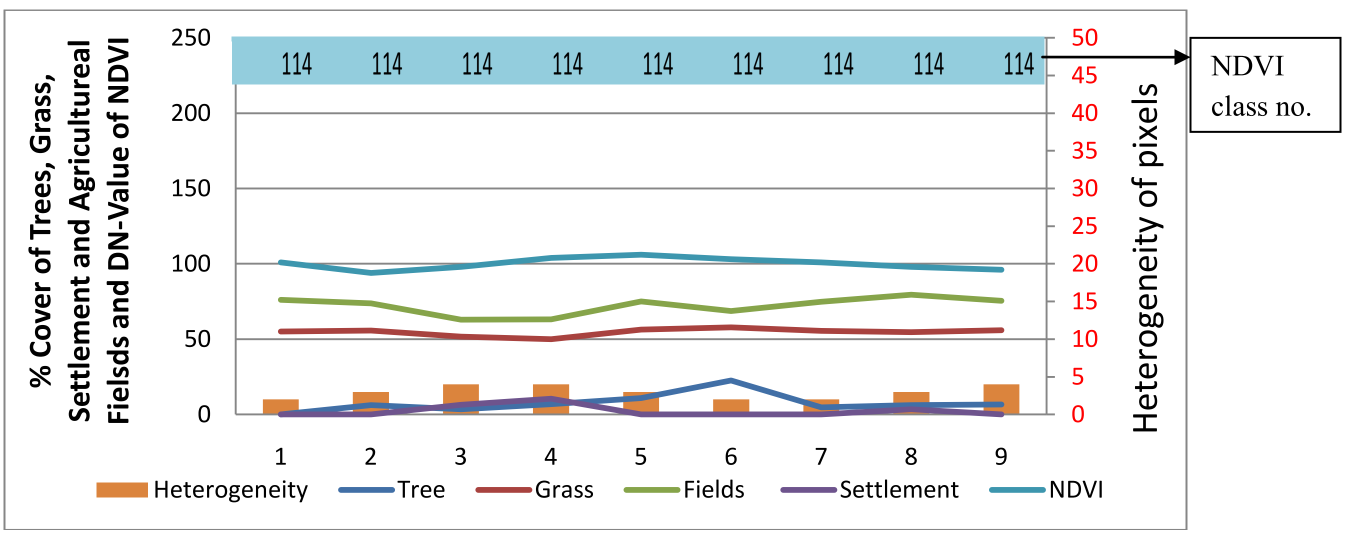


Figure 3-34 Pixel Cover %, NDIVI value (Turner and Gardner) and heterogeneity value as well as NDVI class no. for Sululta site transect 1

In Figure 3-34 cover percent, NDVI value and heterogeneity of boundaries of pixels in transect 1 of Sululta site were displayed. All the pixels are in NDVI class 114 which is characterised by high agricultural fields cover followed by grass. Tree and settlement were very low as the same time, it is characterised by very low of boundary heterogeneity value (See Appendix B).

To find relationship between cover percentages of transects and heterogeneity value of pixels and to analyse the boundary strength, linear regression analysis was executed for each cover percentages, average cover percentages of tree, grass and agricultural fields and heterogeneity value of boundaries of pixels of Sululta site transect 1. Grass, fields, bare land cover and mean of tree, grass and field covers were significantly related to the heterogeneity value of boundaries of pixels (See Table 3-16). Result of regression analysis for agricultural fields and boundary heterogeneity was displayed in Figure 3-35.

Table 3-16 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 1 of Sululta Site (d.f.=8)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field cover %	Average of all cover %
R square	2	**47**	**50**	**46**	11	**44**	30
P-Value %	70	**4**	**3**	**4**	39	**5**	13

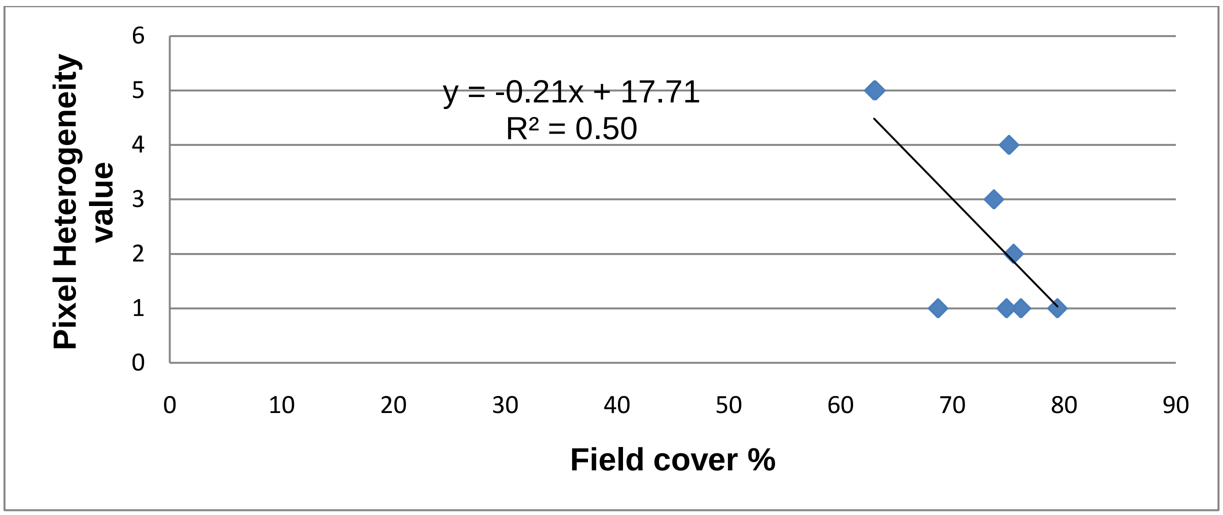


Figure 3-35 Result of regression between cover percentages of agricultural fields and boundary heterogeneity value of pixels in transect 1 of Sululta site

- **Transect 2**

Based on field observation, transect starts with extensive marsh grass land by crossing largest river of the area. This was followed by hill that is covered by agricultural fields, few trees and settlements. Towards the end, forest was the dominant cover. Digitized Google image of transect 2 in Sululta site was shown in Figure 3-36. It was digitized into five classes (See Appendix C).

In Figure 3-37, cover percentage, NDVI value and boundary heterogeneity value were exhibited for Sululta site transect 2A. The first six pixels were in the NDVI class 114 and dominated by grass and fields followed by bare land. Whereas the last two pixels in NDVI class 109 were dominated by tree cover. The peak in NDVI value and heterogeneity of boundaries value were supported by high peak in trees cover and decreasing in agricultural fields, bare land and grass cover percentages (See Appendix B).

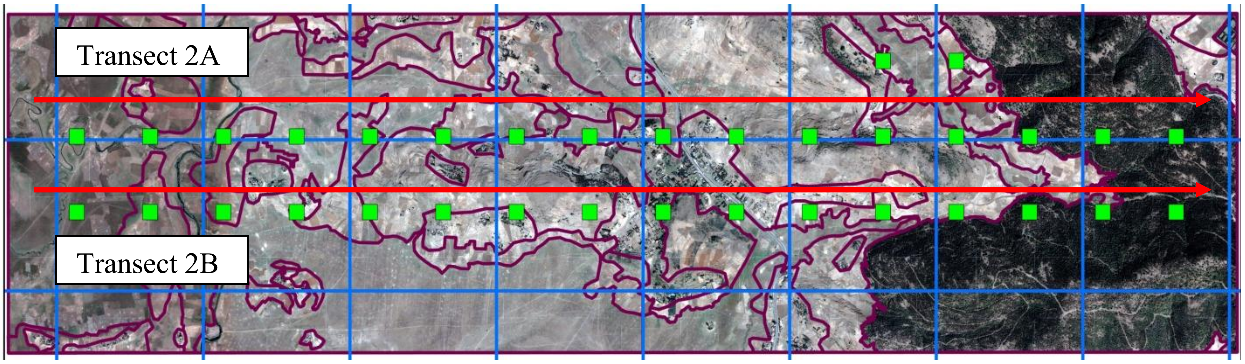


Figure 3-36 **Sululta Site Transect 2 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites**

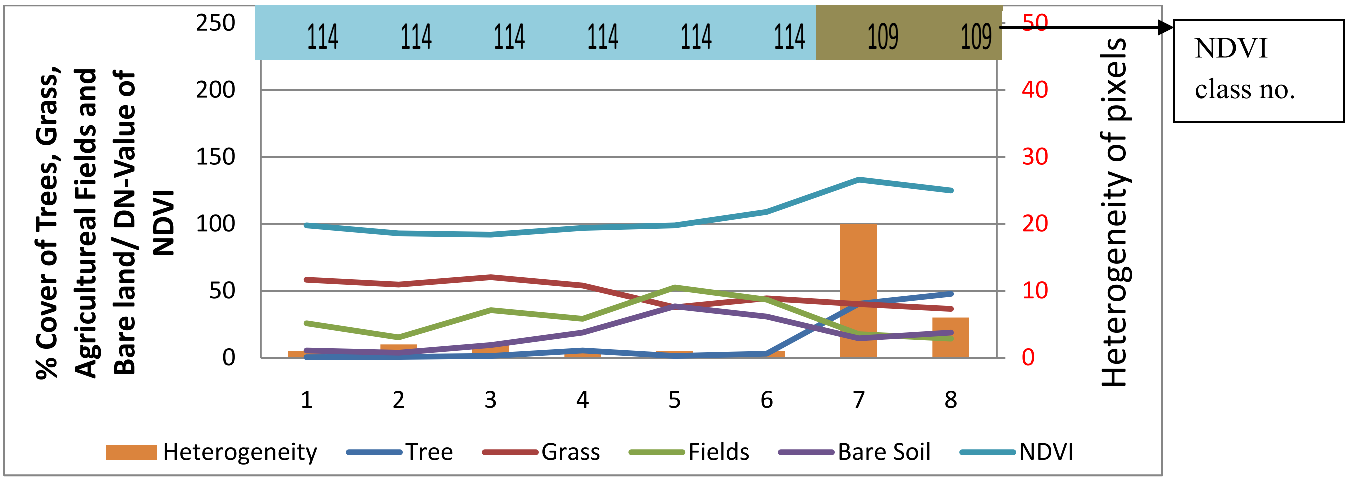


Figure 3-37 **Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class No. for Sululta site transect 2A**

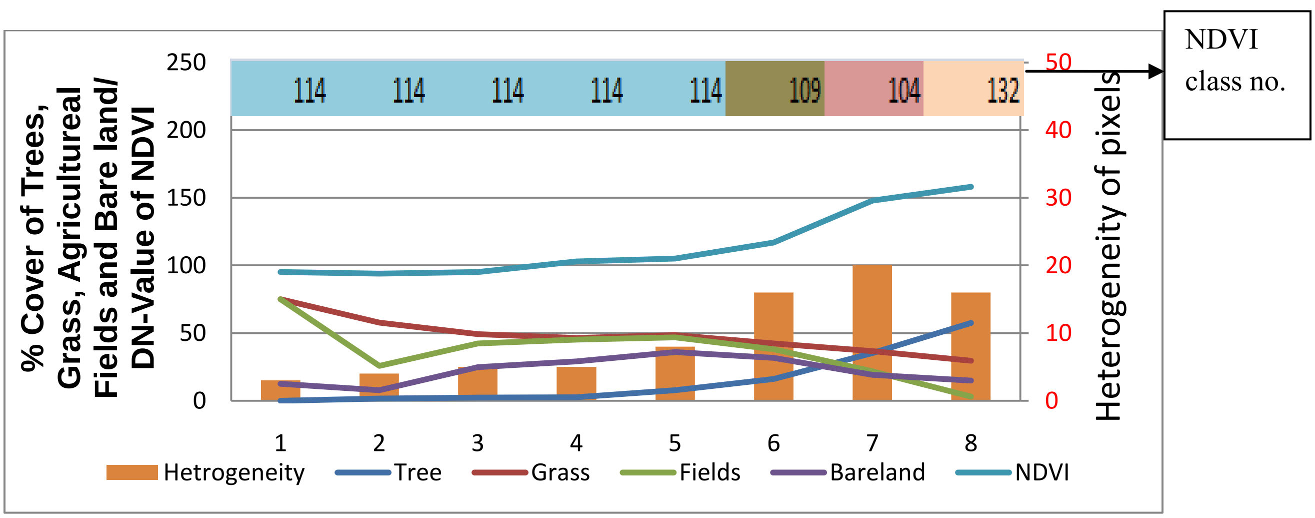


Figure 3-38 **Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class No. for Sululta site transect 2B**

Figure 3-38 shows pixel cover %, NDVI value, boundary heterogeneity and NDVI class of transect 2B in Sululta site. Pixels from 1 up to 5 were in NDVI class 114 which were dominated by grass followed by agricultural fields. Pixel 6 which is in NDVI class 109 and pixel 7 which is in NDVI class 104 were characterised by increase in tree cover but decrease in grass, field and bare land covers. Pixel 8 which is in NDVI class 132 was characterised by tree cover. The high peak in NDVI from class 109 to NDVI class 104 was supported by increasing in cover of trees. This peak supports the hard or strong boundary between classes which indicated by high heterogeneity value of the pixels (See Appendix B)..

To test significance relationship and to find the boundary strength regression analysis were performed for each cover percentages and boundaries heterogeneity value of transect 2A (See Table 3-17). Tree cover percentages were significantly related with boundaries heterogeneity value of pixels (See Figure3.38). It implies that differences in heterogeneity value in pixels have significant relation with differences in tree cover of the pixels in transect 2A which approves the presence of strong boundary between NDVI classes (NDVI class 114, 109, 104 and 132).

Table 3-17 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 2A of Sululta Site (d.f.=7)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**56**	34	13	1	35	19	8
P-Value %	**3**	13	37	84	12	28	50

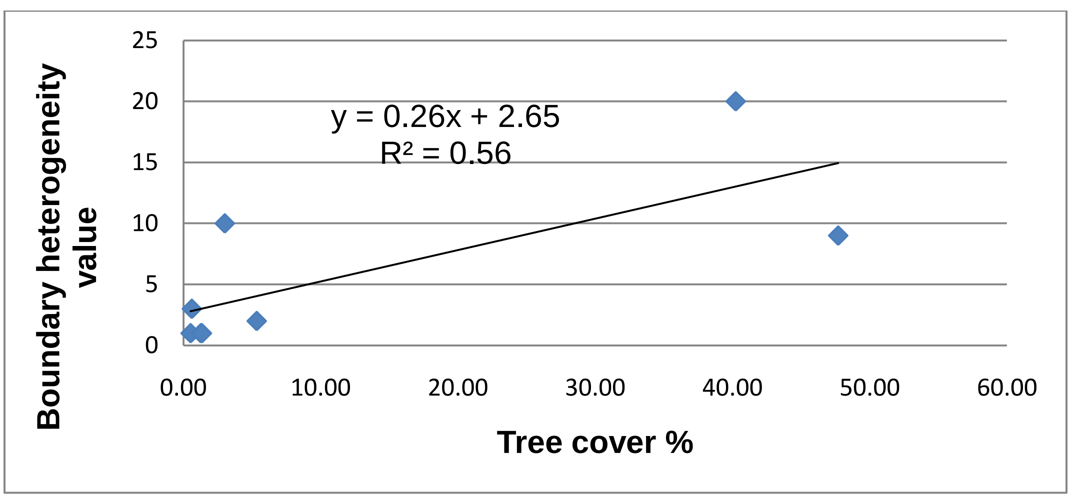


Figure 3-39 Result of regression analysis between tree cover % and boundary heterogeneity value in transect 2A of Sululta site

To test strength of boundaries of pixels in transect 2A of Sululta site, regression analysis was performed for NDVI class differences in pixels and pixels boundary heterogeneity value. As seen in Figure 3-40, NDVI class differences in pixels were significantly correlated with pixels boundary heterogeneity value. Explained variability was 69% f (1, 7) =13.48 (P<0.05).

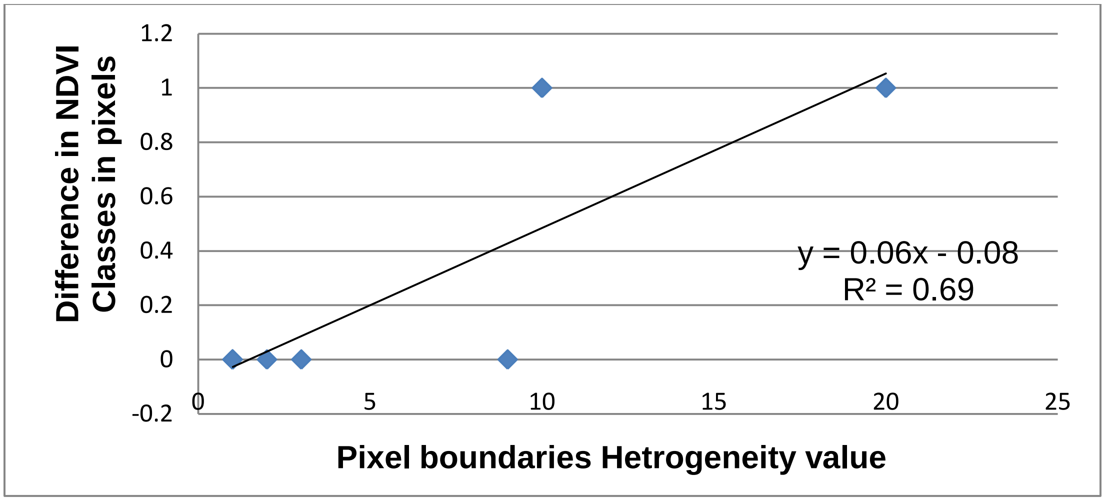


Figure 3-40 Result of regression analysis between boundary heterogeneity value and difference of NDVI class in pixels in transect 2A of Sululta site

To find significant relationship between cover percentages and heterogeneity value of pixels to test strength of boundary between NDVI classes, regression analysis was carrying out in transect 2B (See Table 3-18). Tree and grass cover percentages were significantly related to heterogeneity value of boundaries of the pixels (See Figure 3-41). This implies there is strong boundary between NDVI classes in transect 2B.

Table 3-18 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 2B of Sululta Site (d.f.=7)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**67**	**61**	41	2	22	13	8
P-Value %	**1**	**2**	8	76	24	38	49

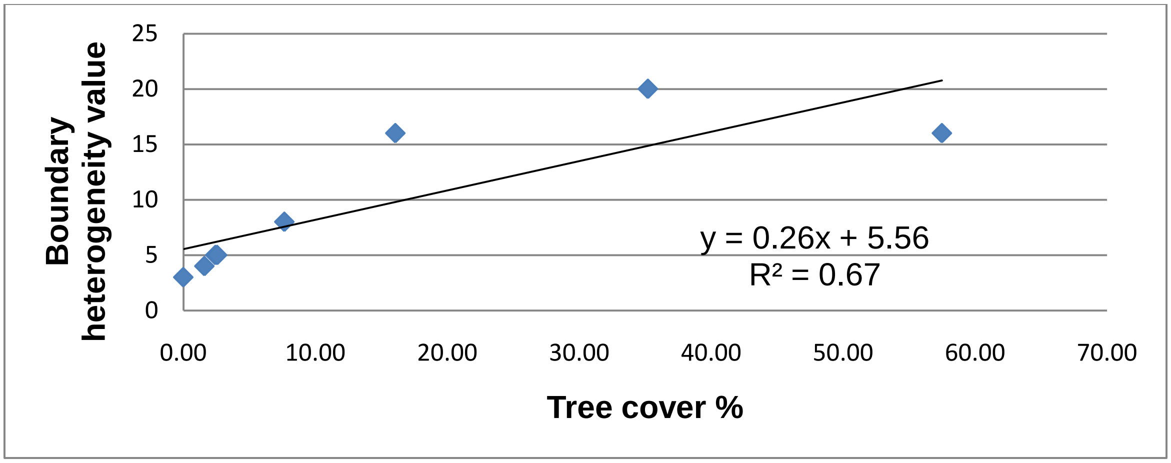


Figure 3-41 Result of Regression analysis between boundary heterogeneity value and tree cover percentages in transect 2B of Sululta site

Analysis was also performed to find relationship between if different NDVI class in pixels and heterogeneity value of pixels in transect 2B. Difference or change in NDVI class was related significantly with heterogeneity of boundary having explained variability 86%, $f_{(1, 7)} = 36$ and ($P < 0.05$). This implies that changes of NDVI class in pixels associates with significant change in heterogeneity value of pixels, which is an indication of strong boundary (See Figure 3-42).

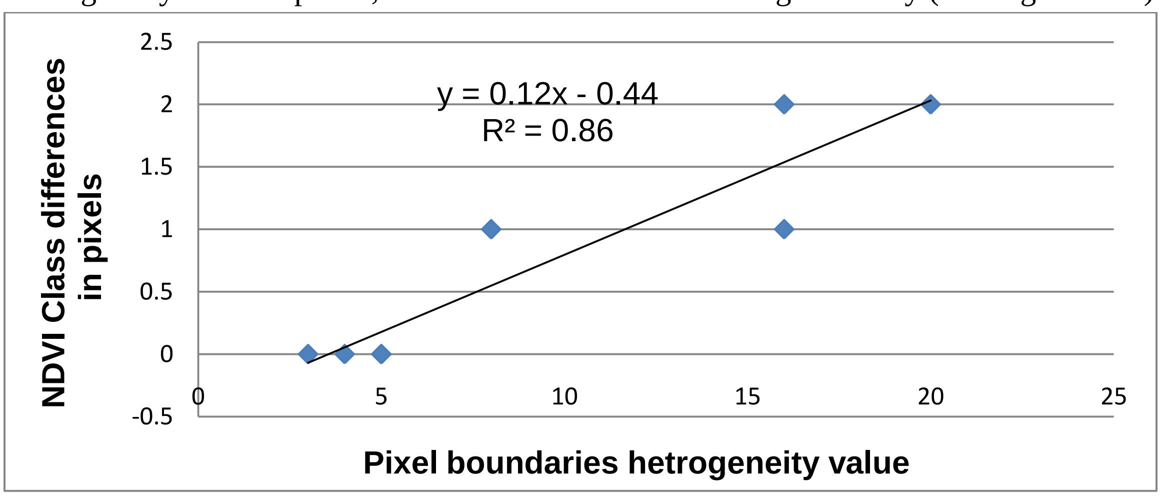


Figure 3-42 Result of regression analysis between boundary heterogeneity value and NDVI class difference in pixels in transect 2B of Sululta site

➢ **Transect 3**

From field observation, transect started with relatively flat area covered by grass and this was followed by small hills with few settlements and extensive grass and agricultural fields. In the middle, there was few tree cover associated with agricultural fields. This also followed with extensive grass covered area. At the end there was a mix of all kind of cover including forest. Figure 3-43 was displayed digitized Google image of transect 3. It was digitized in to six classes (See Appendix C). Red line in the image indicates line and direction of transect.

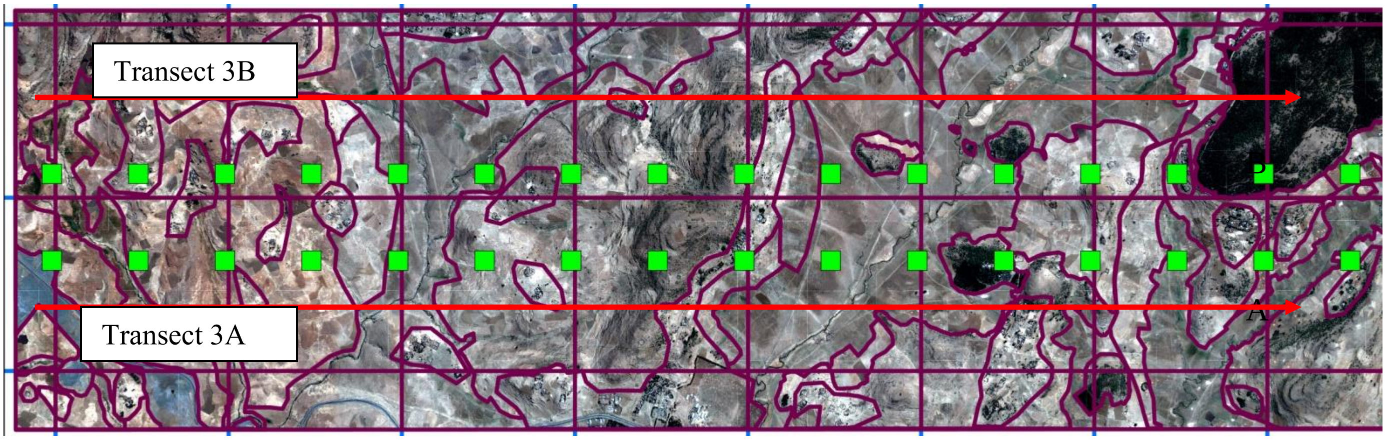


Figure 3-43 Sululta Site Transect 3 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers: ■ are the sample sites

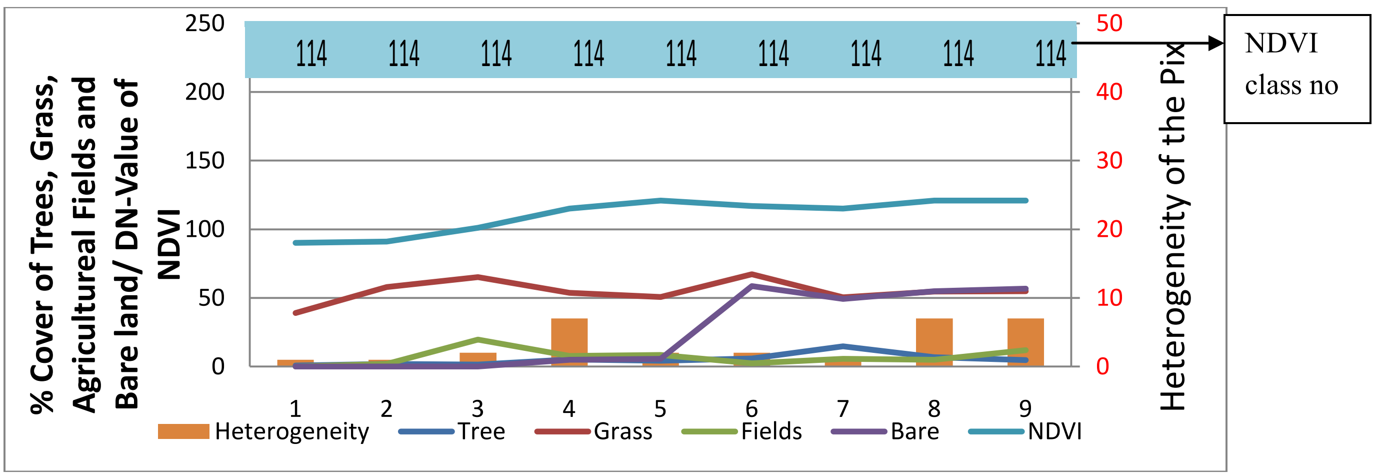


Figure 3-44 Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class no. for Sululta site transect 3A

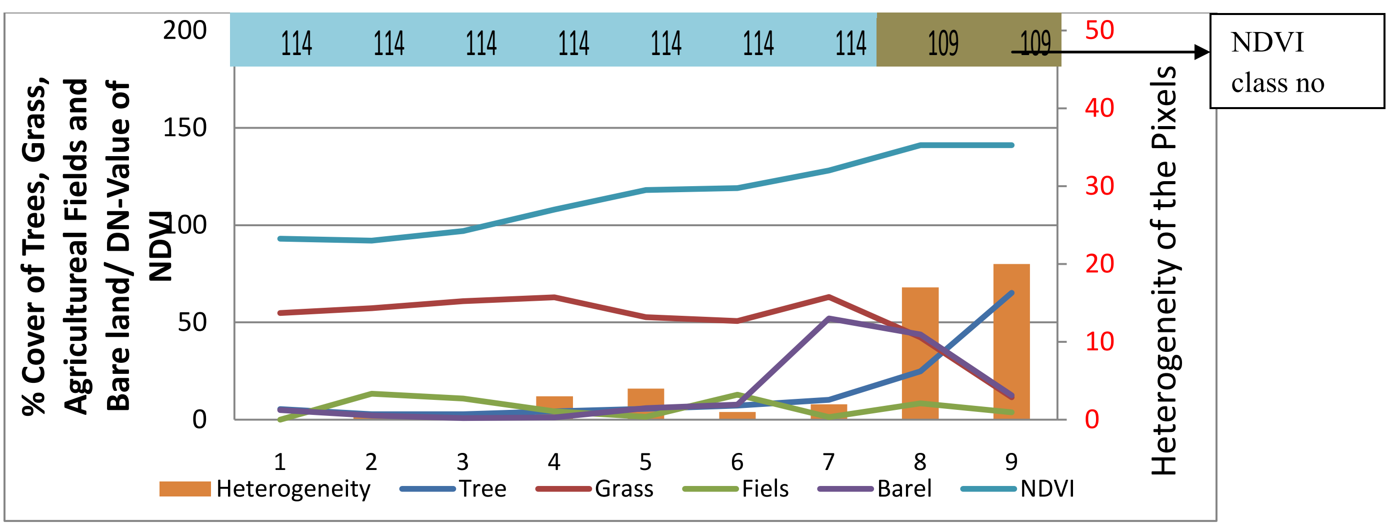


Figure 3-45 Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class no. for Sululta site transect 3B

In Figure 3-44, cover percent per each type, NDVI value and boundary heterogeneity value of all pixels of transect 3A of Sululta site were indicated. All the pixels of transect were in NDVI class 114. It was dominated only by grass cover until the fifth pixel, but followed by bare soil getting high with grass. Agricultural fields and tree cover remained very small in the whole transect (See Appendix B).

In Figure 3-45, each cover percent, NDVI value and boundary heterogeneity of pixels in transect 3B of Sululta site were exhibited. The first seven pixels of transect which are in NDVI class 114 were covered by high grass, but at the end bare land gets as high as grass. The tree cover suddenly gets higher in the pixel 8 which is found in NDVI class 109. This change was conceding with increase in NDVI value, decrease in grass and bare land covers and increase in pixel heterogeneity value which approves the hard or strong boundary between classes (NDVI class 114 and 109) in the transect (See Appendix B).

To find and test significant relationship between cover percentages and heterogeneity value of pixels regression analyses were executed for each cover percentages and boundaries heterogeneity value of pixels in transect 3A. The results of all analysis were not significant (See Table 3-19). This implies that in this transect there is no strong boundary.

Table 3-19 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 3A of Sululta Site (d.f.=8)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	0	0	6	13	1	3	13
P-Value %	88	87	53	33	83	65	34

To assess strong boundary analysis was performed to find relationship between cover percentages and heterogeneity value of pixels in transect 3B of Sululta site (See Table 3-20). As it was shown in Figure 3-46, heterogeneity value significantly related with tree cover percentages. This implies the change in tree concedes with change in heterogeneity value in pixels and approves the strong boundary in transect 3B between NDVI classes.

Table 3-20 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 3B of Sululta Site (d.f. =8)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**81**	**75**	1	13	40	30	23
P-Value %	**0**	**0**	81	33	6	12	19

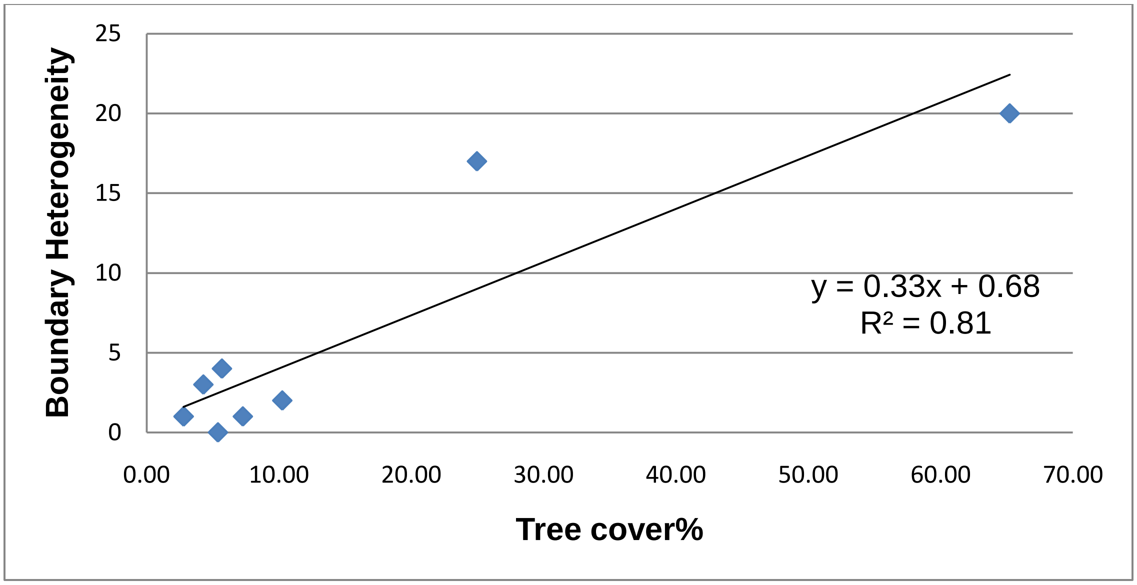


Figure 3-46 Result of Regression analysis between boundary heterogeneity value and tree cover % in transect 3B Sululta site

Analysis was also carried out for differences in NDVI class in pixels and boundary heterogeneity value of pixels in the transect 3B. As seen in Figure 3-47, boundary heterogeneity was significantly related with differences in NDVI classes in pixels having explaining variability of (R square) 55%, $f_{(1,8)}$ =9.11 and P-value< 0.05. This implies change in NDVI is significantly affected by change in heterogeneity value of pixels in transect 3B. Therefore, there is strong boundary between the NDVI classes with in transect 3B.

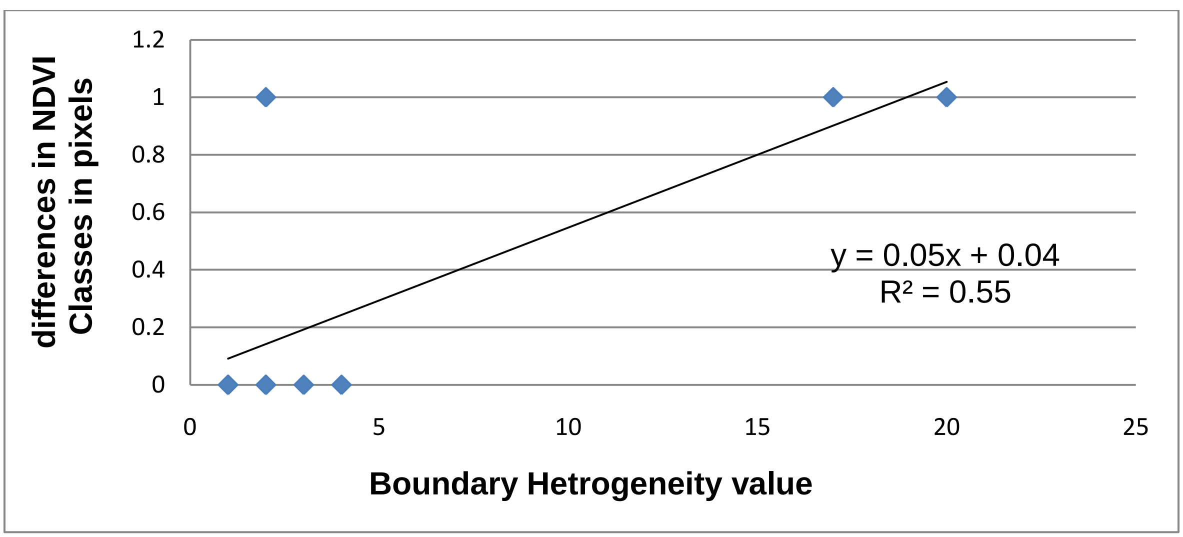


Figure 3-47 Result of Regression analysis between boundary heterogeneity value and difference in NDVI class in transect 3B of Sululta site

- **Transect 4**

Figure 3-48 shows, annual average NDVI generated from stacked image for classes 107, 109, 114, 125 and 127 of transect 4 of Sululta site. As seen in the graph, the gradual gradient is located between the two lines. Therefore, NDVI was extracted from no.27 which was denoted in the stacked image as 315 represented 2nd decade of December, 2006 for transect 4.

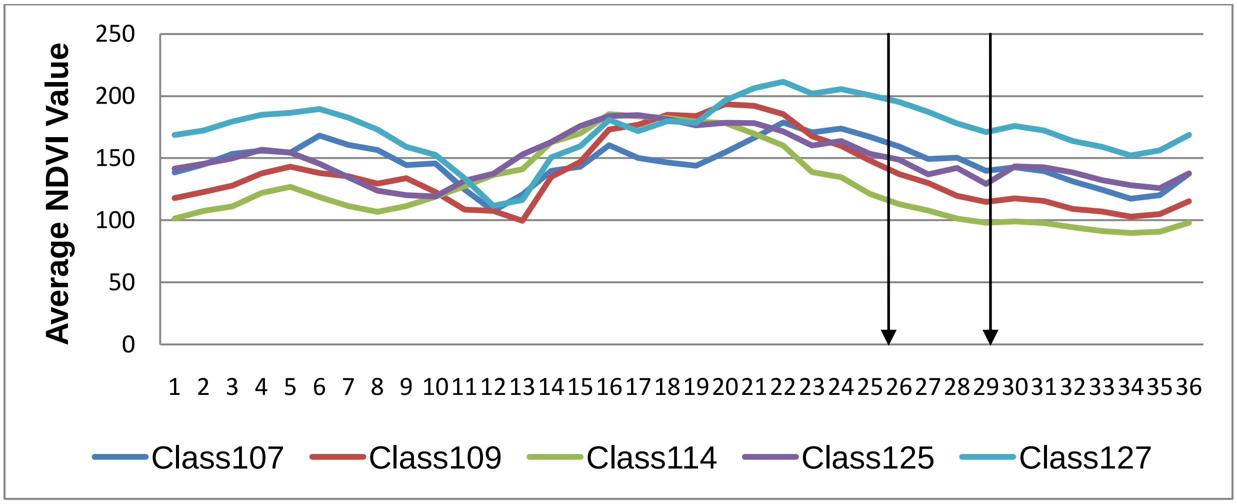


Figure 3-48 Average NDVI value generated from stacked image for classes found in Sululta site transect 4

Based on field observation, transect 4 of Sululta site started with vast marsh area with grass followed by agricultural fields and few settlements in addition to grass lands. In the middle, there were forest patch of Eucalyptus trees. At the end, there was a forest of Eucalyptus and Podocarpus gracilior tree. In Figure 3-49, digitized Google image of Sululta site transect 4 was displayed. It was digitized in to five classes (See Appendix C). Red line in the digitized image represented line and direction of transects.

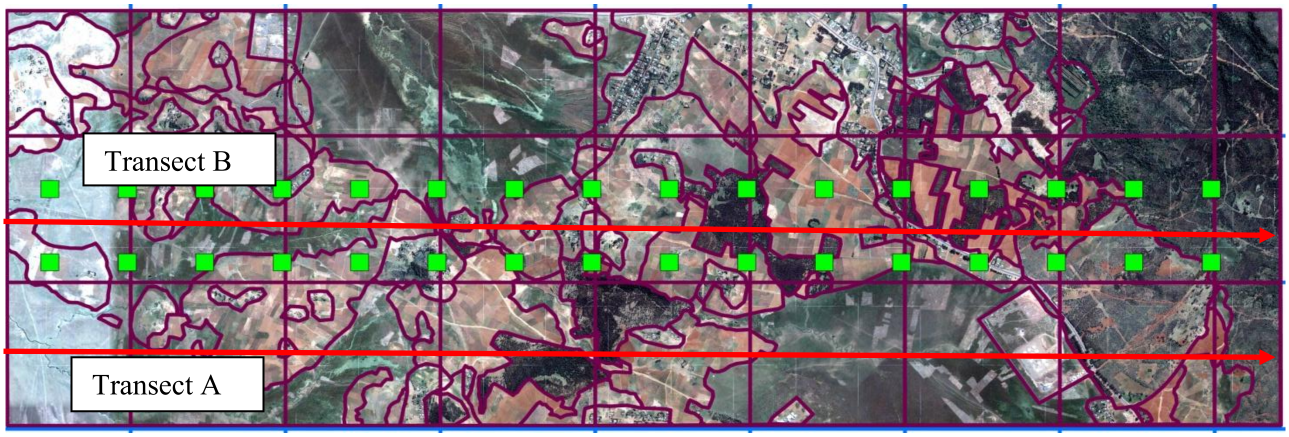


Figure 3-49 Sululta Site Transect 4 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers: ■ are the sample sites

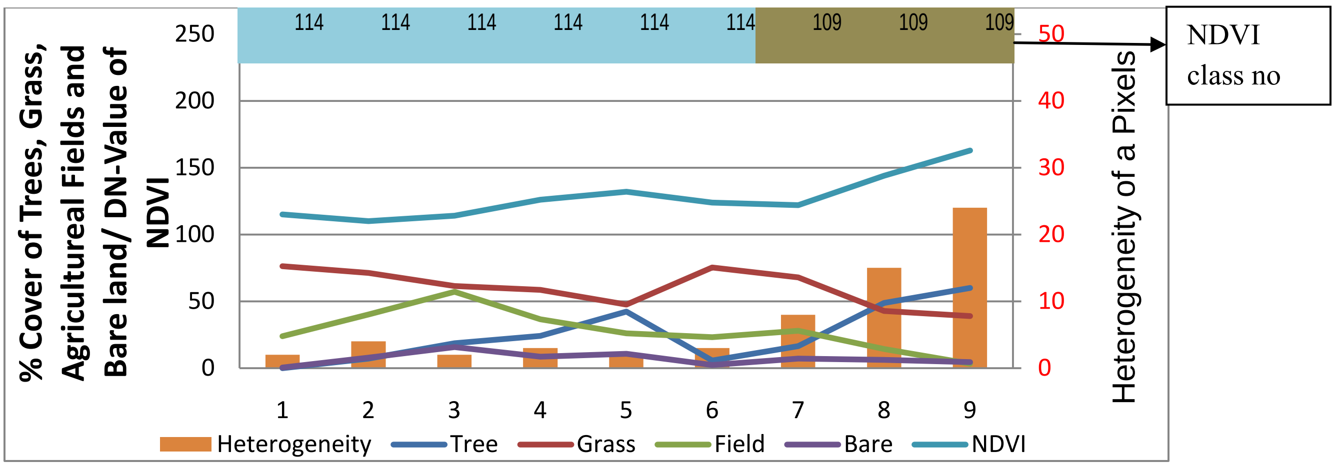


Figure 3-50 Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class no. for Sululta site transect 4A

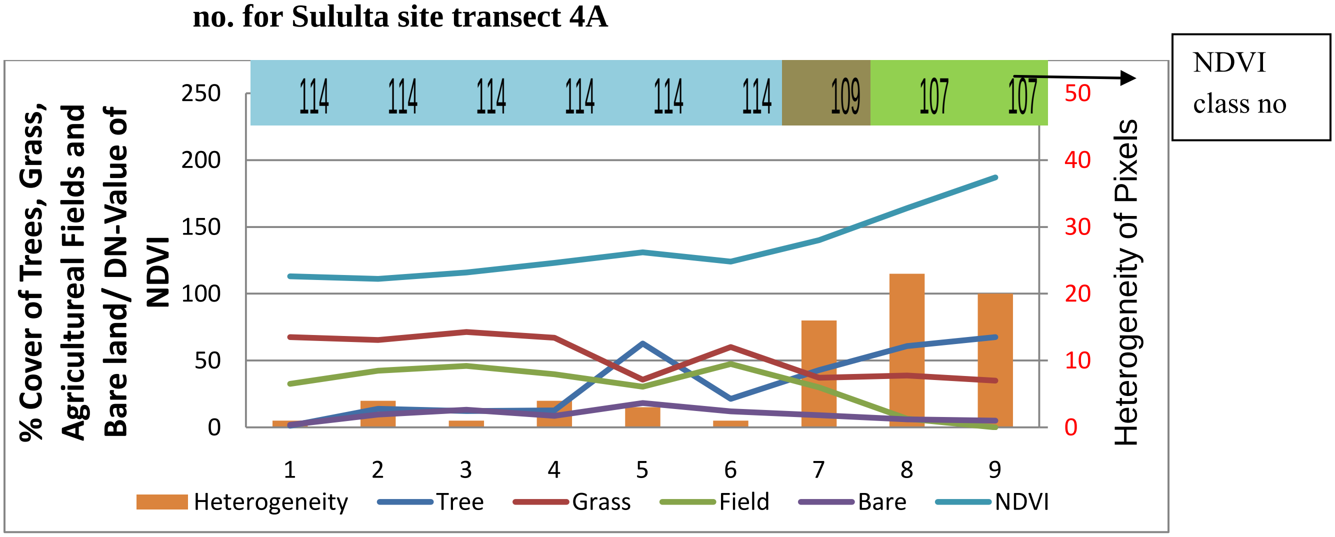


Figure 3-51 Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class No. for Sululta site transect 4B

In Figure 3-50, pixel cover %, NDVI and heterogeneity value of transect 4A in Sululta site were displayed. The first six pixels which are in NDVI class 114 were dominated by grass cover followed by agricultural fields. Whereas pixels from seven up to the end, which are in NDVI class 109 and 107 were dominated by tree cover. This situation supported by an increase in NDVI (DN) and heterogeneity value of these pixels, which is an indication of strong boundary (See Appendix B).

In Figure 3-51, each of cover percentages, NDVI value and heterogeneity value of pixels of transect 4B within Sululta site were displayed. Pixels starting from one up to the six dominated by grass cover followed by fields. This was associated with low heterogeneity and NDVI value for these pixels, but after the fifth pixel heterogeneity and DN value gets higher. This is also associated with high value for tree cover in the last two pixels of transect. Pixels with in NDVI class 109 were dominated by tree cover (See Appendix B).

To find significant relationship and to assess strong boundary between NDVI classes or map units analysis was performed for each cover type percentages and boundary heterogeneity of pixel in transect 4A. Tree, agricultural fields and average of tree and grass cover percentages were significantly related with boundary heterogeneity. Results for other tests were not significant (See Table 3-21). The significant relationship between tree cover percentage and heterogeneity value approves the existence of strong boundary between NDVI classes in transect 4A (see Figure 3-52).

Table 3-21 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 4A of Sululta Site (d.f. = 8)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**90**	46	62	22	**76**	20	8
P-Value %	**0**	6	2	24	**0**	26	49

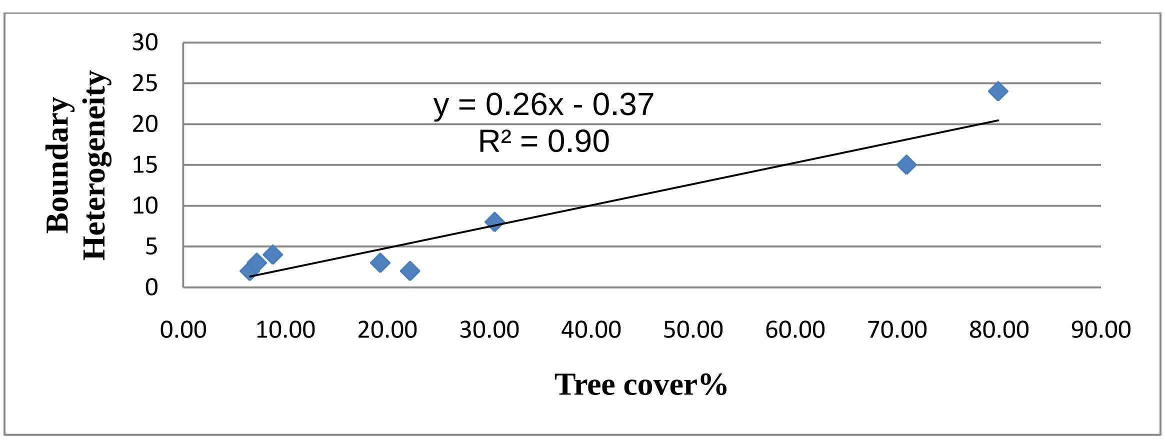


Figure 3-52 Result of Regression analysis between boundary heterogeneity value and Tree cover % in transect 4A of Sululta site

To find significant relationship between cover percentages and heterogeneity value of pixels to test the boundary strength regression analysis was performed for each cover type percentages and boundary heterogeneity of pixels in transect 4B of Sululta site. All cover types percent were significantly related with boundary heterogeneity (See Figure 3.53). The significant relationship between tree cover and heterogeneity value of pixels approves presence of strong boundary between the NDVI classes in transect 4B (see Table 3-22).

Table 3-22 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 4B of Sululta Site (d.f. =8)

Cover Type	Tree	Grass	Field	Bare land	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**60**	**52**	**82**	**54**	19	13	29
P-Value	**2**	**4**	**0**	**4**	28	38	16

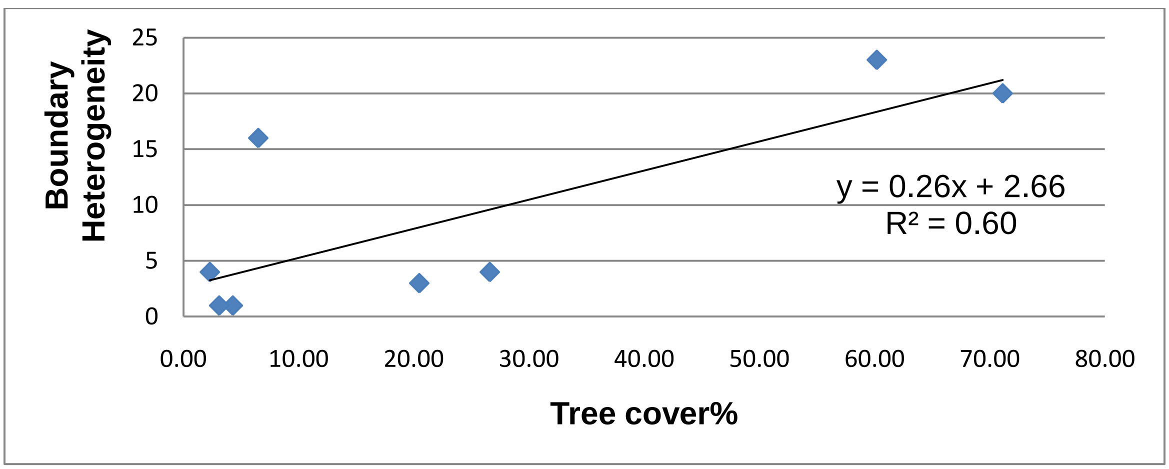


Figure 3-53 Result of regression analysis between boundary heterogeneity value and Tree cover % in transect 4B of Sululta site

To assess strength of boundary regression analysis was carried out for difference in NDVI classes in pixels and boundary heterogeneity values of pixels in transect 4A and 4B of Sululta site. Difference in NDVI classes of pixels and boundary heterogeneity value of pixels were significantly related having explained variability of 63% $f_{(1,7)}$ =10.06 P-value<0.05 for transect 4A and 55% $f_{(1,7)}$ =7.19 P-value<0.05 for transect 4B respectively (see Figure 3-55 and 3-56). This implies there is strong boundary between NDVI classes in transect 4B.

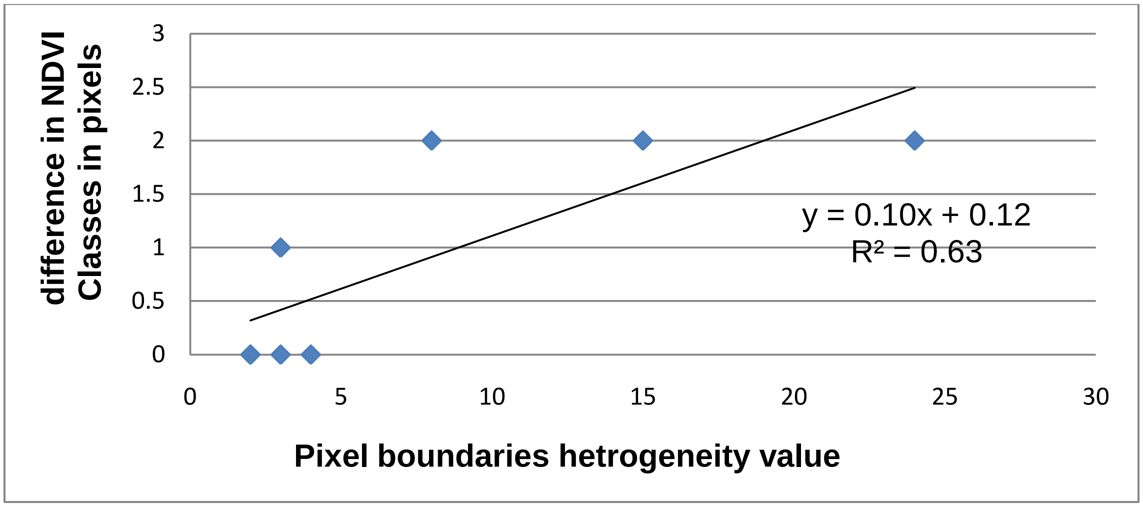


Figure 3-54 **Result of regression analysis between boundary heterogeneity value and difference of NDVI class in transect 4A of Sululta site**

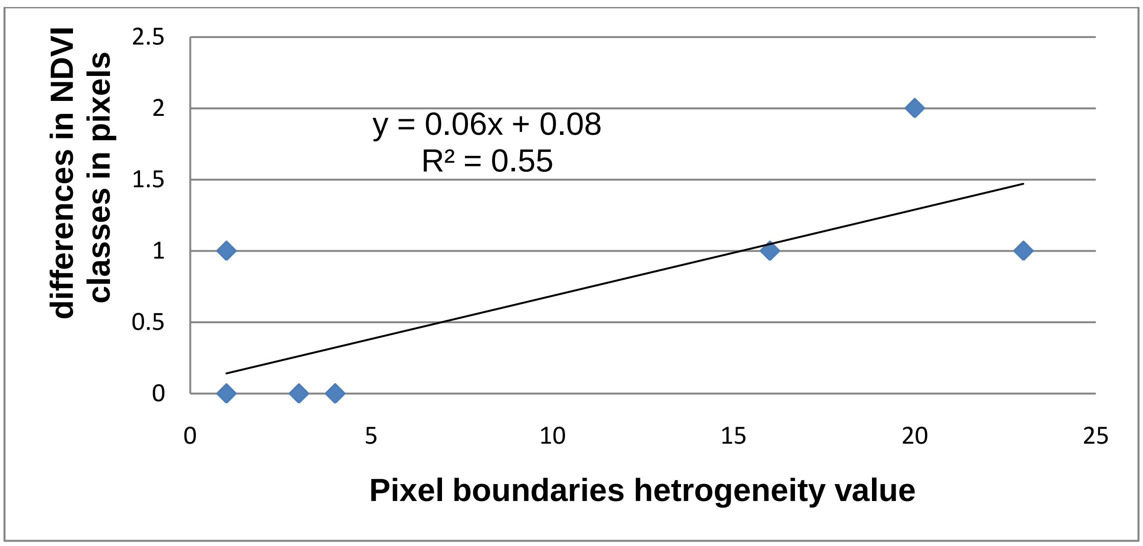


Figure 3-55 **Result of regression analysis between boundary heterogeneity value and difference in NDVI class in transect 4B of Sululta site**

- **Transect 5**

Figure 3-56 displays Average NDVI values generated from stacked image for classes 109, 103, 114 and 98 of transect 5 of Sululta Site. The gradual gradient indicated between two lines in the graph was an area of clear variation of the NDVI classes. Therefore, NDVI was extracted from the 8th which was denoted as 296 layer in the stacked image, represents 1st decade of June, 2006 image layer.

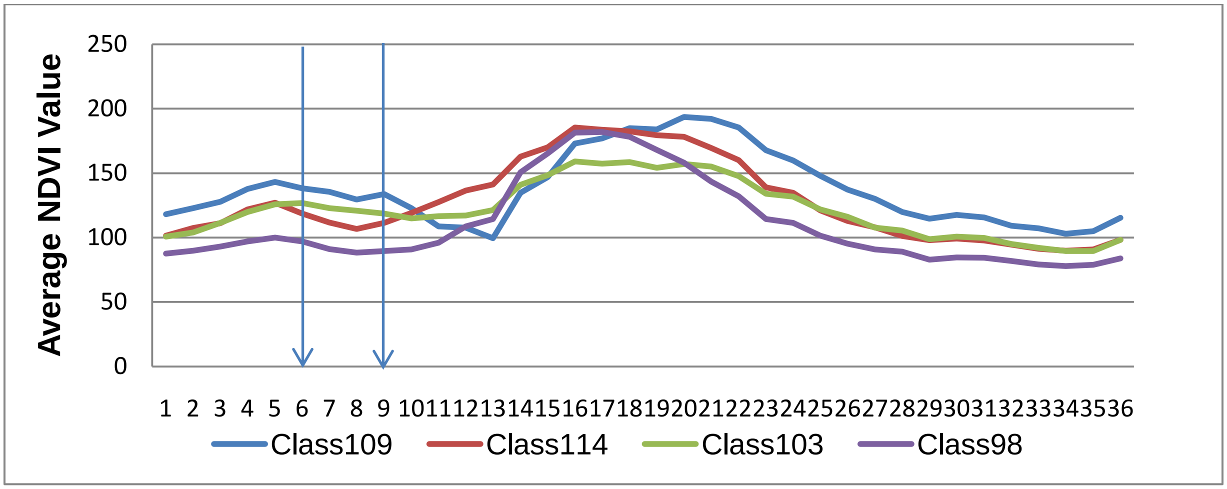


Figure 3-56 Average NDVI value generated from stacked image for classes found in Selale site transect 5

Based on field work observation, transect 5 of Sululta site started from the top of the mountain which was covered by forest of Eucalyptus and Podocarpus gracilior. From the middle up to the end, the area was getting flat and it was covered by grass and agricultural fields. Figure 3-57 displays Google image of transect 5 of Sululta site. It was digitized into 4 classes (See Appendix C). Red lines within the image indicated the line and direction of transects.

Cover percentages, NDVI DN value and heterogeneity of transect 5A was plotted in Figure 3-58. The first four pixels of transect was dominated by high cover of tree. This was supported by high value of NDVI and heterogeneity value of the pixels. The last pixels were dominated by agricultural field followed by grass cover associated with low NDVI value and heterogeneity value in comparison with the first pixels (See Appendix B)..

In Figure 3-59, each type of cover percentages, NDVI and heterogeneity values of pixels in transect 5B of Sululta site were exhibited. Tree and grass cover percentages were higher in the first 5 pixels which are in NDVI class 109, 103 and 98 but, whereas agricultural fields was much higher in the rest pixels in NDVI class 114 (See Appendix B)..

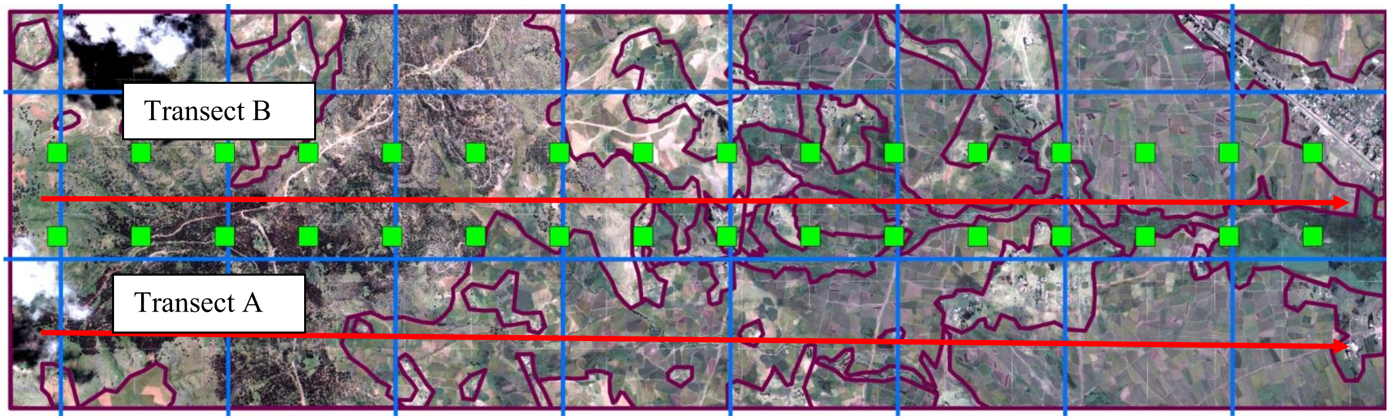


Figure 3-57 Sululta Site Transect 5 digitized high resolution image (2m), with in boundaries of NDVI pixel (1X1km) input layers; ■ are the sample sites

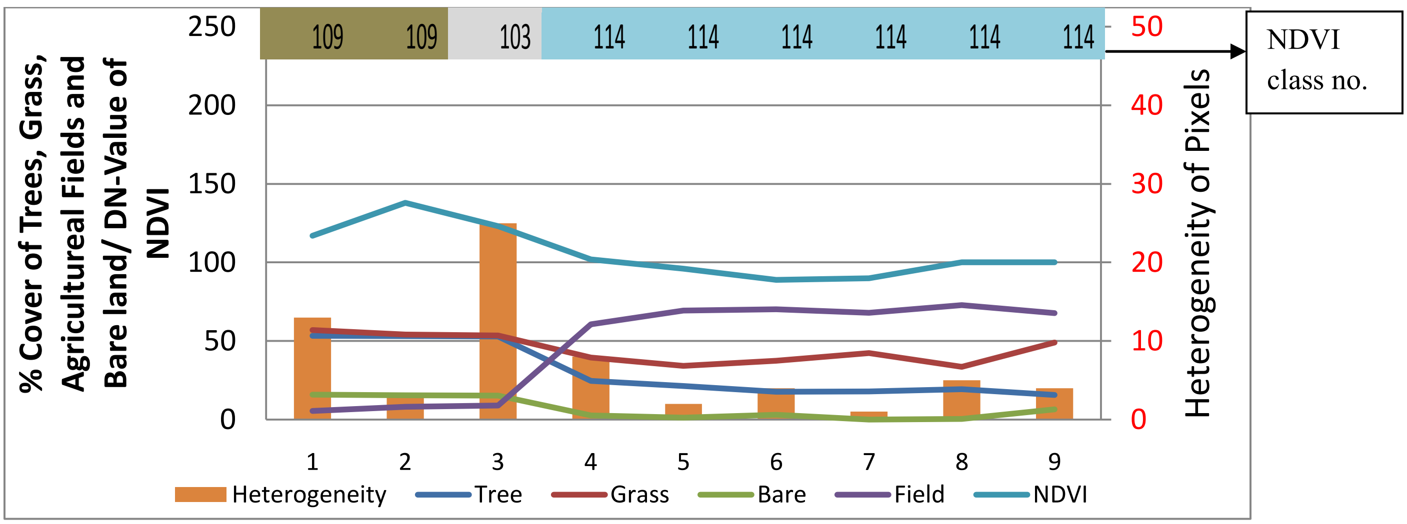


Figure 3-58 **Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class No. for Sululta site transect 5A**

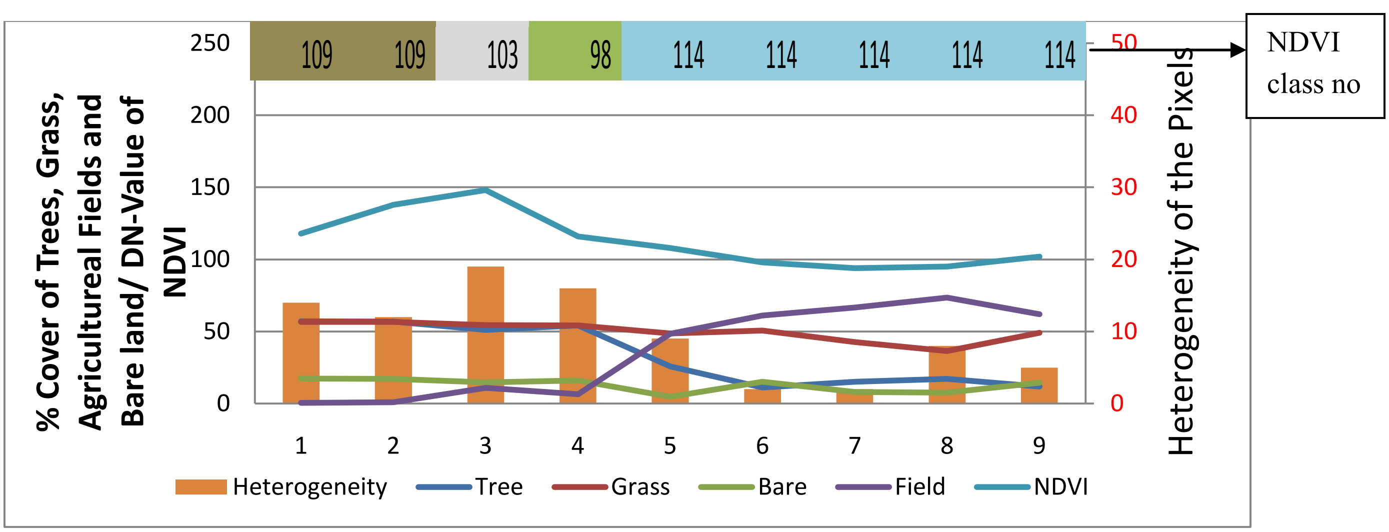


Figure 3-59 **Pixel Cover %, NDIVI value and heterogeneity value as well as NDVI class No. for Sululta site transect 5B**

To find relationship between cover percentages and heterogeneity value analyses were performed for each type of cover percentages and boundary heterogeneity of pixel in transect 5A of Sululta site to test boundary strength. All analyses of cover percentages were significant (see Table 3.25). The significant relationship between tree cover and heterogeneity value of pixels approves the strong boundary between NDVI classes in transect (See Figure 3-60).

Table 3-23 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 5A of Sululta Site (d.f.=8)

Cover Type	Tree	Grass	Bare land	Field	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**93**	**54**	**76**	**90**	**86**	**89**	0
P-Value	**0**	**2**	**0**	**0**	**0**	**0**	90

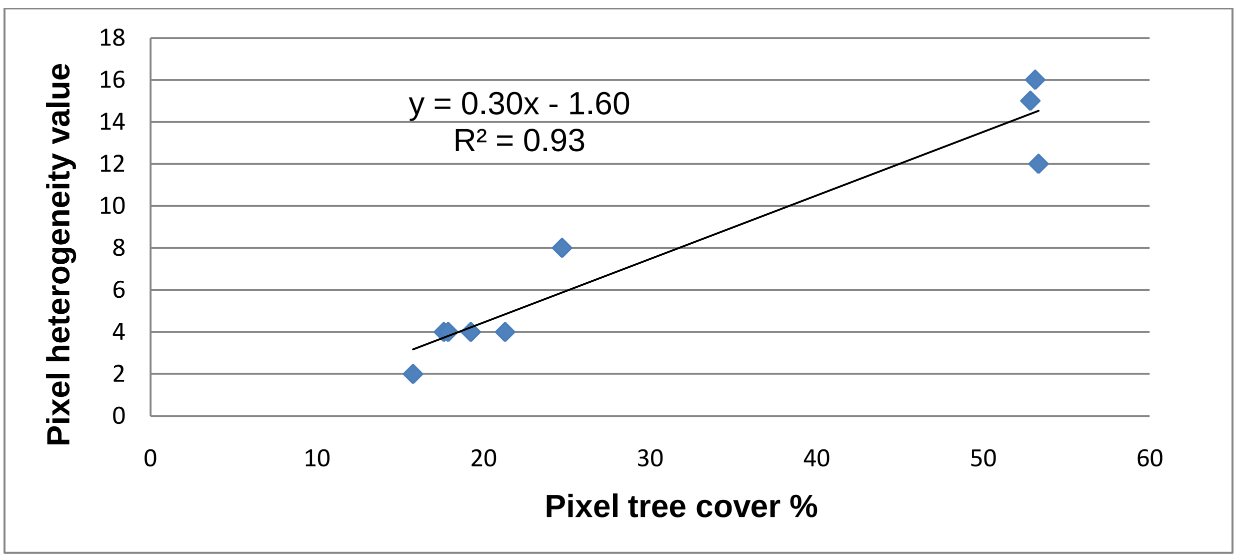


Figure 3-60 Result of correlation analysis between boundary heterogeneity value and Tree cover % in transect 5A of Sululta site

To find significant relationship between cover percentages and heterogeneity value of pixels and to assess boundary strength between NDVI classes in transect 5B regression analysis was carried out (see Table 3.26). All analyses were significant with except that bare land and average of all covers (see Figure 3.). The significant relationship between tree cover and heterogeneity value approves the existence of strong boundary between the NDVI classes in transect.

Table 3-24 Regression analysis results for cover percentages and boundary heterogeneity value of pixels in transect 5B of Sululta Site (d.f.=8)

Cover Type	Tree	Grass	Bare land	Field	Average of tree & grass	Average of tree, grass & field	Average of all covers
R square	**96**	**50**	33	**90**	**92**	**82**	31
P-Value %	**0**	3	12	**0**	**0**	**0**	12

Analysis was also carried out for difference in classes in pixels and boundary heterogeneity value of pixels of transects 5A and 5B to validate the boundary strength. Differences in NDVI class in pixels was significantly related with the heterogeneity value of pixels having explained variability of 57% $f_{(1,8)}$ =9.11 P-value<0.05 for transect 5A and 77% $f_{(1,8)}$ =17.36 P-value< 0.05 for transect 5B respectively.

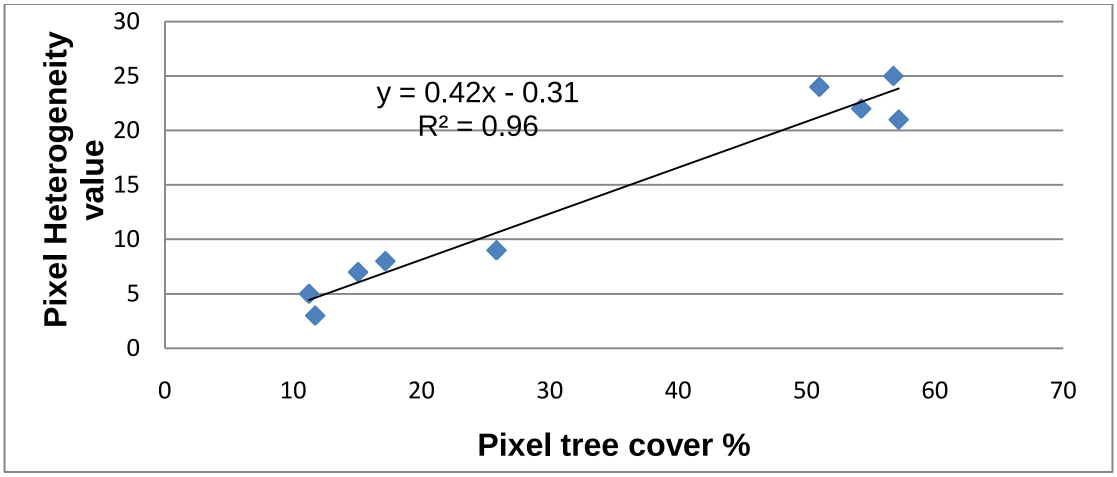


Figure 3-61 Result of regression analysis between boundary heterogeneity value and Tree cover % in transect 5B of Sululta site

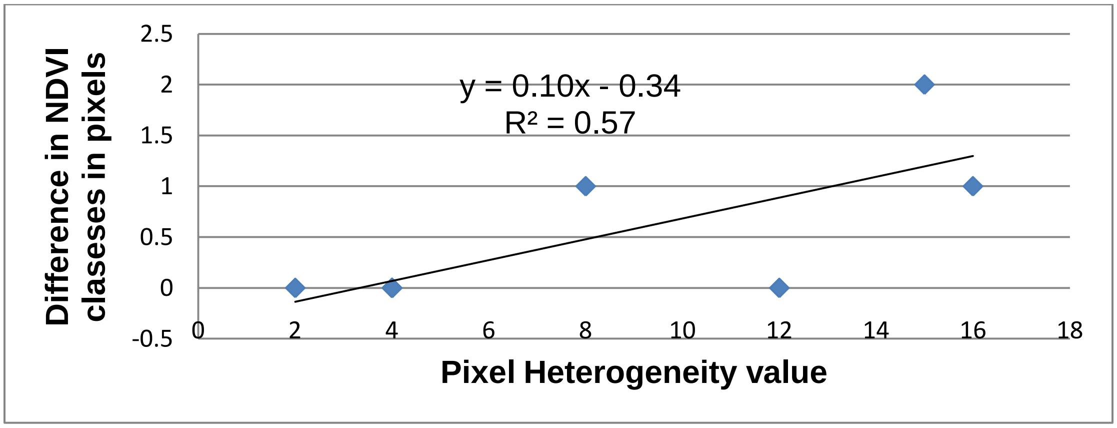


Figure 3-62 Result of regression analysis between boundary heterogeneity value and difference in NDVI class in transect 5A of Sululta site

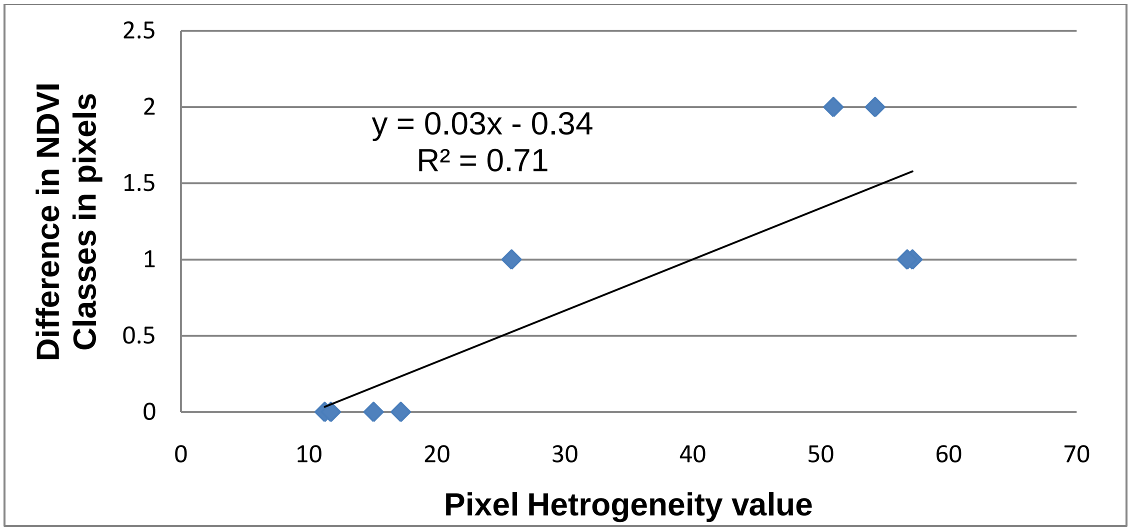


Figure 3-63 Result of regression analysis between boundary heterogeneity value and difference of NDVI class in transect 5B of Sululta site

- **Statistical analysis for Sululta site to test the significance difference between NDVI classes**

To find relationship between NDVI classes as independent variable and cover percentages as dependent variable and to test the significant difference between NDVI classes Stepwise Least Square Dummy Variable regression method was carried out for NDVI Classes with in the Sululta site in SPSS. Results for each cover type tests are reported as follows.

- **Tree Cover percentages as dependent variable**

NDVI class 98 had very low cover of tree than others in transect. This was approved by the results from analysis that all NDVI classes were significantly different than NDVI class 98 using tree cover (See Appendix F).

Table 3-25 Result of linear regression analysis between NDVI classes using Tree cover % of pixels for Sululta site

NDVI class	Coefficients	t	Sig.
Constant	9	6	0.000
Cl109	36	10	0.000
Cl107	66	7	0.000
Cl132	48	4	0.000
Cl103	28	3	0.001
Cl104	26	2	0.035

- **Grass cover percentages as dependent variable**

Using grass cover percent, NDVI class 114 was significantly different from all other NDVI classes in the site (See Appendix F). The result indicates that NDVI class 114 was having more grass than other NDVI classes in the site Table 3.26.

Table 3-26 Result of linear regression analysis between NDVI classes using Grass cover % of pixels for Sululta site

NDVI class	Coefficients	t	Sig.
Constant	43	19	0.000
cl114	11	4	0.000

- **Fields cover percentages as dependent variable**

NDVI class 114 was also significant different than others by having much more agricultural fields cover than others (See Appendix F). This result explained that NDVI class 114 almost twice of the mean of the other NDVI classes (see Table 3.28).

Table 3-27 Result of linear regression analysis between NDVI classes using Field cover % of pixels for Sululta site

NDVI class	Coefficients	t	Sig.
Constant	13	2	0.007
cl114	15	2	0.008

- **Bare land cover percentages as dependent variable**

In transect NDVI class 98 had a very high bare land cover percentages than others. This was proved from the test result that NDVI class 98 was significantly different than others using bare land (See Appendix F). This implies NDVI class 98 is having more than twice of the mean of all the NDVI classes (See Table 3.30).

Table 3-28 Result of linear regression analysis between NDVI classes using bare land cover % of pixels for Sululta site

NDVI class	Coefficients	t	Sig.
Constant	20	7	0.000
Cl98	49	2	0.035

3.2.2. Summary of Analysis

- **Statistical Analysis to find significant differences between NDVI classes**

To find relationship between NDVI classes and cover percentages and to test significant differences between them Stepwise Least Square Dummy Variables Regression method were executed in each survey site. Results of analysis for each site were summarised as follows:

In Metema site analysis using tree and grass cover percent to find significant difference between NDVI classes, NDVI class 115 was found significantly different from the mean of all other NDVI classes that are found in this site. In the analysis using agricultural fields NDVI class 124 was found significantly different from the mean of all other NDVI classes (See Table 3-29).

Table 3-29 Summary of regression analysis results to test significant difference between NDVI classes of Metema site

No.	Regression Equation results of analysis for each cover type	Adjusted R Square %	Predictors in the model
1	Tree % = 31-17 (if NDVI class 115)	10.5	NDVI class 123, 111, 122, 124
2	Grass % = 46-13 (if NDVI class 115)	9.4	NDVI class 123, 111, 122, 124
3	Fields % = 46-25 (if NDVI class 124)	38.8	NDVI class 123, 111, 122, 115

In Gerbe Guracha site analysis of all NDVI classes were found significantly different with each other using grass, settlement and agricultural fields cover, but not using tree cover percentages (See Table 3-30).

Table 3-30 Summary of regression analysis results to test significant difference between NDVI classes of Gerbe Guracha site

No.	Regression Equation results of analysis for each cover type	Adjusted R Square %	Predictors in the model
1	Grass % = 37 + 11(if NDVI class 114)	12	NDVI class 106, 108
2	Settlement % = 16 + 27(if NDVI class 106) -15(if NDVI class 114)	60	NDVI class 108
3	Fields % = 46-25 (if NDVI class 106)+23(if NDVI class 108)	52	NDVI class 114

In Sululta site analysis all NDVI classes were found significantly different from mean of NDVI class 98 using tree cover percentages by excluding NDVI class 114. NDVI class 114 was also found significantly different from mean of all others using grass and agricultural fields. It was found also that NDVI class 98 was significantly different using bare land cover percentages from mean of all other NDVI classes (See Table 3-31).

Table 3-31 Summary of regression analysis results to test significant difference between NDVI classes of Sululta site

No.	Regression Equation results of analysis for each cover type	Adjusted R Square %	Predictors in the model
1	Tree % = 9 + 36 (if NDVI class 109) + 66(if NDVI class 107) + 48(if NDVI class 132) + 28(if NDVI class 103) + 26(if NDVI class 104)	68	NDVI class 98
2	Grass % = 43 - 11(if NDVI class 114)	4.3	NDVI class 109, 104, 132, 107, 103, 98
3	Fields % = 13 - 15 (if NDVI class 114)	7.9	NDVI class 109, 104, 132, 107, 103, 98
4	Bare land % = 20 - 49(if NDVI class 98)	4.5	NDVI class 114,109, 104, 132, 107, 103

Therefore, it is evident that NDVI classes have significant differences between each other within survey site, thus the null hypothesis ($H1_o$) that NDVI classes within the survey sites do not have a significant difference is rejected, and the alternative hypothesis ($H1_1$) that NDVI classes within the survey sites have significant differences at least using one cover type is accepted.

- **Statistical Analysis to assess boundary strength**

Analyses were carried out for boundary heterogeneity value of pixels and cover percentages as well as differences in NDVI classes in pixels within transect to validate the strength of boundaries between NDVI classes using Linear Regression method. All the analysis, that has been done in each transect were summarised in the next tables and reported as follows:

As it was summaries in table 3-32 in Metema site all transects except transect 3 deal with relatively homogeneous land cover patterns. For transect 2, the heterogeneity value was significant related to the tree cover percentages. Transect 3 had larger patches with substantial changing tree cover percentages; this is regulated by the relatively high heterogeneity values (18 and 23). If NDVI classes differ between pixels, the heterogeneity becomes related and this situation validates the strong boundary between the classes.

Table 3-32 Summary of result analysis between tree cover and heterogeneity value in Metema site to validate strong boundary between map units

Transects		Pixels									Tree cover % vs. H.V.		If Different NDVI class Vs. H.V.	
		1	2	3	4	5	6	7	8	9	R square %	P-value %	R square %	P-value %
1	NDVI Class	123									26	N.S.	-	-
	Tree cover %	32 - 41												
	Heterogeneity value	0 - 6												
2	NDVI Class	123									49	5	-	-
	Tree cover %	1 - 53												
	Heterogeneity value	1 -11												
3	NDVI Class	123			111	115		122	124		22	N.S.	74	0
	Tree cover %	26 - 37			**14**	13 - 15		**18**	32 - 44					
	Heterogeneity value	3 - 6			**18**	3 -11		**23**	3 - 36					
4	NDVI Class	124			123		124				5	N.S.	2	N.S.
	Tree cover %	20 - 46			18 - 22		22 - 35							
	Heterogeneity value	5 - 7			1 - 3		1 - 5							
5	NDVI Class	124									1	N.S.	-	-
	Tree cover %	24 - 40												
	Heterogeneity value	2 - 10												

N.S. = not significant

As it was summarised in table 3-33, in Gerbe Guracha site all transects deal with homogeneous land cover patterns. Within NDVI class, variability was very low where unit 108 and 106 are almost similar. The heterogeneity value of pixels was less than 7 and cover percentage was also less than 13%. Thus, all statistical tests were not significant. This implies that in all transects of this site there was no strong boundary between the NDVI classes or map units.

Table 3-33 Summary of result analysis between tree cover and heterogeneity value in Gerbe Guracha site to validate strong boundary between map units

Transects		Pixels									Tree cover % vs. H.V.		If Different NDVI class Vs. H.V.	
		1	2	3	4	5	6	7	8	9	R square %	P-value %	R square %	P-value %
1	NDVI Class	114									66	N.S.	-	-
	Tree cover %	0 - 19												
	Heterogeneity value	4 - 5												
3	NDVI Class	106									0	N.S.	-	-
	Tree cover %	0 - 7												
	Heterogeneity value	0 - 7												
4	NDVI Class	108									21	N.S.	-	-
	Tree cover %	0 - 6												
	Heterogeneity value	0 - 1												
5	NDVI Class	108	106			108					1	N.S.	3	N.S.
	Tree cover %	7	3 - 13			1 - 11								
	Heterogeneity value	1	1 - 2			1 - 2								

N.S. = not significant

As it was summarised in table 3-34 in Sululta site, except transect 1 and 3A all transects had larger patches with substantial change in tree cover percentages; this is regulated by relatively high heterogeneity value ranging from 14 – 25. All tests were significant.

If NDVI classes differ between pixels, the heterogeneity becomes significantly related. Therefore, in this site land cover patter is heterogeneous and boundaries of NDVI classes are mostly strong boundaries.

Table 3-34 Summary of result analysis between tree cover and heterogeneity value in Sululta site to validate strong boundary between map units

Transects		Pixels									Tree cover % vs. H.V.		If Different NDVI class Vs. H.V.	
		1	2	3	4	5	6	7	8	9	R square %	P-value %	R square %	P-value %
1	NDVI Class	114									2	N.S.	-	-
	Tree cover %	0 - 22												
	Heterogeneity value	1 - 5												
2A	NDVI Class	114						109			56	**4**	69	**1**
	Tree cover %	1 - 5						**40 - 48**						
	Heterogeneity value	1 - 10						**9 - 20**						
2B	NDVI Class	114					109	104	132		67	**1**	85	**0**
	Tree cover %	0 - 8					**16**	**32**	**58**					
	Heterogeneity value	3 - 8					**16**	**20**	**16**					
3A	NDVI Class	114									**0**	N.S.	-	-
	Tree cover %	1 - 15												
	Heterogeneity value	1 - 7												
3B	NDVI Class	114							109		81	**0**	55	**0**
	Tree cover %	3 - 10							**25 - 65**					
	Heterogeneity value	0 - 4							**17 - 20**					
4A	NDVI Class	114					109	107			90	**0**	63	**1**
	Tree cover %	7 - 22					31	71 - 80						
	Heterogeneity value	2 - 4					8	14 - 24						
4B	NDVI Class	114					109				60	**2**	55	**3**
	Tree cover %	2 - 27					7 - 71							
	Heterogeneity value	1 - 14					16 - 23							
5A	NDVI Class	109		103	114						93	**0**	57	**2**
	Tree cover %	53		53	16 - 25									
	Heterogeneity value	12 - 16		15	2 - 8									
5B	NDVI Class	109		103	98	114	114	114	114	114	96	**0**	62	**2**
	Tree cover %	57		51	54	11 - 26								
	Heterogeneity value	21 - 25		24	22	3 - 9								

N.S. = not significant

Overall:

Differences in tree cover percent between NDVI pixels relates directly and significantly to the heterogeneity value.

When the NDVI class differs between pixels, the heterogeneity becomes substantially and mostly significantly higher.

Both indicate that the heterogeneity values directly related to the boundary strength of the landscape heterogeneity map.

The heterogeneity value indicates that a change from one NDVI class to another class concerns truly different classes; this is verified by ground observations of which tree cover percentages was the most indicative parameter.

Therefore, there is evidence that there is significant relationship between tree cover percentage and boundary heterogeneity of pixels. Thus the null hypothesis ($H2_o$) that 'there is no significant relationship between cover types and boundary heterogeneity of pixels' is rejected, and ($H2_1$) that 'there is significant relationship between tree cover percentages and boundary heterogeneity of pixels' is accepted.

4. Discussion

Landscape heterogeneity mapping technique using hyper-temporal NDVI images (De Bie, *et al*,. 2008) delineates distinctively various map units and covers substantial variability in land cover. Each land cover class (map unit) has been defined by related NDVI profiles to show its temporal behaviour as well.

By interpretation of high resolution images (Google images) (Feranec, 1999) using unsupervised lookup table approach (lookup table created from ground data) was able to estimate and demonstrate cover percentages for each pixel in transect.

This research found that NDVI classes in the heterogeneity map have significant differences using cover percentages whenever they have major differences in the type of cover based on their pixel cover percentages of transects. Mainly NDVI classes having strong boundaries were found significantly different using tree cover percentages. And this was validated by applying Stepwise Least Square Dummy Variable Regression method techniques using dummy variables (Park, 2005). Analysis was carried out for NDVI classes as independent variables and each cover type percentages of a pixel as dependent variable within the survey area in each site to find relationship and to test significant differences.

The Metema site which is occupied by NDVI classes 123, 111, 122, 115 and 124 was dominantly covered by trees, shrubs, grass and agricultural fields. In this site NDVI class 115 was covered by settlement with agricultural fields but fewer trees and grass cover percentages. This was verified by the results from regression analysis and it was significantly different from all other NDVI classes in transect using tree and grass cover percentages having much less tree cover percentages respectively. Since NDVI class 124 had very less percentages of agricultural fields in transects, it was significantly different than all other NDVI classes having much less agricultural cover percentages. Therefore, settlements, forests and agricultural field land covers were clearly differentiated and forms unique unit in the map.

In Gerbe Guracha site agricultural fields, extensive marsh grass lands and settlements with few trees were dominant cover types. In this site there was no forest cover. Therefore, results shows that all NDVI classes were not having significant differences using tree cover percentages. NDVI class 114 was dominantly covered by grass and agricultural fields but less settlements. NDVI class 106 was dominated by settlement and NDVI class 108 was dominated by agricultural fields.

This was verified by the results from analysis. NDVI class 114 was significantly different from all other NDVI classes using grass having much more grass than others. NDVI class 114 and 106 were significantly different from NDVI class 108 using settlement cover percentages. The results can be interpreted as NDVI class 114 has 15% less settlement cover than NDVI class 108 and NDVI class 106 has 27% more settlement cover percentages than NDVI class 108 of which NDVI class 108 has settlement cover percentage of 16%.

NDVI class 106 and 108 were also significantly different from NDVI class 114 using agricultural fields. Results from analysis can be interpreted as NDVI class 106 has 25% less fields cover percentages than NDVI class 114 and NDVI class 108 has 23% more fields cover percentages than NDVI class 114 of which has 50% agricultural cover percentages. Therefore, area of extensive grass land, settlement and agricultural fields were differentiated successfully.

Sululta site was dominated by grass, agricultural fields, forest batch and bare lands. NDVI class 132, 107, 109, 104 and 103 were dominated by tree cover with different level but NDVI class 114 was dominated by grass and fields cover whereas NDVI class 98 was dominated by bare land cover. This was proved by regression analysis results as follows. NDVI class 132, 107, 109, 104, and 103 were significantly different from NDVI class 98 using tree cover percentages. the results can be interpreted as NDVI classes 109, 107, 132, 103, 103 and 104 has 36%, 66%, 48%, 28%, and 26% more tree cover percentage than NDVI class 98 of which has 9% cover percent of tree by excluding NDVI class 114. NDVI class 114 was significantly different from all other NDVI classes in the transect using grass and fields, since it has 11% more grass and 15% more agricultural cover percentages of which the average of all NDVI classes were 43% grass and 15% agricultural field cover percentages respectively. NDVI class 98 was also significantly different from all other NDVI classes using bare land cover percentages. Thus, extensive grass land, forest and bare land area of the site were distinguished effectively.

It was also possible to assess boundary length by plotting NDVI value, heterogeneity values and tree cover percentages. Wherever, there was strong boundary, heterogeneity value of boundaries had significant relationship with tree cover percentages of pixels in transect.

In Metema site transect 3 NDVI class 115 had less tree cover percentages than NDVI classes 123 and 124. Therefore, there was high boundary of heterogeneity value in NDVI class 111 and 122 of pixels 18 and 23 respectively which were in between the two NDVI classes. This was the indication of strong boundary and it was validated by significant relationship between differences in NDVI class in pixels and heterogeneity value of pixels in transect having R^2 of 74%. This transect deals with heterogeneous patter of land cover. All other transects were homogeneous.

In Gerbe Guracha site all the NDVI classes didn’t have differences in tree coverage; therefore, they couldn’t have high boundary heterogeneity value. The boundary heterogeneity value was so small. Therefore, the statistical test results showed that there is no relation between tree cover percentages and heterogeneity value of pixels. As a result, this site is characterized by homogeneous (Feagin 2005) land cover pattern with smooth boundary of NDVI classes.

In Sululta site the land cover pattern was changing along transect. In most transects there were pixels with high cover of trees. With increasing of tree cove percentages heterogeneity value of pixels is also increases. In this site tree cover percent ranges from 1% to 80%. This concedes with range of heterogeneity value of pixels from 1 up to 25. This was supported by high NDVI value in transects and validated by significant relationship between tree cover and boundary heterogeneity value of the pixels in transects having explained variability of (R^2) vary from 56% to 96%. Thus, this site is characterised by heterogeneous land cover pattern with strong boundary of classes. Forest was significantly differentiated from other cover types.

Heterogeneity/ homogeneity (Fortin, 1997; Jianguo, et al., 2000; Griffith, et al., 2002; Garrigues, et al., 2006; Christopher, et al., 2008; Hufkens, et al., 2009) of the landscape is directly related to the strength of the boundary. Strong boundaries implies heterogeneity whereas, smooth boundaries shows homogeneity of land cover patter of the landscape.

Heterogeneity values of the pixels were directly and significantly related to tree cover percentages. In this research tree cover was found as the most indicative parameter of strong boundary. Whenever, there is high tree covers it concedes with high heterogeneity value of pixels which approves strong boundary. This indicates heterogeneous pattern of the land cover. In areas without tree cover the land cover patter was homogeneous and the boundary between NDVI classes was smooth boundary. But the two NDVI classes were differing significantly at least by one type of cover other than tree from each other.

Difference in classes in pixels, which is associated with high value of heterogeneity, was significantly correlated and it indicates strong boundary.

In general in the survey sites all land covers were differentiated and formed different map unites. Therefore, landscape heterogeneity map is found powerful to explain landscape heterogeneity.

5. Conclusion and Recommendation

5.1. Conclusion

As FAO indicated "the renewable natural resources of many African countries have come under severe strain for over the last two or three decades and most indicators point towards continuation of this trend" (FAO, 1998). Ethiopia is one of these countries which need to take measure to manage its natural resources. For such sustainable resource management efficient, accurate and sufficient information is prerequisite.

This research found the heterogeneity mapped using hyper-temporal NDVI images powerful to give distinctive, efficient, accurate and sufficient information of land cover especially in vegetation land cover of all over the country.

All NDVI classes or map units were significantly different between each other at least using one cover type. Heterogeneity value was directly significantly related to tree cover. Change in NDVI classes which associated with high heterogeneity value was the indications of strong boundary.

It was possible to distinguish heterogeneous and homogeneous land cover patterns between units of land cover at the landscape level. Land cover dominated by forest, extensive grass, settlements, bare lands and agricultural fields were distinguished successfully and effectively.

In this research it was also possible to identify not only spatial variability in land cover but also temporal variability of cover using NDVI profiles.

5.2. Recommendation

Even though the results of this research shown the capability and powerfulness of the hyper temporal mapping methodology to explain the land cover pattern based on the selected survey sites, the country is very vast and diverse. Therefore, research has to be done more in the southern, southeast and south west parts of the country where there is high cover of vegetation to check the consistency of the map throughout the country.

For better results it will be good to use longer transects than 8 km, so, that there would be better chances to get higher representation of NDVI classes in transects.

In order to use this map for different planning purposes it needs legend for all the NDVI classes or map units in the landscape heterogeneity map. Legend for the map has to be prepared.

To prove its applicability in everywhere, it has to be tested in area having different ecological settings.

References

A. P. Field (2005). Discovering Statistics using SPSS London., SAGE Publications Ltd,.

Cho, M. A., A. K. p. Skidmore and S. E. p. van Wieren (2007). Hyperspectral remote sensing of biochemical and biophysical parameters : the derivative red - edge "double - peak feature" : a nuisance or an opportunity? ITC Dissertation;142. Wageningen, Wageningen University**:** 206.

Christopher Pettit, WIlliam Cartwirght, Ian Bishop, Kim Lowell, David Pullar and D. Duncan (2008). Landscape analysis and visualisation : spatial models for natural resource management and planning

De Bie, C. A. J. M., M. R. Khan, A. G. Toxopeus, V. Venus and A. K. Skidmore (2008). "Hypertemporal image analysis for crop mapping and change detection." In: ISPRS 2008 : Proceedings of the XXI congress : Silk road for information from imagery : the International Society for Photogrammetry and Remote Sensing, 3-11 July, Beijing, China. Comm. VII, WG VII/5. Beijing : ISPRS, 2008. pp. 803-812.

De Vries, A. C., W. Klaassen and A. C. van den Broek (1998). Landscape heterogeneity Part II : remote sensing of land surface roughness. Delft, Beleidscommissie Remote Sensing (BCRS).

ERDAS (2003) "ERDAS Field Guide, 7th ed. Leica Geosystems GIS and Mapping ".

FAO. (1998). "Food and Agriculture Organization of The United Nations: Africover." from http://www.africover.org/index.htm.

Feagin, R. A. (2005). "Heterogeneity versus homogeneity: A conceptual and mathematical theory in terms of scale-invariant and scale-covariant distributions." Ecological Complexity **2**(4): 339-356.

Fekadu Bekele (2004). Ethiopian Use of ENSO Information in Its seasonal Forecasts.

Feranec, J. (1999). "Interpretation element "association": analysis and definition." International Journal of Applied Earth Observation and Geoinformation **1**(1): 64-67.

Fortin, M.-J. (1997). "Effects of data types on vegetation boundary delineation." Canadian Journal of Forest Research **27**: 1851-1858.

Garrigues, S., D. Allard, F. Baret and M. Weiss (2006). "Quantifying spatial heterogeneity at the landscape scale using variogram models." Remote Sensing of Environment **103**(1): 81-96.

Gonzallez-Alono F., M.-D.-M. A, A. Roldan-Zamarron, S. G.-G. and and J. M. Cuevas (2006). "Forest biomass estimation through NDVI composites. The role of remotely sensed data to assess Spansh forests as carbon sinks." International Journal of Remote Sensing **Vol. 27**(No. 24,): 7.

Griffith, J. A., E. A. Martinko, J. L. Whistler and K. P. Price (2002). "Interrelationships among Landscapes, NDVI, and Stream Water Quality in the U.S. Central Plains." Ecological Applications **12**(6): 1702-1718.

Hufkens, K., P. Scheunders and R. Ceulemans (2009). "Validation of the sigmoid wave curve fitting algorithm on a forest-tundra ecotone in the Northwest Territories, Canada." Ecological Informatics **4**(1): 1-7.

J. Nyssen, J. Naudts., K. De Geyndt, Mitiku Haile, J. Poesen, J. Moeyersons and J. Deckers (2008). "Soils and land use in the Tigray highlands (Northern Ethiopia)." Land Degradation & Development **19**(3): 257-274.

Jianguo Wu, Dennis E. Jelinski, Matt Luck and P. T. Tueller (2000). "Multiscale Analysis of Landscape Heterogeneity: Scale Variance and Pattern Metrics." Geographic Information Sciences **6**(1): 6-19.

Jose Carlos Munoz-Reinoso and F. G. Novo (2005). "Multiscale control of vegetaion patterns: the case of Donana (SW Spain)." Journal Article **20**.

JUSTICE, C. o., T. J.R.G., H. B.N. and T. C.J. (1985). "Analysis of the phenology of global vegetation useing meteorological satellite data." International Journal of Remote Sensing **6**: 1271-1318.

Liquan Zhang, Jianping Wu, Yu Zhen and J. Shu (2004). "A GIS-based gradient analysis of urvan landscape pattern of Shanghai metropolitan area, China." Science Direct **69**(Landscape and Urban Planning): 16.

Miressa Duffera and W. P. Robarge (1999). "Soil Characteristics and Management Effects on Phosphorus Sorption by Highland Plateau Soils of Ethiopia " Soil Sciences: 8.

Park, H. M. (2005). "Using Dummy Variables in Regression."

Sarkar, S. and M. Kafatos (2004). "Interannual variability of vegetation over the Indian sub-continent and its relation to the different meteorological parameters." Remote Sensing of Environment **90**(2): 268-280.

Sklenicka, P. and T. Lhota (2002). "Landscape heterogeneity--a quantitative criterion for landscape reconstruction." Landscape and Urban Planning **58**(2-4): 147-156.

Turner, M. G. e. and R. H. e. Gardner (1991). Quantitative methods in landscape ecology : the analysis and interpretation of landscape heterogeneity. New York etc., Springer-Verlag.

Appendixes

Appendix A: Data collection format

Transect_____________________ Sample no._________

S.no.	Cover type	Cover %	Asso_c_other Covers	X DBH	Spp Density	Platnt Ht	Pheno_ beg	Pheno_end

1. Serial number
2. Cover type such as tree species, grass, type of agricultural crop in the field etc
3. Cover percentages
4. Association of cover type with the stated cover type, mostly canopy cover with ground cover etc
5. Average trees Diameter at breast height per species
6. Species density within the $30x30m^2$ area
7. Plant average height per species
8. Phenology Beginning
9. Phenology Ending

Appendix B: Cover percentages, Heterogeneity value and NDVI (DN) value per transect

Metama Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 1

Metama Site Transect 1						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Shrub	Field			
34.77	42.26	21.71	44.64	212	0	123
35.48	41.38	19.83	43.72	213	0	123
35.51	43.59	22.01	44.47	216	2	123
40.91	44.89	15.76	40.30	216	4	123
38.31	44.58	19.10	42.42	215	5	123
39.47	44.46	17.73	42.87	213	6	123
31.95	41.82	28.97	56.32	212	4	123
38.72	37.11	28.21	64.85	212	4	123

Metama Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 2

Metama Site Transect 2						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Shrub	Field			
40.19	48.38	20.51	49.93	190	4	123
22.63	46.56	12.15	23.66	188	4	123
19.55	38.37	9.07	16.53	177	3	123
1.38	34.33	3.16	35.47	179	4	123
27.65	41.27	11.93	27.33	183	6	123
53.00	58.00	27.00	45.00	191	11	123
45.33	57.87	21.85	47.44	179	7	123
21.83	60.33	5.46	54.01	179	1	123

Metama Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 3

Metama Site Transect 3						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Shrub	Field			
37.40	39.30	18.12	45.40	170	3	123
29.67	42.58	8.14	53.57	170	3	123
26.45	46.90	17.06	52.26	167	6	123
14.12	38.46	10.79	46.68	168	18	111
12.75	25.96	7.82	61.59	174	11	115
15.01	40.60	15.24	58.39	170	3	115
18.22	52.75	23.54	53.01	172	23	122
32.40	32.42	25.26	16.87	188	16	124
43.52	31.13	35.65	16.89	199	3	124

Metama Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 4

Metama Site Transect 4						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Shrub	Field			
46.21	38.76	17.91	9.21	133	5	124
25.78	46.39	23.02	5.99	129	7	124
19.98	44.94	37.80	20.12	124	6	124
22.16	40.32	28.06	55.90	126	3	123
18.08	44.03	29.66	49.95	127	1	123
34.83	45.43	29.84	43.15	125	4	124
31.04	46.04	32.25	39.75	126	5	124
22.27	49.80	37.24	54.20	125	3	124
30.70	54.56	37.22	78.40	128	1	124

Metama Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 5

Metama Site Transect 5						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Shrub	Field			
36.91	56.46	5.23	17.74	138	7	124
24.25	54.51	10.27	3.78	133	9	124
34.64	45.43	4.29	8.37	130	2	124
24.89	61.68	6.06	5.38	127	2	124
33.76	60.57	11.15	9.17	125	2	124
40.11	56.10	3.92	19.87	124	5	124
33.95	56.10	11.40	15.41	126	5	124
33.68	49.51	37.02	0.79	144	10	124
39.09	55.48	20.22	1.47	144	4	124

Gerba Guracha Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 1

G/Guracha Site transect 1						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Settlement	Field			
0.00	50.00	0.00	50.00	181	4	114
0.57	49.94	0.13	50.06	181	4	114
12.04	48.63	2.74	51.37	177	4	114
19.16	47.82	4.35	52.18	168	5	114
0.00	50.00	0.00	50.00	168	4	114

Gerbe Guracha Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 3

G/Guracha Site transect 3						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Settlement	Field			
2.77	46.71	53.27	15.59	129	6	106
1.65	38.91	53.97	9.28	129	2	106
5.07	22.97	48.97	54.28	128	7	106
2.17	43.93	53.65	12.19	120	1	106
4.49	37.65	52.19	25.27	120	0	106
1.55	13.39	54.03	8.71	129	3	106
1.78	49.94	53.89	10.02	135	4	106
0.04	54.00	54.98	0.20	144	1	106
7.16	35.99	50.53	40.25	150	1	106

Gerbe Guracha Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 4

G/Guracha Site transect 4						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Settlement	Field			
0.00	47.95	22.09	81.74	0	1	108
2.40	38.81	0.00	93.97	90	0	108
3.00	43.43	12.02	81.10	75	0	108
4.00	44.12	15.05	84.05	0	0	108
2.22	47.46	20.00	82.55	84	0	108
5.72	43.63	11.11	87.86	87	0	108
3.94	43.48	28.61	70.56	88	0	108
2.00	45.68	19.70	82.86	95	1	108
4.10	45.11	10.26	88.64	95	1	108

Gerbe Guracha Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 5

G/Guracha Site transect 5						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Settlement	Field			
6.91	21.55	14.28	65.70	104	2	108
10.98	26.78	22.69	48.08	112	1	106
13.20	31.91	27.27	35.02	104	1	106
2.99	46.02	6.18	49.42	110	1	106
2.77	14.57	5.73	85.49	88	2	108
1.25	14.34	2.59	90.13	89	1	108
11.44	32.11	23.65	40.74	83	2	108
10.60	40.01	46.49	0.00	85	2	108

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 1

Sululta Site transect 1						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare soil			
0.00	55.00	76.15	0.00	101	1	114
6.14	55.80	73.73	0.00	94	3	114
3.53	51.56	63.01	6.46	98	5	114
6.77	49.94	63.13	10.43	104	5	114
10.79	56.40	75.08	0.00	106	4	114
22.45	57.92	68.73	0.00	103	1	114
4.78	55.55	74.86	0.13	101	1	114
6.14	54.66	79.41	3.43	98	1	114
6.54	55.85	75.49	0.00	96	2	114

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 2A

Sululta Site transect 2 A						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare soil			
0.52	58.29	25.72	5.38	99	1	114
0.61	54.77	15.29	3.83	93	3	114
1.26	60.28	35.57	9.41	92	1	114
5.34	53.88	29.02	18.77	97	2	114
1.34	37.66	52.50	38.51	99	1	114
3.01	44.37	43.41	30.67	109	10	114
40.25	39.99	17.62	14.59	133	20	109
47.72	36.48	14.33	18.75	125	9	109

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 2B

Sululta Site transect 2 B						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare land			
0.00	75.00	75.00	12.50	95	3	114
1.60	57.69	25.69	7.66	94	4	114
2.43	49.08	42.28	24.83	95	5	114
2.57	46.23	45.18	29.08	103	5	114
7.66	48.52	46.87	35.95	105	8	114
16.07	42.34	37.99	31.61	117	16	109
35.22	36.74	21.62	19.12	148	20	104
57.50	29.48	3.12	14.89	158	16	132

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 3A

Sululta Site transect 3A						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare land			
0.81	38.96	0.00	0.00	90	1	114
1.79	57.86	1.82	0.00	91	1	114
1.29	65.05	19.53	0.00	101	2	114
5.10	53.71	7.72	4.98	115	7	114
4.27	50.72	8.44	5.59	121	2	114
5.81	67.20	2.25	58.58	117	2	114
14.68	50.33	5.62	49.19	115	1	114
6.82	54.72	4.79	54.83	121	7	114
4.67	54.77	11.91	56.79	121	7	114

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 3B

Sululta Site transect 3B						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare land			
5.39	54.83	0.00	5.02	93	0	114
2.80	57.30	13.33	2.11	92	1	114
2.79	60.85	10.82	0.88	97	1	114
4.29	62.93	4.30	1.20	108	3	114
5.69	52.74	1.49	5.91	118	4	114
7.27	50.69	12.90	7.81	119	1	114
10.25	63.08	1.33	52.03	128	2	114
24.96	42.35	8.36	43.74	141	17	109
65.22	11.55	3.84	12.62	141.00	20	109

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 4A

Sululta Site transect 4A						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare land			
8.79	71.33	40.26	7.77	110	4	114
6.53	61.41	57.09	15.79	114	2	114
7.22	58.54	36.53	8.57	126	3	114
22.25	47.54	25.92	10.80	132	2	114
19.32	75.38	23.15	2.41	124	3	114
30.55	67.91	27.85	7.13	122	8	109
70.93	42.80	14.19	6.14	144	15	107
79.91	38.89	3.27	4.55	163	24	107

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 4B

Sululta Site transect 4B						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare land			
2.29	65.34	42.28	9.56	111	4	114
4.28	71.35	46.00	13.08	116	1	114
26.59	67.04	39.71	8.74	123	4	114
20.47	35.68	30.38	18.32	131	3	114
3.10	60.10	47.31	12.06	124	1	114
6.49	37.14	30.02	9.19	140	16	109
60.19	38.92	6.49	6.05	164	23	109
71.12	35.05	0.02	4.99	187	20	109

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 5A

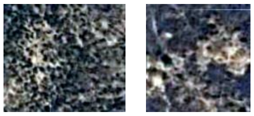
Sululta Site transect 5A						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Field	Bare land			
53.33	57.04	15.80	5.50	117	12	109
53.13	54.19	15.52	8.11	138	16	109
52.84	53.57	15.35	9.03	123	15	103
24.72	39.47	2.64	60.55	102	8	114
21.30	34.28	1.21	69.46	96	4	114
17.62	37.51	3.13	70.27	89	4	114
17.88	42.38	0.00	67.93	90	4	114
19.24	33.50	0.46	72.93	100	4	114
15.77	49.05	6.62	67.70	100	2	114

Sululta Site: Cover %, NDVI (DN) value, Heterogeneity value and NDVI class of transect 5B

Sululta Site transect 5B						
Cover %				NDVI	Heterogeneity	NDVI class no.
Tree	Grass	Bare land	Bare land			
57.18	56.56	17.37	0.41	138	21	109
56.77	56.64	17.21	0.92	148	25	109
51.00	54.48	14.65	10.90	116	24	103
54.26	54.21	15.99	6.47	108	22	98
25.84	48.59	4.80	48.34	98	9	114
11.23	50.54	15.02	61.19	94	5	114
15.05	42.57	8.00	66.71	95	7	114
17.18	36.52	7.49	73.59	102	8	114
11.71	49.15	14.35	62.08	102	3	114

Appendix C: Legend for Google image digitized polygons in each site

Legend for Metema Site Study Area

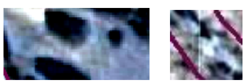
 Class 1

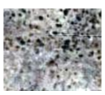
Class2

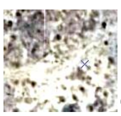
 Class3

Class4

Class 5

 Class 6

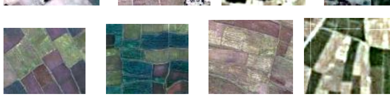
 Class7

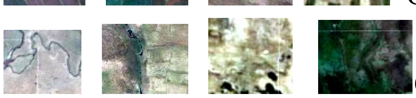
Class 8

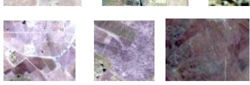
 Class 9

Legend for Gerbe Guracha Site Study Area

 Class 1

 Class 2

Class 3

 Class 4

 Class 5

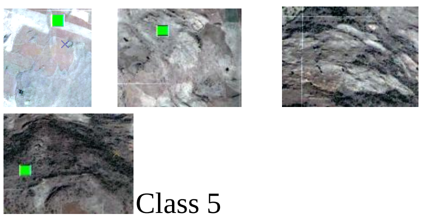
Legend for Sululta Site study area


Class 1


Class 2


Class 3


Class 4


Class 5


Class 6

Appendix D: Linear Regression analysis results for Metema site

- **Tree cover**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.355[a]	.126	.105	9.8483377

a. Predictors: (Constant), Cl115

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	574.535	1	574.535	5.924	.019[a]
	Residual	3976.580	41	96.990		
	Total	4551.115	42			

- **Grass cover**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.340[a]	.115	.094	8.0128372

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	343.561	1	343.561	5.351	.026[a]
	Residual	2632.428	41	64.206		
	Total	2975.989	42			

- **Field cover**

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.634[a]	.402	.388	15.9236433

a. Predictors: (Constant), Cl124

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6999.914	1	6999.914	27.606	.000[a]
	Residual	10396.059	41	253.562		
	Total	17395.973	42			

Appendix E: Linear Regression analysis results for Gerbe Guracha site

- Grass cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.387[a]	.149	.120	10.8440186

a. Predictors: (Constant), Cl114

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	599.087	1	599.087	5.095	.032[a]
	Residual	3410.189	29	117.593		
	Total	4009.276	30			

a. Predictors: (Constant), Cl114

b. Dependent Variable: Grass

- Settlement Cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.755[a]	.570	.556	13.8695859
2	.797[b]	.635	.609	13.0094704

a. Predictors: (Constant), Cl106

b. Predictors: (Constant), Cl106, Cl114

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7405.881	1	7405.881	38.499	.000[a]
	Residual	5578.597	29	192.365		
	Total	12984.478	30			
2	Regression	8245.581	2	4122.791	24.360	.000[b]
	Residual	4738.897	28	169.246		
	Total	12984.478	30			

a. Predictors: (Constant), Cl106

b. Predictors: (Constant), Cl106, Cl114

c. Dependent Variable: Settlement

- Field cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.693[a]	.480	.462	22.0768586
2	.744[b]	.553	.522	20.8269711

a. Predictors: (Constant), Cl106

b. Predictors: (Constant), Cl106, Cl108

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13065.392	1	13065.392	26.807	.000[a]
	Residual	14134.243	29	487.388		
	Total	27199.635	30			
2	Regression	15054.279	2	7527.139	17.353	.000[b]
	Residual	12145.356	28	433.763		
	Total	27199.635	30			

a. Predictors: (Constant), Cl106

b. Predictors: (Constant), Cl106, Cl108

c. Dependent Variable: Field

Appendix F: Linear Regression analysis results for Sululta site

- Tree Cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.586[a]	.343	.334	17.31168
2	.758[b]	.575	.564	14.01343
3	.799[c]	.639	.624	13.01653
4	.827[d]	.683	.666	12.26492
5	.838[e]	.703	.682	11.96607

e. Predictors: (Constant), cl109, cl107, cl132, cl103, cl104

ANOVA[f]

Model		Sum of Squares	df	Mean Square	F	Sig.
4	Regression	23384.626	4	5846.157	38.863	.000[d]
	Residual	10830.833	72	150.428		
	Total	34215.459	76			
5	Regression	24049.187	5	4809.837	33.591	.000[e]
	Residual	10166.272	71	143.187		
	Total	34215.459	76			

e. Predictors: (Constant), cl109, cl107, cl132, cl103, cl104

f. Dependent Variable: Tree

- Grass Cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.432[a]	.186	.176	10.37629

a. Predictors: (Constant), cl114

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1849.603	1	1849.603	17.179	.000[a]
	Residual	8075.053	75	107.667		
	Total	9924.657	76			

a. Predictors: (Constant), cl114

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.432[a]	.186	.176	10.37629

b. Dependent Variable: Grass

- Agricultural Fields Cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.302[a]	.091	.079	22.59120

a. Predictors: (Constant), cl114

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3837.197	1	3837.197	7.519	.008[a]
	Residual	38277.162	75	510.362		
	Total	42114.359	76			

a. Predictors: (Constant), cl114

b. Dependent Variable: Field

- Bare land Cover

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.240[a]	.058	.045	22.82489

a. Predictors: (Constant), cl98

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2395.290	1	2395.290	4.598	.035[a]
	Residual	39073.187	75	520.976		
	Total	41468.477	76			

a. Predictors: (Constant), cl98

b. Dependent Variable: Bareland