Evaluation of Vegetation Conditions for Green Legacy Using Geospatial Technology: A Case of Entoto Natural Park, Addis Ababa, Ethiopia

Ifa Dinsa Negeri

A Thesis Submitted to
The department of Geomatics Engineering
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geoinformatics

Office of Graduate Studies
Adama Science and Technology University

October, 2023
Adama, Ethiopia

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APPROVAL SHEET

I, the advisor of the thesis entitled "Evaluation of Vegetation Conditions for Green Legacy Using Geospatial Technology: A Case of Entoto Natural Park, Addis Ababa, Ethiopia" and developed by Ifa Dinsa Negeri, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Roba Gemechu (PhD)	______________________	_______________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Ifa Dinsa Negeri have read and evaluated the thesis entitled "Evaluation of Vegetation Conditions for Green Legacy Using Geospatial Technology: A Case of Entoto Natural Park, Addis Ababa, Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-informatics.

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Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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DECLARATION

I hereby declare that this Master Thesis entitled "Evaluation of Vegetation Conditions for Green Legacy Using Geospatial Technology: A Case of Entoto Natural Park, Addis Ababa, Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Ifa Dinsa Negeri	______________________	___________________
Name of the student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Evaluation of Vegetation Conditions for Green Legacy Using Geospatial Technology: A Case of Entoto Natural Park, Addis Ababa, Ethiopia" prepared under my guidance by Ifa Dinsa Negeri submitted in partial fulfillment of the requirements for the degree of Master's of Science in Geo-informatics. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Roba Gemechu (PhD)	____________________	________________
Advisor	Signature	Date

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TABLE OF CONTENTS

CONTENTS PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

NDWI	Normalized Difference Water Index
GNDVI	Green Normalized Difference Vegetation Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
SWIR	Short Wave Infrared
GLI	Green Legacy Initiative
EMR	Electro Magnetic Spectrum
UV	Ultraviolet
USGS	United States Geological Survey
OLI	Operational Land Imager
ETM+	Enhanced Thematic Mapper Plus
TM	Thematic Mapper
GIS	Geographic Information System
ERDAS	Earth Resources Data Analysis System
SPSS	Statistical Package for Social Sciences
USDA	United States Department of Agriculture
MIR	Middle Infrared
RS	Remote Sensing

ABSTRACT

Vegetation is the most significant natural resource that provides the basic necessities for human existence on Earth. It serves as a vital source of oxygen, food, shelter, and raw materials for manufacturing industries. Additionally, vegetation plays a crucial role in mitigating global warming and climate change. This study was conducted in Entoto Natural Park to evaluate vegetation conditions during dry and wet seasons. The study focused on examining vegetation leaf moisture, chlorophyll concentration, and overall health status of vegetation in Entoto Natural Park. To accomplish this, multi-spectral satellite imagery and spectral indices such as NDWI, GNDVI, and NDVI were utilized. Data analysis was carried out using ArcGIS and ERDAS Imagine software. Spectral indices were calculated from multispectral satellite imagery of vegetation for both dry and wet seasons. The results of the study reveal that eucalyptus trees and Juniperus procera, which are the dominant vegetation in Entoto Natural Park, exhibit relatively low leaf moisture content during the dry season and moderate leaf moisture during the wet season. Also, the study indicates that eucalyptus trees have lower chlorophyll concentration compared to other varieties of vegetation. This implies that the contribution of eucalyptus trees to oxygen emission and CO2 absorption in the environment is relatively lower due to their lower photosynthetic activity when compared to other types of vegetation in the park. Additionally, the study reveals that vegetation health status is relatively lower during the dry season but improves during the wet season. These findings provide valuable information for policymakers regarding the management and preservation of natural resources to combat global warming and climate change. By considering the fluctuations in vegetation health throughout the year and developing strategies to address these variations, policymakers can contribute to the sustainability of ecosystems and the well-being of human populations.

Keywords: *NDWI, Vegetation, GNDVI, NDVI, Green legacy, Eucalyptus tree*

CHAPTER I: INTRODUCTION

1.1.Background of the Study

Vegetation is the most significant natural resource that provides essential services for the existence of human beings on Earth. These services include the supply of oxygen, food, water, shelter, and the absorption of CO_2 from the environment (Kumari et al., 2021a). Furthermore, vegetation plays a significant role in protecting against global warming and climate change worldwide. It is a fundamental component of life on Earth and is essential to global biogeochemical cycles. Additionally, it acts as a carbon sink, effectively reducing CO_2 pollution and mitigating the impacts of climate change (Rewald et al., 2020).

This study specifically focused on evaluating the vegetation conditions for sustainable green legacy in Entoto Natural Park using multispectral remote sensing and spectral indices. The analyzed vegetation conditions included leaf water content, chlorophyll concentration, and vegetation health status. Insufficient water supply can lead to water stress in vegetation, compromising their growth, production, reproduction, and survival. Water stress in vegetation is a complex physiological response to limited water availability. When vegetation experiences water stress, a series of detrimental vegetation-water interactions occur, disrupting the physiology of the vegetation. These interactions include a decrease in cell water potential, cell turgor, and relative water content (Hsiao, 1973a).

The leaf water content of vegetation in Entoto Natural Park was analyzed using the Normalized Difference Water Index (NDWI). The NDWI is a satellite-derived index calculated from the near-infrared (NIR) and short-wave infrared (SWIR) channels (Razali & Nuruddin, 2011a). The SWIR reflectance captures changes in both the vegetation water content and the spongy mesophyll structure within vegetation canopies. On the other hand, the NIR reflectance is influenced by leaf internal structure and leaf dry matter content, but not by water content. By combining the NIR with the SWIR, variations caused by leaf internal structure and leaf dry matter content are eliminated, leading to improved accuracy in retrieving the vegetation water content (Jackson et al., 2004a).

The vegetation chlorophyll concentration in Entoto Natural Park was analyzed using the Green Normalized Difference Vegetation Index (GNDVI). Chlorophyll is a crucial component in the photosynthetic process and has been utilized to study vegetation stress, nutrient cycling, productivity, growth stages, and diseases. It provides valuable insights into vegetation health and overall productivity (Nandibewoor et al., 2017). The chlorophyll content in green leaves is responsible for high absorption in the red portion of the electromagnetic spectrum and the reflectance in the infrared region is influenced by the cell structure. Therefore, accurate estimation of vegetation chlorophyll content is of great significance. The vegetation health status in Entoto Natural Park was examined based on the Normalized Difference Vegetation Index (NDVI), which was derived from the visible light and near-infrared channels (Huang et al., 2021a)

This study aims to evaluate the vegetation conditions in Entoto Natural Park using multispectral remote sensing and spectral indices. Three different spectral indices were employed to achieve the specific objectives of the study. These spectral indices include the Normalized Difference Water Index (NDWI), Green Normalized Difference Vegetation Index (GNDVI), and Normalized Difference Vegetation Index (NDVI). The Normalized Difference Water Index is a satellite-derived index calculated using the Near Infrared (NIR) and Short-Wave Infrared (SWIR) channels (Razali & Nuruddin, 2011b).

The spectral index used to examine chlorophyll concentration of vegetation in Entoto Natural Park was GNDVI. This index is utilized for estimating photosynthetic activity and chlorophyll concentration. Additionally, another satellite-derived spectral index used to assess the healthy status of vegetation at Entoto Natural Park was the Normalized Difference Vegetation Index. This index is calculated based on the reflection of visible and near infrared light by vegetation. Healthy vegetation absorbs a significant amount of visible light and reflects a substantial portion of near infrared light (Oliech, 2019).

1.2.Statement of the Problem

The introduction of Eucalyptus tree species to Ethiopia and its planting on Entoto mountain dates back to 1895 during the reign of Emperor Menelik II. The main objective was to address the critical shortage of fuel wood and construction materials in Addis Ababa and other towns in the country. The Emperor recognized that urban development and the preservation of natural forests could contradict each other without alternative measures. To encourage landowners to plant more trees for various purposes, he implemented various incentive mechanisms such as tax relief and the free distribution of Eucalyptus seeds and seedlings (Gil et al., 2010). Additionally, in July 2019, the current government of Ethiopia gained global attention when it claimed to have broken a world record by planting over 350 million trees in one day, with Entoto Natural Park being one of the locations where the tree plantation campaign commenced. Since then, Prime Minister Abiy Ahmed's Green Legacy Initiative (GLI) has become an annual tree-planting program. (Fikreyesus et al., 2022)

The vegetation in Entoto Natural Park plays a significant role in reducing air pollution in the vicinity of Addis Ababa. It achieves this by absorbing carbon dioxide and releasing oxygen into the atmosphere through the process of photosynthesis. Additionally, the park's vegetation helps to address issues related to land degradation, global warming, and climate change. Furthermore, the vegetation in Entoto Natural Park serves as a recreational area for millions of Ethiopians and foreign visitors. People can enjoy the natural beauty of the park, engage in various activities such as hiking, picnicking, and find solace in the peaceful surroundings it offers (Tesema & Berhan, 2019).

However, the technology-based management and preservation of natural resource particularly vegetation conditions including Eucalyptus trees has not been utilized in Entoto Natural Park. The Eucalyptus tree is the dominant vegetation in Entoto Natural Park. But the vegetation conditions like leaf water content, chlorophyll concentration and vegetation health status has not been investigated for effective management and conservation of natural resources.

Hence, this study evaluates the vegetation conditions in Entoto Natural Park to have deep understanding of vegetation leaf moisture, chlorophyll concentration and vegetation health status for effective management of natural resource and preservation of vegetation to minimize the problems related to global warming, land degradation and air pollution.

1.3. Objectives of the Study

1.3.1. General Objectives

To evaluate vegetation conditions in Entoto Natural Park during dry and wet seasons using multispectral satellite imagery and spectral indices.

1.3.2. Specific Objectives

- To evaluate vegetation leaf moisture using Normalized Difference Water Index (NDWI) in Entoto Natural Park
- To examine chlorophyll concentration of vegetation employing Green Normalized Difference Vegetation Index (GNDVI).
- To analyse vegetation health status in Entoto Natural Park using NDVI.

1.4. Research Questions

- How Normalized Difference Water Index (NDWI) is used to evaluate vegetation leaf moisture?
- What is the role of Green Normalized Difference Vegetation Index (GNDVI) in examining chlorophyll concentration of vegetation?
- How Normalized Difference Vegetation Index (NDVI) is used to analyse vegetation health status in Entoto Natural Park?

1.5. Significance of the Study

This study has a great contribution to the effective conservation of natural resources and provides technology-based characterization of vegetation conditions for sustainable Green Legacy. In addition to supporting Green Legacy Initiatives (GLI), evaluating vegetation condition has great significance in controlling global warming, protecting against climate change, and reducing air pollution.

1.6. Scope of the Study

The scope of the study was spatially limited to Entoto Natural Park, Addis Ababa, Ethiopia, covering an area of 2300 hectares. The study focused only on evaluating vegetation conditions for green legacy using multispectral remote sensing and spectral indices derived from satellite imagery. Generally, the study emphasizes analyzing vegetation leaf water content, chlorophyll concentration, and vegetation health status in Entoto Natural Park.

1.7.Limitation of the study

One drawback of this study is the challenge of characterizing vegetation conditions for small plant seedlings that are located under dense tree canopies or within thick vegetation. This issue could be addressed in future studies by employing more advanced remote sensing techniques like LiDAR technology or incorporating ground-based measurements to accurately assess the health and condition of these smaller plants. Additionally, further research could focus on developing specific methodologies or algorithms that are better suited for analyzing vegetation conditions in areas with dense vegetation cover.

1.8.Organization of the research Thesis

This study is organized into five chapters. The first chapter elaborates the background of the study, statement of the problem, general and specific objectives, significance of the study, scope and limitation of the study. The next section, chapter two, focuses on theoretical and conceptual framework of literature review and related work for this study. This section presents brief understanding on evaluation of vegetation conditions for sustainable green legacy. The third chapter focuses on the general methodology followed, the data sets used in this study and detail explanation of the study area. This chapter highlights all the procedures and techniques applied for evaluating vegetation condition for sustainable green legacy. The fourth chapter deals with the results and discussion which presents the quantified results about vegetation leaf water content, chlorophyll concentration and vegetation health status in Entoto Natural Park. The last chapter presents conclusions and recommendations. This chapter elaborates the key findings and critical points that need further study have been forwarded as a recommendation for future work.

CHAPTER II: LITERATURE REVIEW

2.1. Green Legacy Initiative

The Green Legacy is a national reforestation initiative launched by the Ethiopian government to combat deforestation and increase forest cover in the country. By studying its impact on climate change, researchers can evaluate the effectiveness of this initiative in terms of mitigating greenhouse gas emissions, enhancing carbon sequestration, and promoting climate resilience. It is impossible to have a green and healthy world without planting trees. The reason is simple: the living organisms cannot survive without trees. Trees are an important tool in the fight against climate change. They store carbon and help cool the environment. Forests are the habitat of countless species of plants and animals and serve as an important source of biodiversity. Trees provide oxygen, food, water, clean air, medication, and jobs. That’s how trees ensure a healthy living environment for everyone (Edward Lambert,2023).

2.2. Use of Remote Sensing Tools in Vegetation Condition Assessment

Remote sensing is widely recognized as a valuable tool for determining and monitoring the state of vegetation over time (Pinter et al., 2003). However, when examining how vegetation responds to environmental changes, it is important to consider their spectral reflectance properties. When radiation interacts with a leaf, it can be reflected, absorbed, or transmitted, depending on the leaf's chemical composition and physical structure. The proportions of reflection, absorption, and transmission vary with different wavelengths (Blackburn, 2007).

Remote sensing is particularly useful in monitoring the presence, biophysical properties and seasonal dynamics of vegetation. The scientific basis of one of the most important satellite missions, the Landsat program, lies in the fact that photosynthetically active vegetation produces a unique electromagnetic reflectance spectrum (Almalki et al., 2022). Vegetation plays a crucial role in soil-water-atmosphere systems by reflecting and regulating the global energy budget, carbon, hydrological, and biogeochemical cycles. It also helps maintain climatic stability and provides stability against erosion and sediment transport. Therefore, vegetation can serve as a reliable indicator of changes in environmental, climatic, and hydrological factors such as precipitation, temperature, evapotranspiration (ET), and soil moisture (Kumari et al., 2021b)

2.3. Reflective properties of Electromagnetic Spectrum by Vegetation

Vegetation has got unique spectral reflectance properties, which quickly distinguishes it from other land cover categories in an optical image. The key to interpret multispectral data is to thus to understand the reflectance properties of different surfaces. The spectral properties of canopies of different plants are produced by the combination of optical properties of individual vegetative components, its effect on growth forms, density, height, tidal stage and soil type. Vegetation has different optical properties in visible, NIR and mid-infrared region (MNIR). Due to pigment absorption, there is low reflectance in the blue and red region of the electromagnetic spectrum. Infrared (IR) energy reflects well off healthy vegetation so the infrared bands can be useful in detecting changes in vegetation (Hardisky et. al., 1986).

The near-infrared (NIR) region of the electromagnetic spectrum has the highest reflectance in vegetation due to multiple scattering between airspaces in the leaf. The mid-infrared region is sensitive to leaf water content. Healthy leaves have elevated reflectance values in the NIR bands, so a reduction in spectral value over time can indicate vegetation stress or damage (Guyot, 1989)

2.4. Role of Remote Sensing Technology in Analysing Vegetation Chlorophyll

The amount of chlorophyll present in leaves plays a crucial role in the photosynthetic process and affects the spectral variation in visible bands. Therefore, accurately estimating the chlorophyll content in forest canopies is essential for assessing forest growth and identifying stress caused by diseases. Hyperspectral remote sensing with a high level of detail can be utilized to estimate chlorophyll content (Yang et al., 2015).

Precise determination of chlorophyll content in vegetation is extremely important. Remote sensing is a developing technology that offers a reliable method for detecting chlorophyll concentration in plants. Previous research has demonstrated that healthy and stressed plants exhibit distinct reflection patterns in the green peak and red edge areas, which are influenced by changes in pigment levels. Alterations in chlorophyll concentration directly affect plant productivity (Nandibewoor et al., 2017). The light energy to be converted into chemical energy by photosynthesis is first taken up by plant pigments, primarily related to green pigments chlorophyll. The absorption of light in the plants leaves causes energized state (Varpe et al., 2018a)**.**

In agricultural systems, the accurate spatial mapping of leaf chlorophyll content is important for monitoring vegetation health and plant stress, which can be used to guide fertiliser application in order to optimise crop yield and reduce excessive nutrient loss. Chlorophyll molecules facilitate the conversion of absorbed solar irradiance into stored chemical energy, through harvesting light energy and supply of electrons to the electron transport chain. The amount of solar radiation absorbed by a leaf is largely a function of the foliar concentration of photosynthetic pigments, and low chlorophyll contents can limit the photosynthetic capacity and reduce primary productivity of the plant (Croft et al., 2020).

The concentration of chlorophyll in leaves is an important factor that is regularly measured to indicate the content of chloroplasts, the mechanism of photosynthesis, and the metabolism of plants. Chlorophyll is a type of antioxidant compound that is stored in the chloroplasts of green leafy plants, and it is primarily found in the green areas of leaves, stems, flowers, and roots (Kamble, 2015). However, it remains unclear how leaf chlorophyll content varies among plant species, functional groups, and natural forest communities, especially on a large scale. Considering the importance of chlorophyll for photosynthesis, plants in natural communities should optimize light absorption and photosynthesis by adjusting chlorophyll content and ratios to enhance long-term growth and survival at an evolutionary scale (Li et al., 2018).

Chlorophyll is the main pigment responsible for photosynthesis, a crucial process that allows plants to absorb light energy and convert CO2 into dry matter. Therefore, monitoring chlorophyll content is a critical indicator for assessing plant growth (Wang et al., 2023).Biochemical parameters of plants are mainly controlling their overall photosynthetic and physiological activities. The most critical leaf biochemical properties are chlorophyll pigments which largely affect the photosynthetic activities. Pigments of chlorophyll are in the form of chlorophyll a and b, and each has distinct spectral absorption properties (Darvishzadeh et al., 2019). Both forms of chlorophyll pigments are valuable for plants’ energy conversion.

Chlorophyll is an antioxidant compounds which are present and stored in the chloroplast of green leaf plants and mainly it is present in the green area of leaves, stems, flowers and roots. However, the chlorophyll production is mainly depended on penetration of sun light and it is the main source of energy for plant (Kamble, 2015).

2.5. Application of Remote Sensing in detecting vegetation water content

Water in plants is necessary to enable important processes such as photosynthesis, respiration and absorption of nutrients. Grasses absorb water from the soil through their roots, which is transported to their plants, leaves and flowers to support various vital processes. When the water supply is insufficient, plants can experience water stress which can affect their growth, reproduction and survival. Water stress in plants is a complex health response to excess water in plants. When plants suffer from water stress, harmful interactions between plants and water occur, which can damage the physiology of plants. These include a decrease in cell water potential, cell turgor, and water content (Hsiao, 1973b).

Many researchers have investigated the possibility of using data analysis to estimate plant water content. The distance description of different plant water content by the amount of water per leaf or surface area (i.e. water depth) and water mass per plant mass dry matter. The problem was addressed at the level of trees, plants and forests. The function of the paper scales is well defined while the coating is more difficult known from the first principle (Jackson et al., 2004).

2.6. Electromagnetic Radiation and Spectral reflectance

When electromagnetic radiation hits the target, three different relationships are possible to do. A light that shines on a surface can have a part that is out, and another part that is out. devote yourself wholeheartedly, to the third part it is displayed. This part reflects the radiation made to us see the real thing. Furthermore, the color of an object is the result of a combination of wavelengths of light reflected by the object. The number of things that reflect, concentrate and emit The proportion of EMR varies between different materials of the earth (rocks, minerals, land, grass, water, etc.) depending on their type and condition (Hinkelman et al., 2020).

Thus, objects can be distinguished in remote sensing images using reflected EMR at different wavelengths of ultraviolet (UV), visible (VIS, 400–700 nm), near-infrared (NIR, 700–1200 nm), and short-wave infrared. (SWIR, 1200-2500 nm) spectral regions known as spectral signatures (Hardisky et. al.,1986).

2.6.1. Visible reflectance

The visible region ranges from 0.4-0.7 µm (400-700 nm), it is an extremely small portion of the electromagnetic spectrum but this corresponds to the spectral sensitivity of the human eye. The blue, green and red colours are ascribed to the approximate ranges of 0.4-0.7 µm (400-500 nm), 0.5-0.6 µm (500-600 nm) and 0.6-0.7 µm (600-700 nm) respectively. Reflectance in this region is mostly affected by absorption by chlorophyll and to a varying extent, other photosynthetic and photoprotective pigments (Blackburn, 2007).

2.6.2. Red-edge region of Electromagnetic Spectrum

The red-edge region is found within wavelengths 690 and 750 nm, where change in reflectance is prominent and is dominated by the strong absorption of red light by chlorophyll and high scattering of radiation in the leaf mesophyll. In this region, reflectance rises rapidly leading to a plateau of high reflectance in the near-infrared, where pigments no longer absorb radiation (Blackburn, 2007).

Red-edge position has been applied in the study of biomass and estimation of chlorophyll contents in vegetation, while some studies have found that this position is less prone to the effects of soil background and atmosphere. Strong correlation has been reported between red-edge position, chlorophyll concentration and leaf area index. The red-edge region of the reflectance spectrum has been used as a means of identifying stress in plants (Varpe et al., 2018b).

2.6.3. Near-infrared (NIR) region of Electromagnetic Spectrum

Near NIR wavelengths between 700 and about 1000 nm. The area is displayed with a high resolution mainly due to light scattering by the tissue or cellular structure. THE The internal structure of the foil is 70-80% of the reflection difference and NIR to dry paper describes the remaining differences. A book high reflectance in the NIR at ~800 nm and a decrease at A signal at 800 nm can be taken as an indication of a reduction in the aperture and leaf mesophyll under stress conditions (Hakkel et al., 2022).

2.6.4. Shortwave infrared (SWIR) region of Electromagnetic Spectrum

The SWIR ranges between 1000 and 2500 nm and is characterised by radiation absorption by the leaf water. It is heavily influenced by water in plant tissue. Water stress influences reflectance in the SWIR region because of a reduction of water content. The wavelengths at 1530 and 1720 nm were the most appropriate for assessing vegetation water as they are heavily influenced by water in plant tissue. variables such as the equivalent water thickness are not the only parameters responsible for significant reflectance variations within the SWIR range (Thimsen et al., 2017).

Other controls including interior design and dry matter content. Internal structure and dry matter ontent affects attention in the wavelength range of 700-2500 nm, where the water vapor equation affects the wavelength from 900 to 2500 nm. This represents 86.7% of the reflectivity in SWIR, internally Nature and dry matter represent only 5.8% and 7.5% individually. Therefore, the SWIR reflection value alone is not sufficient for it recover the water content of the grass and the number of leaves (Thimsen et al., 2017).

2.7. Spectral Properties of Vegetation

Visualization of vegetation is done by acquisition Information and display of electromagnetic waves from canopies to use sensor. He is well aware of the reflectance of light spectrum of wood changes in plant species, tissue water content, and other internal factors something. Plant exposure to various electromagnetic fields (the appearance or characteristics of the vegetation) is determined by the chemistry and morphology of the organ surface (Xue & Su, 2017)**.**

In spectral reflectance measurement, the reflected light can be measured as a percentage of the incident light at different wavelengths across an entire electromagnetic spectrum. The spectrum spans from the cosmic, gamma, X-rays, ultraviolet, visible, and near infrared, far infrared, microwave and the long radio wavelengths. Spectral reflectance signatures represent the relationships between electromagnetic radiation (EMR) and the physical and chemical properties of the object of interest. They are the fundamental means of data representation and analysis in all forms of passive reflected sunlight remote sensing. (Varpe et al., 2018b)**.**

2.8. Spectral Indices

2.8.1. Normalized Difference Water Index (NDWI)

NDWI, derived from the NIR and short infrared (SWIR) channels, reacts to changes in water content (absorption of SWIR radiation) and spongy mesophyll (NIR radiation reflectance) in plant cover, individually (Gu et al., 2008). Normalized Difference Vegetation Index (NDWI) is a satellite based near-infrared (NIR) and atmospheric index Infrared (SWIR) channel. The SWIR spectrum reflects changes in both water content of grass and spongy mesophyll structure of grass canopies, where the NIR reflectance affects the internal structure of the leaves and leaf dry content but not as a function of water content (Jackson et al., 2004a).

The combination of NIR and SWIR eliminates the resulting differences The internal structure of the paper and the dry paper content, thereby improving accuracy recover the water content of the grass. The amount of water in the internal structure of the leaves largely controlled different wavelengths in the SWIR range of the electromagnetic spectrum. SWIR As a result, negative feedback is associated with the water content of the paper (Gu et al., 2008). It is computed using the near infrared (NIR) and the short-wave infrared (SWIR) reflectance (Eq.1), which makes it sensitive to changes in liquid water content and in spongy mesophyll of vegetation canopies (Jackson et al., 2004a).

$$NDWI = (NIR-SWIR) / (NIR+SWIR) \quad \text{Equation 2.1}$$

2.8.2. Green Normalized Difference Vegetation Index

Green Normalized Difference Vegetation Index (GNDVI) is a vegetation index to measure photosynthetic activity and is also a commonly used vegetation index to measure chlorophyll. grazing. The grass index from the reorganized green leaf is different (GNDVI) is directly related to the photoactive pigment of plants separates itself from NDVI by using green bands instead of red (Alvino et al., 2020)

$$GNDVI = (NIR - Green)/ (NIR + Green) \quad \text{Equation 2.2}$$

2.8.3. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI), one of the first remote sensing analytical products used to simplify the complexity of multispectral imaging, is currently the most widely used index for vegetation assessment. This popularity and widespread use is related to how NDVI can be calculate that any multispectral sensor has a visual bandwidth in the near-IR band. NDVI is an intermediate range function reflected radiation in the near infrared (NIR) and visible (VIS) from the surface (Anjali & Patil, 2021).

Normalized Difference Vegetation Index (NDVI) converts multi spectral data into single image band which displays vegetation distribution. To quantify the healthy green vegetation based on satellite images, NDVI a graphical indicator makes use of the differential reflection of green vegetation in the visible and near infrared-portions (NIR) portion of the spectrum thus providing condition of the vegetation. The value of NDVI ranges from -1 to +1, value leaning towards +1 denoting healthier vegetation (Anjali & Patil, 2021)

NDVI is calculated as:

$$NDVI = (NIR-RED) / (NIR+RED) \qquad \text{Equation 2.3}$$

NIR represents irradiance reflectance in the near infrared spectrum and RED in the visible. Applying the concept of normalization, the comparison of absorbed incident light to reflected can be placed in a simple ratio on a scale varying between -1.0 and 1.0 making evaluation of vegetation responses comparable. Active sensors contain modulated light emitting diodes that emit light at specific wavelengths on a canopy. Rather than being reliant on ambient sunlight, active sensors measure the amount of emitted light reflected (Seidlová et al., 2022). NDVI values can be impacted by any factor causing a reduction in vegetation growth. Users of NDVI must be aware of limiting factors imparting stress on a production area.

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2.9. Forest Development and Eucalyptus Plantation in Ethiopia

The practice of afforestation or modern tree planting in Ethiopia, specifically using the exotic species of Eucalyptus, was initiated during the reign of Emperor Menelik II in the late 19th century. Emperor Menelik II conducted experiments with over ten different varieties before embarking on this endeavor (Birara Dessie et al., 2019). The development of forest plantations in Ethiopia is characterized by the predominant use of non-native species, such as eucalyptus trees, alongside indigenous species like junipers (Gil et al., 2010).

In the initial decade, the radius of eucalyptus cultivation expanded from the capital city of Addis Ababa. Subsequently, missionaries played a role in introducing eucalyptus cultivation in Ghimbi, Debre Tabor, and Harar. Over time, eucalyptus cultivation spread from these initial nodes to rural areas. It began with planting in urban areas, then extended to homesteads, and eventually reached agricultural lands through the efforts of farmers and urban residents (Stanturf et al., 2013).

Eucalyptus plantations in Ethiopia have experienced significant growth, particularly among smallholder farmers and small forestry firms. As a result, Ethiopia now ranks second in Africa in terms of the total area dedicated to eucalyptus cultivation (Gil et al., 2010). The introduction of eucalyptus species in Ethiopia aimed to meet the increasing demand for wood as a fuel source and construction material, while also alleviating pressure on the existing natural vegetation (Jenbere et al., 2012). In Ethiopia, eucalyptus is primarily utilized for firewood and building materials. However, there is significant untapped potential for the production of organic oil, especially from eucalyptus globulus, as it is less susceptible to diseases and insect pests (Dessie et al., 2019).

Ethiopian farmers showed a preference for cultivating eucalyptus trees instead of indigenous trees due to the financial benefits it provided. These benefits included covering expenses like government taxes, school fees, contributions to social organizations such as mahibers, zikirs, iddirs, and using the income for construction purposes at different stages (Zerga & Berta, 2016a). The establishment and ongoing presence of eucalyptus plantations have had a substantial impact on enhancing the well-being of rural communities, reducing poverty, and alleviating the strain on remaining native forests in the highlands of Ethiopia (Tadele et al., 2014).

Furthermore, various components of eucalyptus serve different purposes for small-scale farmers and impoverished urban households in Ethiopia. Branches, leaves, stems, roots, and barks are utilized for fuelwood, while the stem can be employed for construction, fuelwood, or transmission poles. In many regions of Ethiopia, all parts of the eucalyptus tree, including the stem, bark, branches, leaves, and roots, are harvested to support daily livelihood activities (Daba, 2016).

Introduction of Eucalyptus species to Ethiopia and utilization for versatile purposes has passed more than a century. Currently, its high adaptability, wide distribution even on degraded lands and socio-economic contribution as a short rotation and high yielding cash crop is significant. It became the primary species to many farmers and wood lot growers of Ethiopia and a controversial and dilemma species forest products demand; well-managed Eucalyptus species could be one alternative species to Ethiopia. Eucalyptus since its introduction have been widespread in the country and used as alternative source of raw material to supply the ever-increasing demand for different forest products including construction, industrial, fuel wood and composite products. Since 1985 to present time out of the 800 Eucalyptus species of the world, about 60 have been introduced and planted most species as trial research in the different regions of Ethiopia (Gil et al., 2010).

2.9.1. Environmental and socio-economic implication of Eucalyptus

Eucalyptus can be cultivated with minimum management activities for different products and services. The main cultivation practice needed to produce Eucalyptus were weed control, pruning, fertilization, pest and disease control, harvesting and post harvesting activities. Different literatures revealed that, Eucalyptus species were planted for the first time for the purpose of curiosity in botanic gardens, arboreta (tree collec-tions), parks and for amenity (Dessie et al., 2019).

Later, various interested parties understood the various benefits of eucalyptus trees, including their benefits as trees source of firewood, charcoal, wood, poles, poles, I support, plywood, paper paper, fiberboard, eucalyptus oil production, shade and shelter, decoration for commercial purposes and as a source of nectar for honey production (Turnbull, 1999).

Zerga & Berta (2016) also indicated that, Ethiopian farmers primarily cultivate Eucalyptus trees with the intention of utilizing them as a source of fuel wood, for fencing, as farm tools, in the construction of houses, for generating cash income, and for soil and water conservation purposes.

Eucalyptus can start providing output from third or fourth year depending on the intention of farmers and type of the product to be extracted if the planting sites have a good condition of nutrient and water. Moreover, Eucalyptus species have been accepted as suitable for shelterbelts and for mixture with agricultural crops in Columbia, Tunisia, Senegal, Nigeria, Cameroon, Pakistan, India, China, Sri Lanka, and Bangladesh. Given the diverse products of Eucalyptus plantation and arguable diverse effects, no single fact should have taken as sufficient evidence either to promote or discourage the planting of the Eucalypts, though results from many studies taken together may yield valid generalizations (Dessie et al., 2019).

For many reasons, there is increased interest in using wood for energy, and short-rotation plantings of Eucalyptus will likely be an important source of feedstock. Many Eucalyptus species have desirable properties for bioenergy plantations, including rapid growth rates and high wood density. The indeterminant growth pattern and evergreen foliage allow eucalypts to grow whenever climatic conditions are suitable. The sclerophyllous leaves of eucalypts allow them to withstand very dry conditions and may also be an adaptation to low nutrient conditions (Stanturf et al., 2013).

2.9.2. The Dilemma of Eucalyptus

Although Eucalyptus trees provide significant socio-economic and environmental advantages globally and in Ethiopia, there is considerable disagreement among different stakeholders regarding the benefits and drawbacks of cultivating Eucalyptus. While some completely oppose its planting, others strongly support it, and there are those who have reservations or uncertainties about it. For instance, Gil et al., (2010) revealed that Eucalyptus has negative impacts when it is planted on wrong sites, done by replacement of existing natural forests coupled with poor management and silvi-culture. When planted in appropriate locations that are marginal or degraded, and with effective management and care, Eucalyptus species can have more positive impacts that outweigh the negative ones. While there is a general perception that Eucalyptus plantations contribute to environmental issues, researchers have not reached a consensus on the disadvantages.

Controversies surrounding Eucalyptus include debates on its water consumption, nutrient uptake from the soil, impact on undergrowth biodiversity, and its effectiveness in controlling soil erosion. Turnbull (1999) revealed that enacting laws mandating the use of fast-growing tree species like Eucalyptus for the production of charcoal, poles, and firewood would be essential in order to mitigate the ongoing depletion of natural forests. The primary reasons in favor of planting Eucalyptus trees include their rapid growth rate, low maintenance requirements, adaptability to various ecological zones and poor conditions, ability to regenerate after harvesting, resilience against environmental stress and diseases, as well as the convenience of collecting and storing their seeds without the need for pre-sowing treatments(Zerga & Berta, 2016b).

Eucalyptus species have been widely recognized in various countries for their versatility, particularly in Columbia, Tunisia, Senegal, Nigeria, Cameroon, Pakistan, India, China, Sri Lanka, and Bangladesh. They are highly regarded for their suitability in creating shelterbelts and for their ability to be combined with agricultural crops. Likewise, no other species be it indigenous or exotic, can replace them in the future to bridge the widening gap between demand and supply of wood (Turnbull, 1999).

2.10. Research Gaps from Empirical Review

I have reviewed several empirical research articles which are published on international journals which are related to my thesis title 'Evaluation of Vegetation Conditions for Sustainable Green Legacy: A case of Entoto Natural Park, Addis Ababa, Ethiopia'. The research and knowledge gap have been identified as follows:

- Most of the studies are conducted outside Ethiopia. No research is conducted on evaluation of vegetation condition in Entoto Natural Park, suggests more studies are required to evaluate vegetation conditions in Entoto Natural Park
- The reviewed articles deliberated on the identification of vegetation from other land use land covers, the vegetation leaf water moisture, vegetation chlorophyll concentration and vegetation health status have not been well investigated.
- Studying vegetation condition using Remote Sensing has not been well investigated in Ethiopia; this indicates that more studies are required to provide increased understanding about the vegetation conditions like leaf moisture content, chlorophyll concentration and vegetation health status using Remote Sensing technology.

2.11. Knowledge gap from the reviewed articles

Although the above body of research clearly evaluated the vegetation conditions employing various spectral indices, the vegetation leaf water content, chlorophyll concentration and vegetation health status and its contribution in combating climate change has not been properly investigated. Global climate change has resulted in heat waves due to rising temperature, increased atmospheric CO2 level, frequent spells of drought and higher precipitations. In addition to climate change, the natural resource depletion as well as the anthropogenic activities have created serious challenges to agriculture sustainability causing lower agricultural yields, threat to the food security and food and feed safety (Miraglia et al., 2009; Pisante et al., 2012). Furthermore, the research analysed the vegetation conditions through in situ sampling and ground survey investigation. However, the multispectral satellite image and other geospatial indices has not been fully utilized for the entire investigation.

CHAPTER III: METHODS AND MATERIALS

3.1. Description of the Study Area

3.1.1. Geographic Location

Entoto Natural Park is located between 38° 48'00" and 38° 47'01" East and 09°04 '05" and 09°07'33" North. The Park is located on the south-eastern slopes of Mount Entoto between the northern border of the city of Addis Ababa (2,600 m) and the ridge (over 3,100 m). Its total area is 2300 hectares. However, the total area of the Entoto slope together with the Entoto Natural Park is 1300 ha (Tesema & Berhan, 2019). The base of the Entoto mountain range has a geological structure similar to the mountain top, consisting of volcanic rocks, reddish rhyolite, trachytes, ignimbrites, tuffs, feldspars and black obsidian. The natural flora is Afro-Montana. Where the drainage is blocked, there is forest with open grassland.

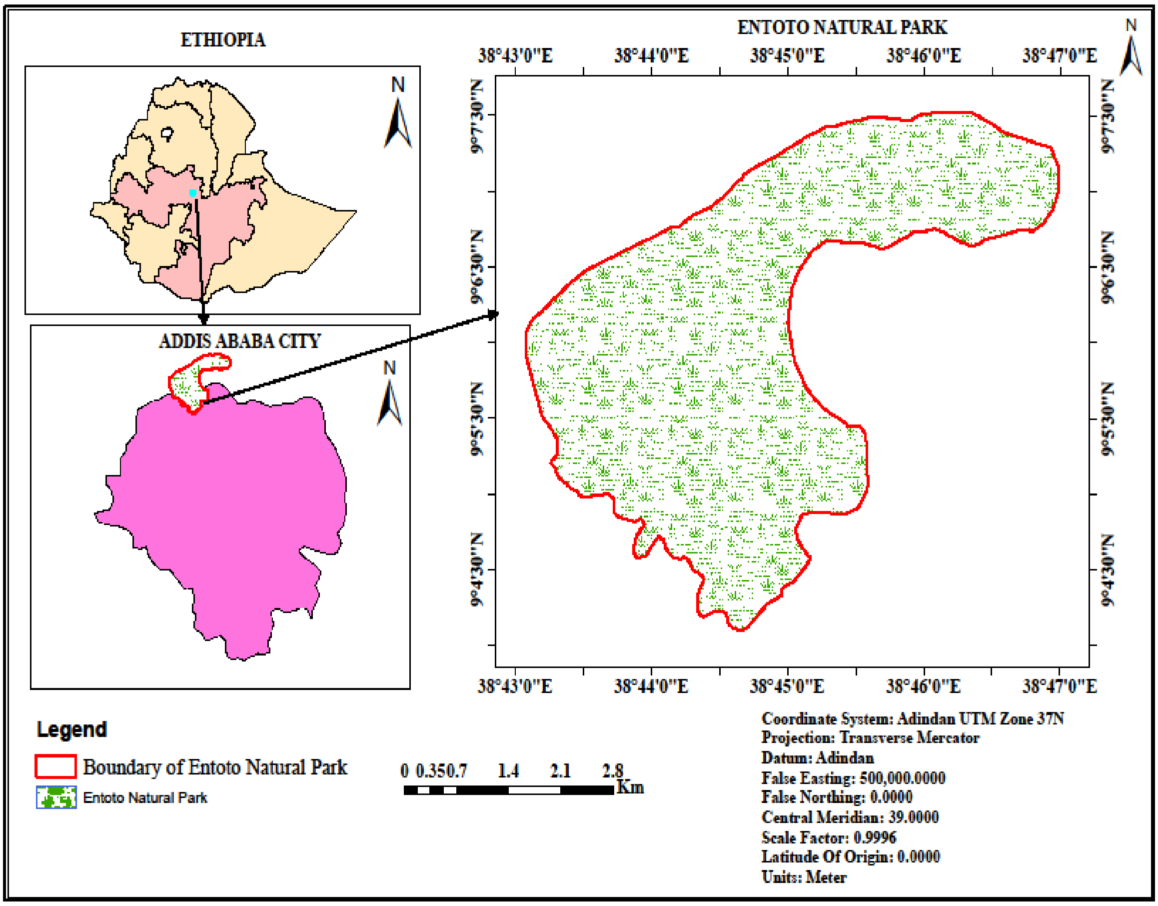


Figure 3.1. Location map of the study area

3.1.2. Topography

Entoto Natural Park is located on the south-eastern slopes of Mount Entoto between the northern border of the city of Addis Ababa (at an altitude of 2,600 m) and the path along the ridge (above 3,100 m). The climate of Entoto Natural Park is a low-pressure area, also known as the Tropical Convergence Zone, which moves north and south across the equator on the African continent seasonally. The average maximum temperature varies from 24 .3 °C in May to 20.3 °C in August. The average minimum temperature varies from 11.8 °C in May to 7.7 °C in December. The main rainy season is from June to September, accounting for approximately 70% of the annual rainfall, with the highest peak in August. Another small rain peak is in April (Tesema & Berhan, 2019). According to the National Meteorological Agency of Ethiopia (NMAE, 2014), Addis Ababa and its surrounding areas receive 270 mm of rainfall during the summer season (June, July and August) and at least 12-32 mm during the winter season (December, January and February). The average annual rainfall in the study area and the city of Addis Ababa is (1165-1170 mm). Entoto Natural Park has a trail that forms the border between Addis Ababa and Oromia regions and separates two important watersheds, the Abay (Blue Nile) in the north and the Awash in the south.

3.2. Data Source and Material

3.2.1. Data Source

For this study Landsat-8 OLI (Operational Land Imager), Landsat -7 ETM+ (Enhanced Thematic Mapper) and Landsat -5 TM (Thematic Mapper) was used. The Operational Land Imager (OLI) measures the near infrared, visible and short-wave infrared portions of the electromagnetic spectrum.

Table 3-1: Data used and its sources

S/N	Satellite	Sensor	Resolution	Source	Acquisition season
1	Landsat 5	TM	30m	USGS Earth Explorer	Dry & wet seasons
2	Landsat 7	ETM+	30m	USGS Earth Explorer	Dry & wet seasons
3	Landsat 8	OLI	30m	USGS Earth Explorer	Dry & wet seasons

Table 3-2: Band Specifications for Landsat 5 Thematic Mapper (TM) and Landsat 7 ETM+

Landsat 5 TM		
Bands	Wavelength (micrometres)	Resolution (meters)
Band 1 - Blue	0.45-0.52	30
Band 2 - Green	0.52-0.60	30
Band 3 - Red	0.63-0.69	30
Band 4 - Near Infrared (NIR)	0.76-0.90	30
Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75	30
Band 6 - Thermal	10.40-12.50	120 (30)
Band 7 -Shortwave Infrared (SWIR) 2	2.08-2.05	30
Landsat 7 ETM+		
Bands	Wavelength (micrometres)	Resolution (meters)
Band1-Blue	0.45-0.52	30
Band 2-Green	0.52-0.60	30
Band 3-Red	0.63-0.69	30
Band 4-NIR	0.77-0.90	30
Band 5-SWIR1	1.55-1.75	30
Band 6-TIR	10.40-12.50	30/60
Band 7-SWIR2	2.09-2.35	30
Band 8-Panchromatic	0.52-0.90	15

Table 3-3: Band specifications for Landsat 8 Operational Land Imager (OLI)

	Landsat 8 OLI	
Bands	**Wave length (micrometre)**	**Resolution (meters)**
Band 1- Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3-Green	0.53-0.59	30
Band 4-Red	0.64-0.67	30
Band 5- Near Infrared	0.85-0.88	30
Band 6 –SWIR1	1.57-1.65	30
Band 7-SWIR 2	2.11-2.29	30
Band 8-Panchromatic	0.50-0.68	15
Band 9-Cirrusus	1.36-1.38	30
Band 10- TIRS1	10.6-11.19	100
Band 11 -TIRS2	11.50-12.51	100

3.2.2. Software Used

Software used in this study was selected based on the capability to work on the existing problems in achieving the predetermined objectives. The details of software's used in this study are tabulated and explained in Table 3.2 below.

Table 3.4 Software used

S.no	Software	Version	Purpose
1	Erdas Imagine	2015	For image pre-processing and calculating spectral indices
2	ArcGIS	10.8	For preparing vegetation condition layout map
3	Google Earth Pro	-	Use as a base map in visual image interpretation, and generate coordinate points for the image
4	SPSS 22	2022	For making graphs and charts

3.2.3. Data acquisition techniques

To achieve the objective of this study, multispectral satellite imagery like Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI for different chronological timelines were downloaded from USGS (United States Geological Survey) Earth Explorer website. The official USGS Earth Explorer website for scientific research data source is https://earthexplorer.usgs.gov. USGS Earth Explorer allows downloading satellite imagery and other geospatial data for free. Additionally, various journal papers which are related to this study were also used as secondary data.

3.2.4. Variables and Indicators

Table 3-5: Indicators of the selected variables for evaluation of vegetation condition in Entoto Natural Park

S.No	Variables	Indicators
1	Vegetation leaf water moisture	Values of Normalized Difference Water Index (NDWI)
2	Vegetation chlorophyll Concentration	Values of Normalized Difference Chlorophyll Index (NDCI)
3	Vegetation health status	Values of Normalized Difference Vegetation Index (NDVI)

3.3.Method of Data Analysis

This study analysed the vegetation condition in Entoto Natural Park using Multispectral Remote Sensing and spectral Indices. To achieve the objectives of the study, three different spectral indices were used. These are Normalized Difference Water Index (NDWI), Normalized Difference Chlorophyll Index (NDCI) and Normalized Difference Vegetation Index (NDVI). The three spectral indices were derived and calculated from multispectral satellite imagery. The satellite imageries employed in this study were downloaded from USGS Earth Explorer official website. These satellite imageries are Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) from the year 1993 to 2023 with 10 years interval.

3.3.1. Image Pre-processing

Satellite image by its nature have some distortion, noise, haze and stripes. Therefore, before processing the data, image pre-processing activities were done. Preprocessing includes importing, layer stacking, and sub-setting of the image based on the boundary of Entoto Natural Park, geometric correction, radiometric correction, and removal of stripes, pan sharpening and other image enhancement techniques. Radiometric correction is a removal of atmospheric noise to make more representatives of the ground truth conditions based on the sensors.

3.3.2. Image Classification

In remote sensing, Image classification is the task of extracting information classes from a multiband raster image or extracting information based on the reflectance of the object and it serves specific aims; which is converting image data into thematic data. Digital image classification techniques assemble pixels to represent classes. Image classification uses the reflectance statistics for individual pixels. Pixels were grouped based on the reflectance properties of pixels called clusters. The users identify the number of clusters to generate and which bands to use. With this information, the image classification software generates clusters. In this research supervised classification techniques are used.

3.3.3. Accuracy Assessment

An overall accuracy was calculated by dividing the sum of the correctly classified sample units by the total number of sample units. Accuracy Assessment is a kind of process to compare the classification with ground truth or other data. It allows evaluating a classified image file (Eastman, J. R., 2009).

Overall Accuracy is essentially tells us out of all of the reference sites what proportion were mapped correctly. The overall accuracy is usually expressed as a percent, with 100% accuracy being a perfect classification where all reference site were classified correctly. Overall accuracy is the easiest to calculate and understand but ultimately only provides the map user and producer with basic accuracy information. The diagonal elements represent the areas that were correctly classified. To calculate the overall accuracy you add the number of correctly classified sites and divide it by the total number of reference site.

3.3.4. Derivation of Normalized Difference Water Index (NDWI)

To achieve the first specific objective of this study, Normalized Difference Water Index was used. Gao (1996) developed the Normalized Difference Water Index (NDWI) for determination of vegetation water content based on physical principles.

NDWI = (NIR – SWIR) / (NIR + SWIR)   Equation 3.1

Table 3-6: Required bands to determine NDWI from different Landsat imagery

Spectral Index	Satellite Image	Required bands	Formula	Reference
NDWI	Landsat 8	B5 & B6	(B5-B6) / (B5+ B6)	Bahadur, 2018
	Landsat5	B4 & B5	(B4- B5) / (B4 + B5)	
	Landsat7	B4 & B5	(B4 –B5) / (B4 + B5)	

The SWIR channel is critical for estimating vegetation water content, and the NIR channel was needed to account for changes in leaf internal structure and dry matter content. The indices that separated the SWIR channel from the NIR channel were sensitive to water mass or volume, not water percentage (Acharya et al., 2018). The Normalized Difference Water Index (NDWI) is a satellite-derived index from the Near-Infrared (NIR) and Short-Wave Infrared (SWIR) channels. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content (L. Wang et al., 2013). The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content (Jackson et al., 2004b).

The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. SWIR reflectance is therefore negatively related to leaf water content. The NDWI product is dimensionless and varies between -1 to +1, depending on the leaf water content but also on the vegetation type and cover. High values of NDWI correspond to high vegetation water content and to high vegetation fraction cover (Serrano et al., 2019) .

Low NDWI values correspond to low vegetation water content and low vegetation fraction cover. In period of water stress, NDWI will decrease. Vegetation water content at the leaf and canopy scales is often estimated using specific spectral reflectance bands and spectral reflectance indices from near infrared, middle infrared (MIR) and short-wave infrared (SWIR) regions of the electromagnetic spectrum (Jackson et al., 2004b). NIR and MIR spectral bands are highly correlated to water content of vegetation and soils. Spectral bands from these regions have been used to delineate stressed trees from non-stressed trees.

In these regions of the electromagnetic spectrum, leaf water content has been remotely assessed using bands 1550 nm to 1750 nm (Tucker, 1980), as well as the ratio of spectral bands 1550 nm to 1750 nm and 2080 to 2350 nm. Several relationships have been identified between specific spectral bands in the SWIR region and different ground-based measurements of vegetation water stress such as relative water content and leaf water potential (Wayant et al., 2018.)

In particular, Foutry and Baret (1997) reported that the spectral wavelengths at 1530 nm and 1720 nm are most appropriate for assessing vegetation water content in both woody and herbaceous vegetation species. Several spectral indices have been derived to detect changes in vegetation water content for the remote assessment of vegetation water stress. The sensitivity of such spectral indices to changes in vegetation water content is influenced by the internal leaf structure. Therefore, some spectral indices may not be suitable for the detection of low or moderate levels of vegetation water stress. The spectral index that has been successfully used is the normalised difference water index (Gao, 1995).

3.3.5. Estimating Green Normalized Difference Chlorophyll Index (GNDVI)

To achieve the second specific objective of this study, GNDVI (Green Normalized Difference Vegetation Index) was derived from satellite imagery. GNDVI is modified version of NDVI to be more sensitive to the variation of chlorophyll content in the vegetation. GNDVI spectral index has the capability to identify different concentration rates of chlorophyll (Alvino et al., 2020)

$$GNDVI = (NIR-GREEN)/(NIR+GREEN) \qquad \text{Equation 3.2}$$

Table 3-7: Required bands to determine GNDVI from different Landsat imagery

Spectral Index	Satellite Image	Required bands	Formula	Reference
GNDVI	Landsat 8	B5 & B3	(B5-B3) / (B5+B3)	Gitelson et al. 1996
	Landsat5	B4 & B2	(B4-B2) /(B4 + B2)	
	Landsat7	B4 & B2	(B4-B2) / (B4+B2)	

3.3.6. Derivation of Normalized Difference Vegetation Index (NDVI)

To achieve the third specific objective of this study, Normalized Difference Vegetation Index (NDVI) was used. This spectral index has the capability to analyse the vegetation health status based on its spectral reflectance. NDVI value was calculated from satellite imagery for different temporal scale. According to (Anjali & Patil, 2021), the reason NDVI relates to vegetation is that, the one which is well vegetated reflects better in the near infrared part of the spectrum. The value of NDVI is between -1and 1. Normalized difference vegetation index (NDVI) was acquired from spectral reflectance measurements in the visible (RED) and near infrared regions (NIR) in the ArcGIS environment (Wayant et al., 2018.).

The index was defined by the following equation.

$$NDVI = NIR-RED/NIR+RED \qquad \text{Equation 3.3}$$

Where RED is visible red reflectance and NIR is near infrared. The wavelength range of the NIR band is (750-1300 nm), the red band is (600-700 nm) and the green band is (550 nm).

Table 3-8: Required bands to determine NDVI from different Landsat imagery

Spectral Index	Satellite Image	Required bands	Formula	Reference
NDVI	Landsat 8	B5 & B4	(B5-B4)/(B5+B4)	Rouse, 1973
	Landsat5	B4 & B3	(B4-B3)/(B4+B3)	
	Landsat7	B4 & B3	(B4-B3)/(B4+B3)	

NDVI is driven by perceived vegetation, which is the difference between the NIR and the red zone. Very low NDVI values (-1 to 0) describes dead plants (Huang et al., 2021b).
Low NDVI values (0-0.33) represent diseased pant or vegetation. Moderate values (0.33 – 0.66) describe moderately healthy green vegetation. While high values (0.66-1) describe very healthy green vegetation. NDVI values closest to 0 shows bare soil and while negative NDVI value is for water body (Robinson et al., 2017).

3.4. Conceptual Framework

The theoretical framework presented the review of literature on different theories related to the different methods of analysing vegetation condition and different models of calculating spectral indices from satellite imagery and its role in examining vegetation leaf water content, chlorophyll concentration and vegetation health status. In addition, the empirical review has presented vegetation condition in the previous studies. Previous studies conducted on utilizing various satellite datasets and methods for deriving spectral indices and vegetation condition assessment. Depending on the reviewed theories and empirical frameworks, to answer the questions, objectives and statement of the problem of this study the conceptual framework is developed.

The rationale for utilizing remote sensing for evaluating vegetation condition in this study is that RS method is faster and applicable to various natural resource management including, vegetation. RS allows analysis of vegetation condition at spatial scales that are impossible to achieve with traditional methods. Conventional approaches to evaluation of vegetation condition rely on field surveys vegetation at sampled locations. Such approaches are however characterized as being labour-intensive and time-consuming. Moreover, it is often difficult to achieve the desired analysis just based on a limited number of sampled points. The conceptual framework is presented below graphically to achieve the objectives and answer the research questions of this study.

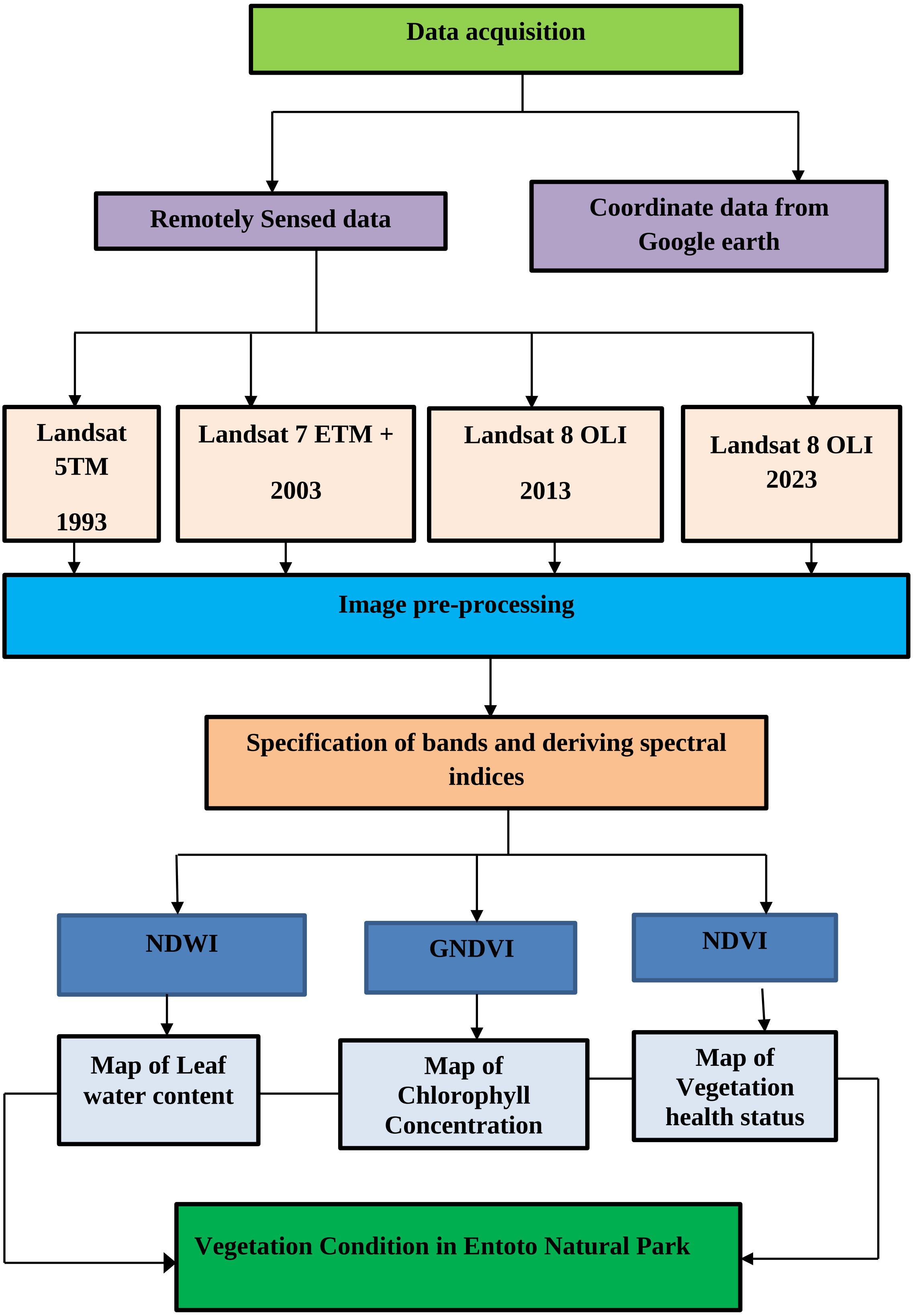


Figure 3.2: Methodological Scheme of the Study

CHAPTER IV: RESULT AND DISCUSSION

In this chapter, the results obtained from data analysis as per the study objectives, and discussion on result are presented and described in detail.

4.1. Rainfall Status of Entoto Natural Park

The dry season in Entoto Natural Park lasts from mid-September until the end of May, while the primary rainy season occurs from June to September. During the short rainy season, which takes place from February to April, there is a significant increase in rainfall and temporary rises in river flows within the park. The long rainy season, on the other hand, spans from June to September and experiences the highest amount of precipitation. Over a period of 30 years, the average rainfall during this season amounts to approximately 900 mm, as determined from meteorological data.

In Entoto Natural Park, there are distinct seasons that affect the weather patterns and water levels. The dry season stretches from mid-September to the end of May, bringing with it drier conditions and less rainfall. This period allows for a drier and more arid environment within the park. However, from June to September, the main rainy season occurs. This is when the park experiences the highest amount of rainfall, with an average of about 900 mm over a span of 30 years.

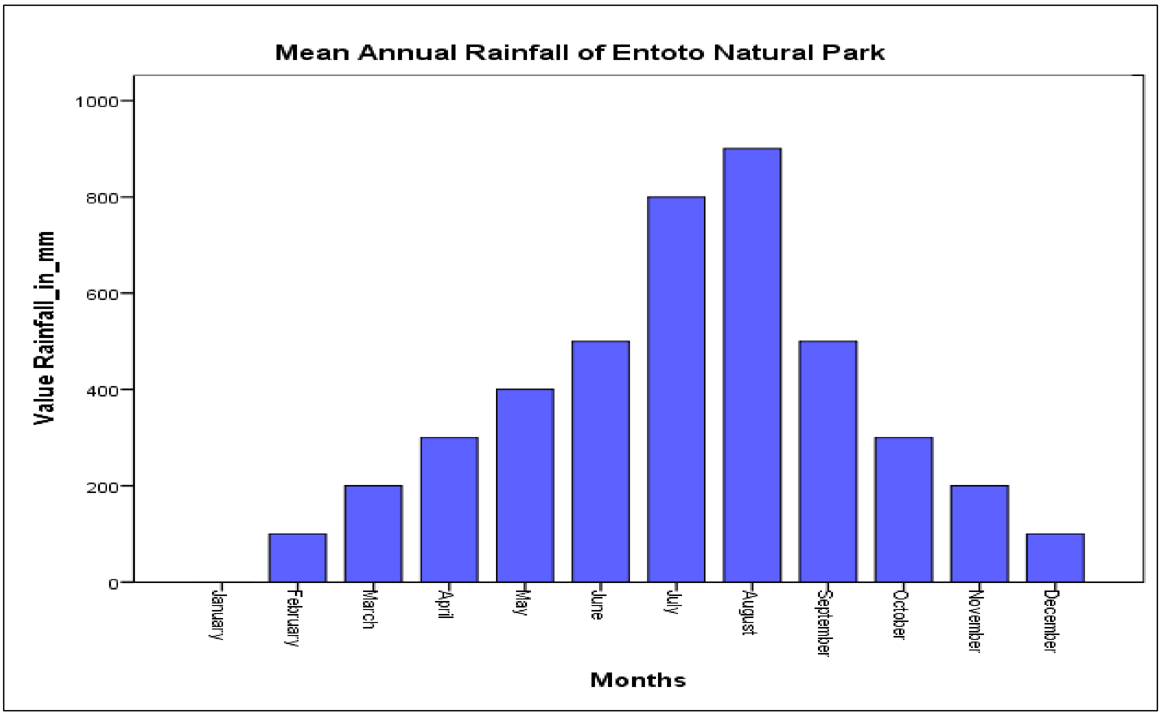


Figure 4-1: Mean annual rainfall of Entoto Natural Park

4.2. Physical Properties of Soil in Entoto Natural Park

Entoto Natural Park has different soil types which are characterized by different physical properties. It includes sand, silt and clay soils. Sandy soils are characterized by their high proportion of sand particles and low clay content. They are often referred to as light soils due to their weight. Clay soils are characterized by their high proportion of clay particles, which gives them a heavy and sticky texture. They have a higher nutrient content compared to sandy soils, making them fertile for plant growth.

Silt soils are made up of intermediate-sized particles and are considered fertile. They have a good drainage capacity and can hold more moisture than sandy soils. However, silt soils are prone to compaction, meaning they can become densely packed and difficult for plant roots to penetrate. These soils are often found in river valleys and floodplains where they are deposited by water. They have a smooth texture and can be easily worked with. Silt soils tend to be rich in nutrients, making them suitable for agriculture. The following graph illustrates the physical properties of soil in Entoto Natural Park.

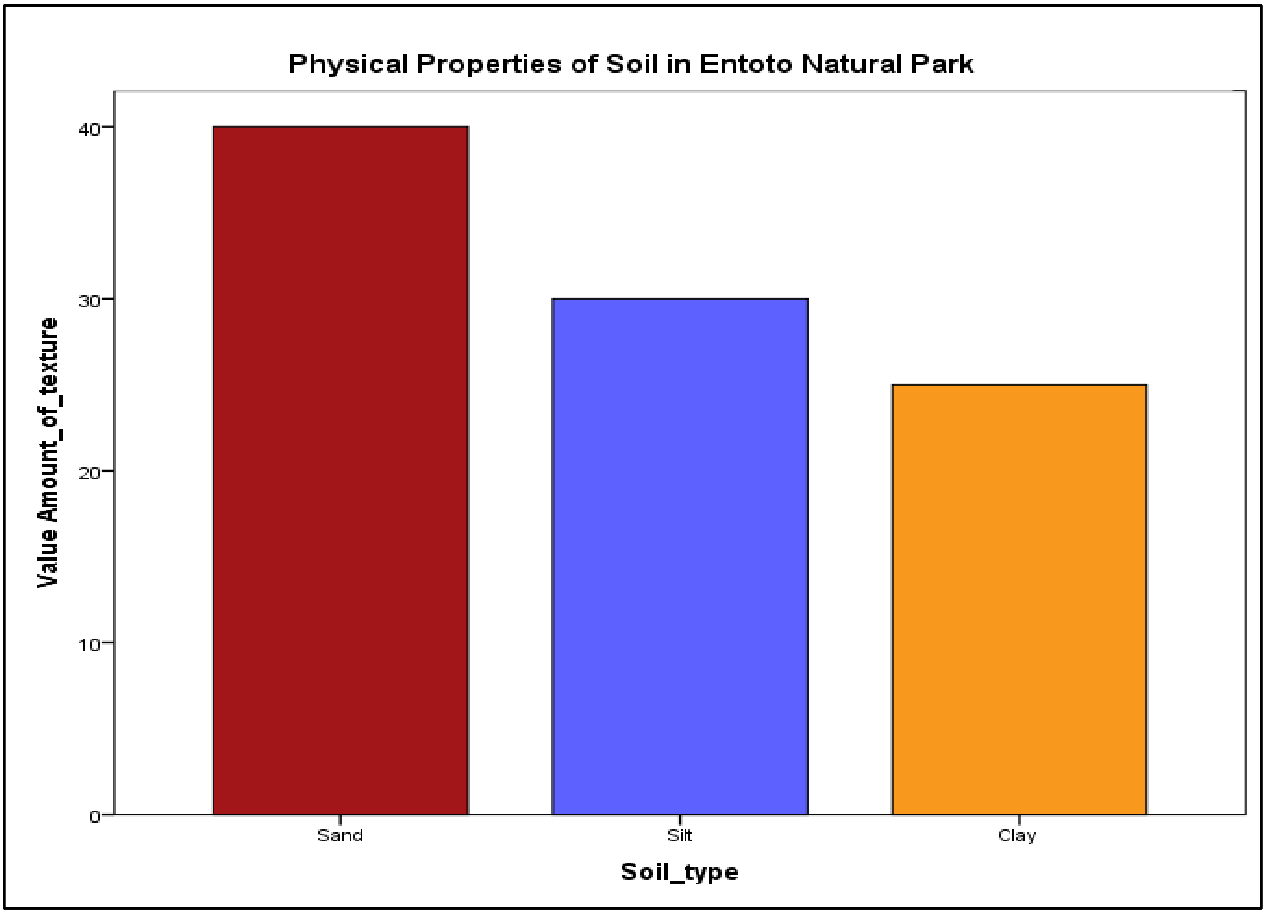


Figure 4-2: Physical Properties of Soil in Entoto Natural Park

4.3. Classification of Plant Species in Entoto Natural Park

Various plant species are found in Entoto Natural Park. These plant species includes Eucalyptus globulous, Juniperus pirocera, Hagenia abyssinica and Erica arborea. The following map illustrates the classified plant species in the park.

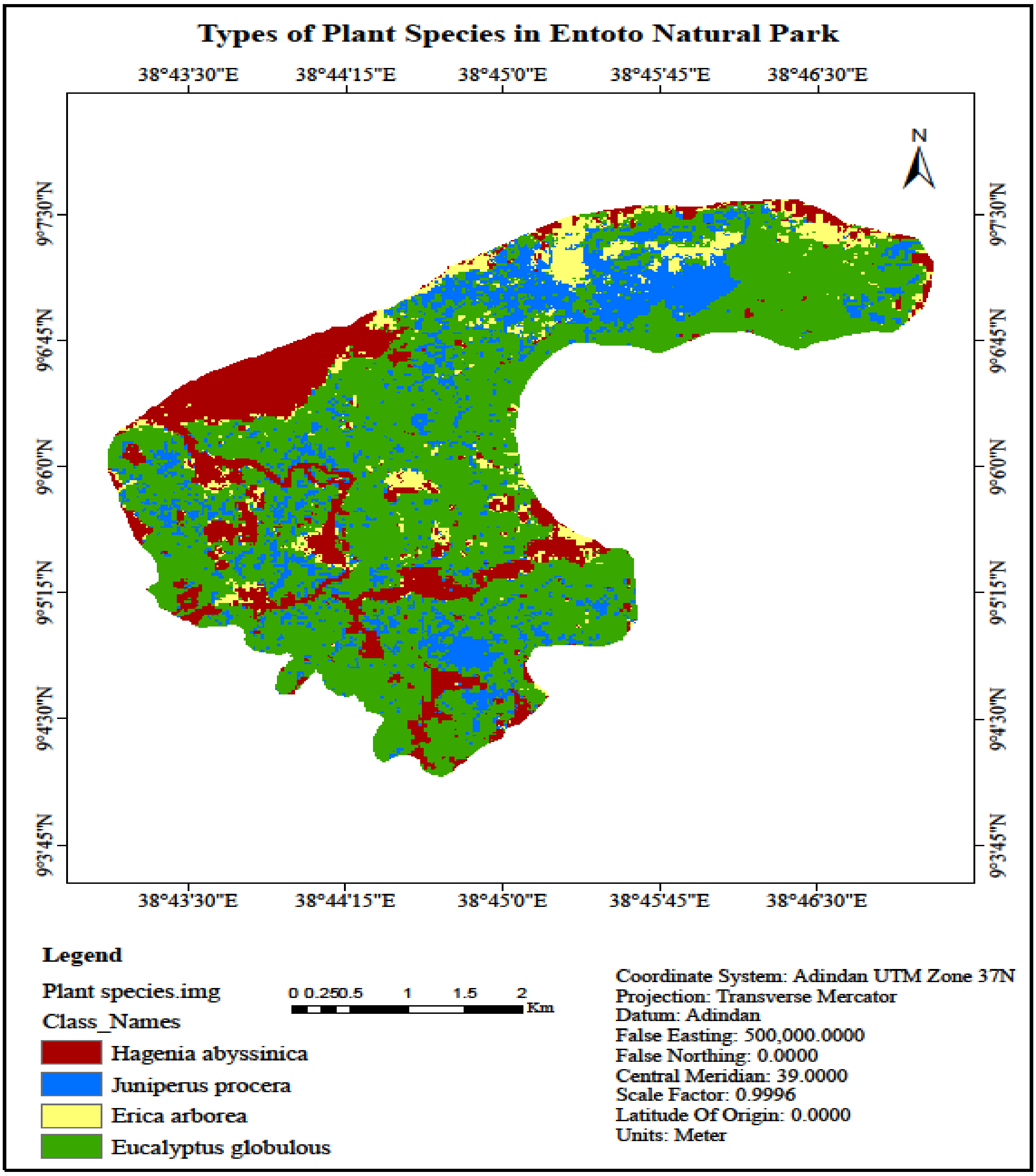


Figure 4-3 Map of Plant species in Entoto Natural Park

4.4. Leaf Moisture Content of Vegetation in Dry and Wet Season

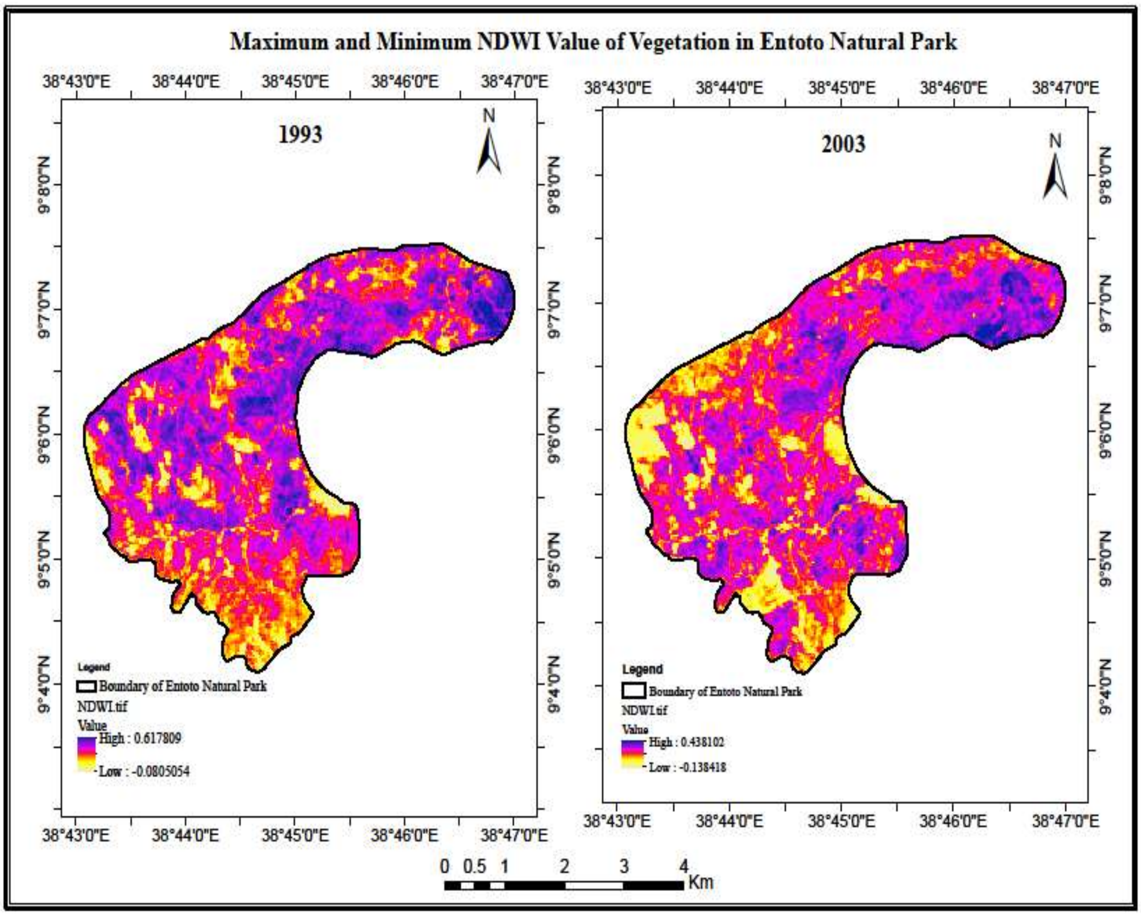
4.4.1. Leaf Moisture Content of Vegetation in Dry Season

The leaf water content of vegetation in Entoto Natural Park was analyzed using multispectral satellite imagery during the dry season. The analysis involved deriving the Normalized Difference Water Index (NDWI). The findings of this study are discussed in this section.

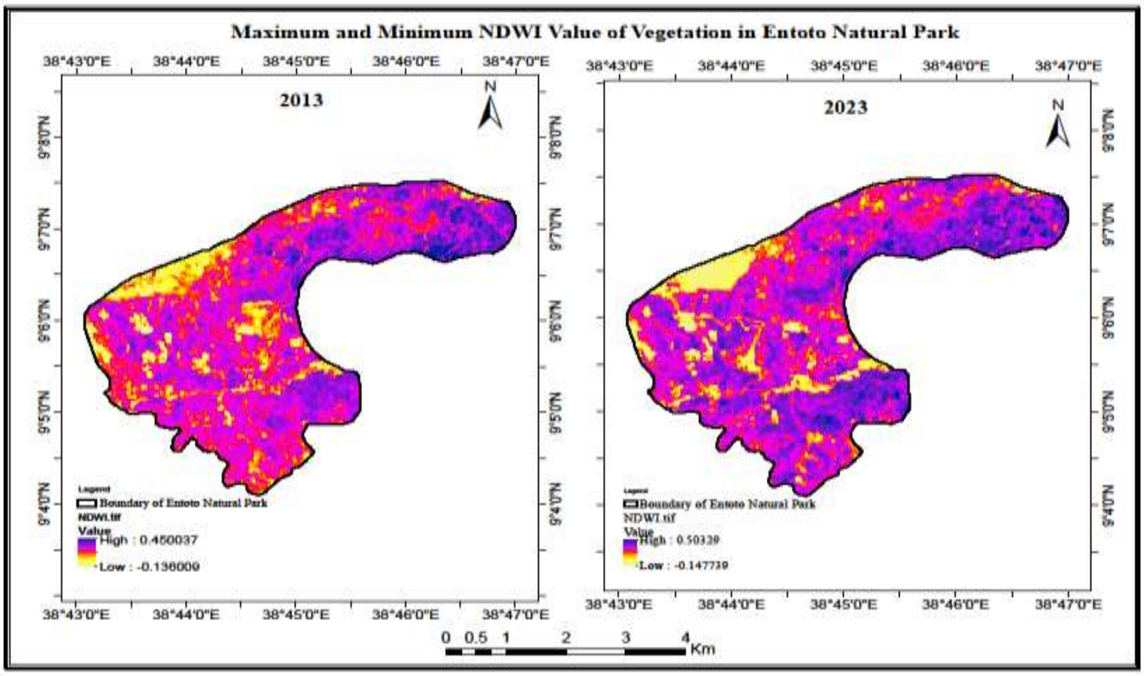
The study examined the leaf water content of both existing vegetation and planted seedlings as part of the Green Legacy campaign. The results revealed that the dominant vegetation in Entoto Natural Park, which is the eucalyptus tree, has relatively low leaf moisture. Therefore, the analyzed leaf water content of characterizes the moisture content of vegetation in Entoto Natural Park. Figure 4-1 illustrates the minimum and maximum NDWI values of the vegetation in Entoto Natural Park during the dry season.

There is variation in the NDWI values in Entoto Natural Park during the dry season from 1993 to 2003 (refer to Figure 4:1). The minimum and maximum NDWI values for 1993 are -0.081 and 0.618, respectively. A high NDWI value indicates areas with high water content or leaf moisture in the vegetation, while a low NDWI value represents areas with low water content or leaf moisture.

For the year 2003, the minimum and maximum NDWI values of the vegetation are -0.138 and 0.438, respectively. The maximum NDWI value calculated for 1993 is relatively higher than that of 2003. This indicates that the leaf water content of vegetation in 1993 was relatively higher than in 2003, suggesting a decrease in vegetation leaf moisture in 2003. Please refer to Figure 4-2 for maps showing the maximum and minimum NDWI values of vegetation in Entoto Natural Park during the dry season.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-4: NDWI values of vegetation during the dry season

The values of the Normalized Difference Water Index (NDWI) for all observed years were different. In 2013, the minimum and maximum NDWI values were -0.136 and 0.450, respectively. For the year 2023, the calculated minimum and maximum NDWI values were -0.148 and 0.503. This indicates that the leaf moisture of vegetation in 2023 was relatively higher than that of 2013, suggesting an increased amount of vegetation leaf moisture in 2023.

Table 4-1 shows the maximum and minimum NDWI values of vegetation from the year 1993 to 2023 in Entoto Natural Park during the dry season. These values were calculated from spectral bands of satellite imagery using the Normalized Difference Water Index (NDWI). The variation of NDWI for each year indicates the variation of vegetation leaf moisture over different periods of time in Entoto Natural Park.

Table 4-1: NDWI values of vegetation during dry season

Year	**NDWI Value**	
	Minimum	**Maximum**
1993	-0.081	0.618
2003	-0.138	0.438
2013	-0.136	0.450
2023	-0.148	0.503

In order to enhance the accuracy of comparison, the NDWI values were rounded to three decimal places. NDWI values close to +1 indicate a higher level of vegetation leaf water content, while values close to -1 indicate a lower level of vegetation leaf water content in Entoto Natural Park during the dry season.

The spatial distribution of the minimum and maximum NDWI values of vegetation in the study area was depicted on a map to visualize the variation. The analysis revealed that the lowest NDWI value during the dry season was observed in 1993 (as shown in Figure 4-2). Similarly, the analysis indicated that the highest NDWI value during the dry season was recorded in 1993 (refer to Figure 4-3).

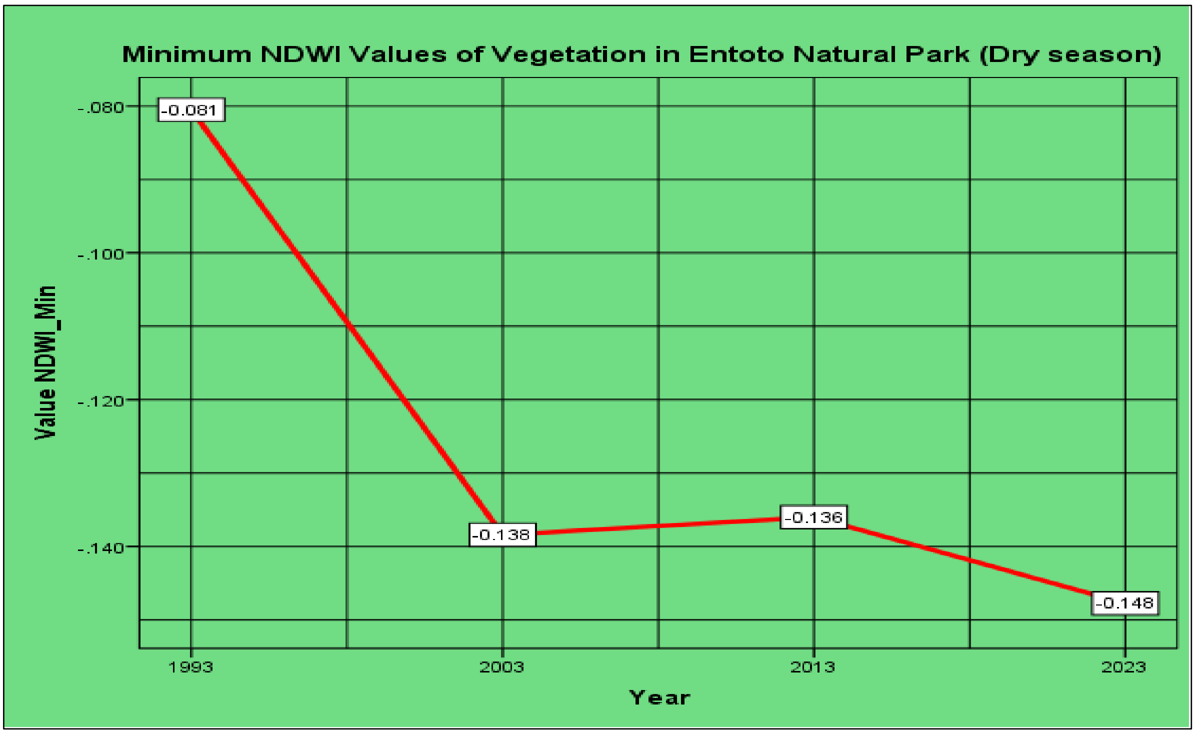


Figure 4-5: Minimum NDWI value of vegetation during dry season

The following graph illustrates the maximum NDWI values of vegetation from the years 1993 to 2023 in 10 years interval. The values of NDWI spectral index were calculated from multispectral satellite imagery of vegetation in Entoto Natural Park during dry season. The result of the analysis indicates that the highest value of NDWI was recorded in 1993.

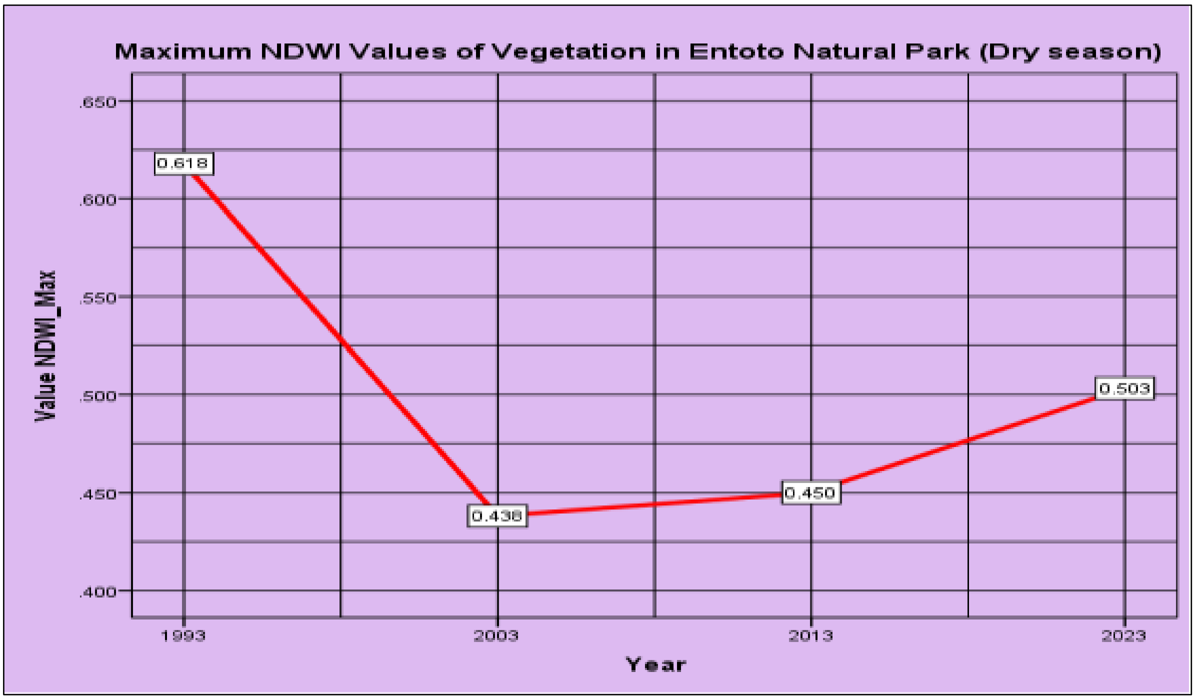


Figure 4-6: Maximum NDWI value of vegetation during dry season

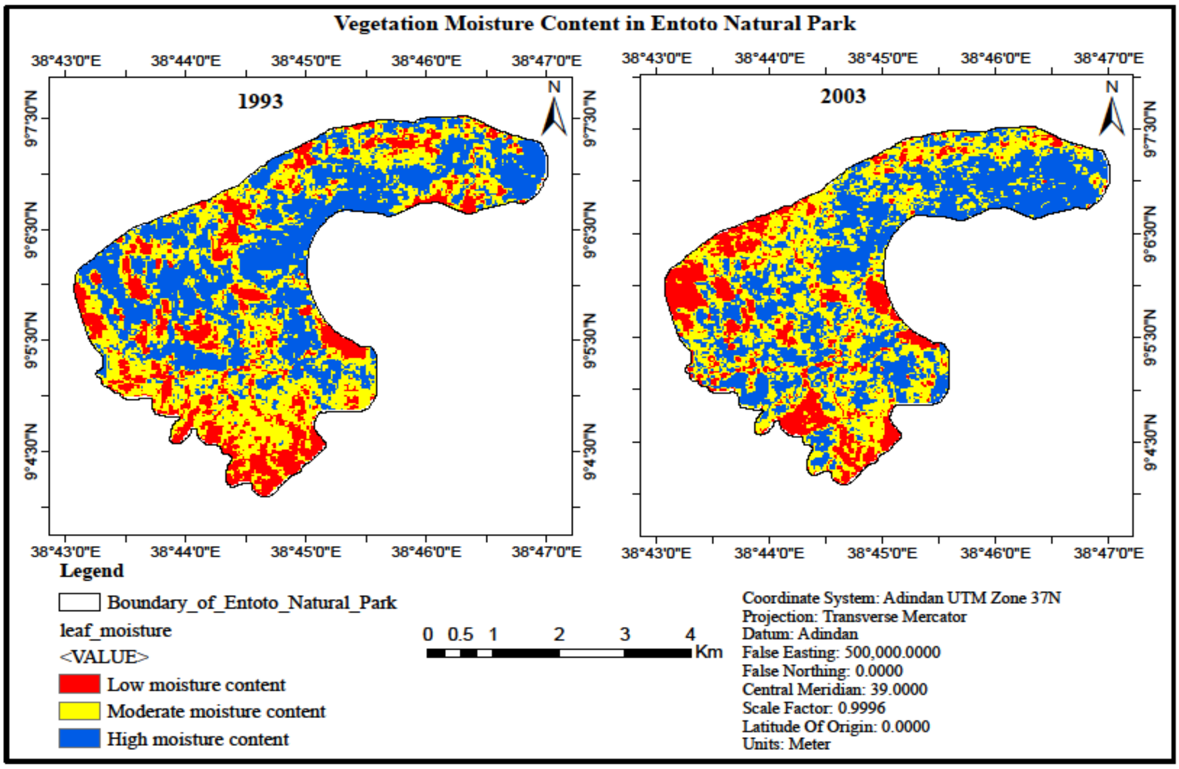
The maximum Normalized Difference Water Index (NDWI) was calculated during the dry season using Landsat imagery from different time periods, based on the spectral bands of the satellite imagery. The NDWI values varied for each year, indicating the variability of vegetation leaf moisture content in Entoto Natural Park during the dry season. As a result of the analysis, it was found that the highest NDWI value for vegetation was recorded in 1993, suggesting the highest level of vegetation leaf water content during that year. The table below presents the categories of NDWI with their corresponding descriptions. Different ranges of NDWI values represent distinct levels of leaf moisture.

Table 4-2: NDWI value categories with its description

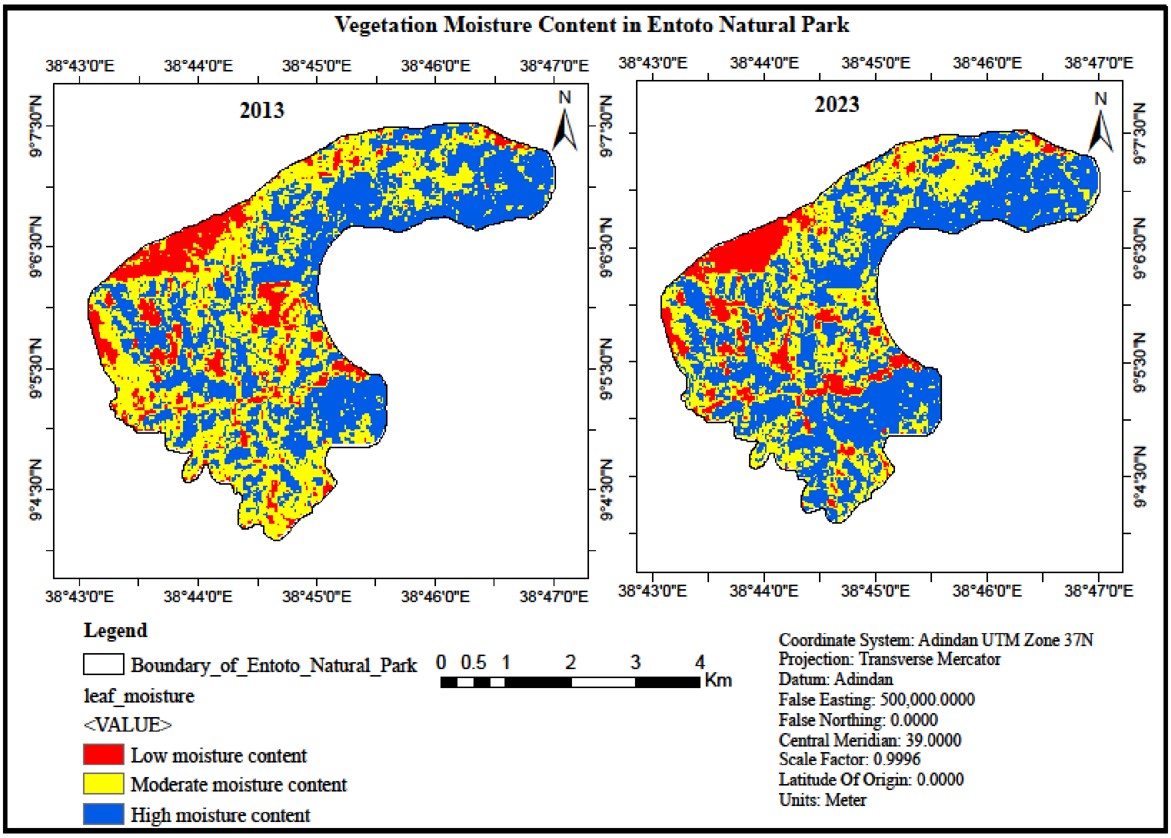
NDWI Categories	Description
0.7 <=NDWI	Very high moisture content
0.6 <=NDWI <0.7	High moisture content
0.6 <=NDWI <0.5	Moderate moisture content
0.4 <= NDWI<0.5	Low moisture content
0.3 <=NDWI <0.4	Weak drought
0.2 <=NDWI<0.3	Moderate drought
0<=NDWI<0.2	Strong drought
NDWI<0	Very Strong drought

According to the findings of this study, the vegetation in Entoto Natural Park showed low NDWI values during the dry season. This suggests that the vegetation had low moisture content in its leaves during this time, and it indicates a positive relationship between NDWI values and leaf moisture. High NDWI values indicate high leaf moisture in the vegetation, while low NDWI values suggest low water content or moisture in the leaves of the vegetation in Entoto Natural Park.

The dark green vegetation in Entoto Natural Park displayed relatively high NDVI and NDWI values. High NDVI values indicate a healthy state of vegetation, while high NDWI values indicate the presence of abundant leaf moisture. Therefore, vibrant and healthy green vegetation in the park has a high amount of water content or moisture in its leaves, whereas infected or damaged vegetation signifies a low level of leaf moisture in study area.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-7: Vegetation moisture content in Entoto Natural Park during dry season

The findings of the study conducted in Entoto Natural Park shed light on the vegetation dynamics, specifically focusing on the dominant vegetation type, the eucalyptus tree, during the dry season. The study utilized the NDWI (Normalized Difference Water Index) spectral index to assess the leaf water content and moisture levels of the eucalyptus trees in Entoto Natural Park.

The results revealed that the eucalyptus trees exhibited very low leaf water content during the dry season. This suggests that these trees face challenges in maintaining adequate hydration levels when water availability is limited. In contrast, other vegetation types in the study area demonstrated relatively higher leaf water moisture levels during the same period. The lower leaf water content of the eucalyptus trees could be attributed to their physiological characteristics and adaptations. Eucalyptus trees are known for their ability to tolerate and even thrive in dry conditions. They have developed mechanisms to conserve water, such as narrow leaves and deep root systems that help them access water from deeper soil layers. However, these adaptations may result in lower leaf water content compared to other vegetation types that may be better adapted to retain moisture during dry periods.

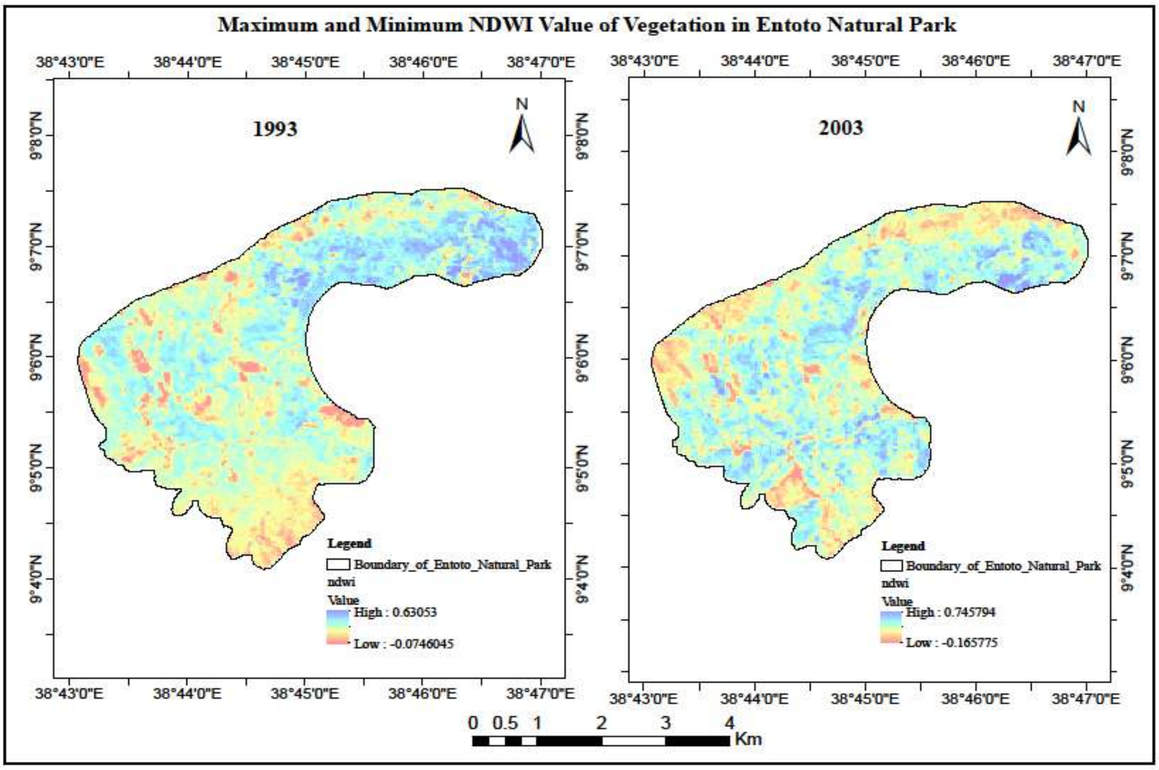
Furthermore, the study also found that the eucalyptus trees exhibited moderate chlorophyll concentration during the dry season. Chlorophyll is essential for photosynthesis, the process through which plants convert sunlight into energy. The moderate chlorophyll concentration indicates that the eucalyptus trees were still able to perform photosynthesis, albeit at a slightly reduced rate compared to other vegetation types. Overall, the findings suggest that eucalyptus trees in Entoto Natural Park have specific adaptations to cope with dry conditions, including lower leaf water content and moderate chlorophyll concentration. These findings contribute to our understanding of the ecological dynamics and adaptations of the dominant vegetation in the park, providing valuable insights for its management and conservation.

4.4.2. Leaf Moisture Content of Vegetation in Wet Season

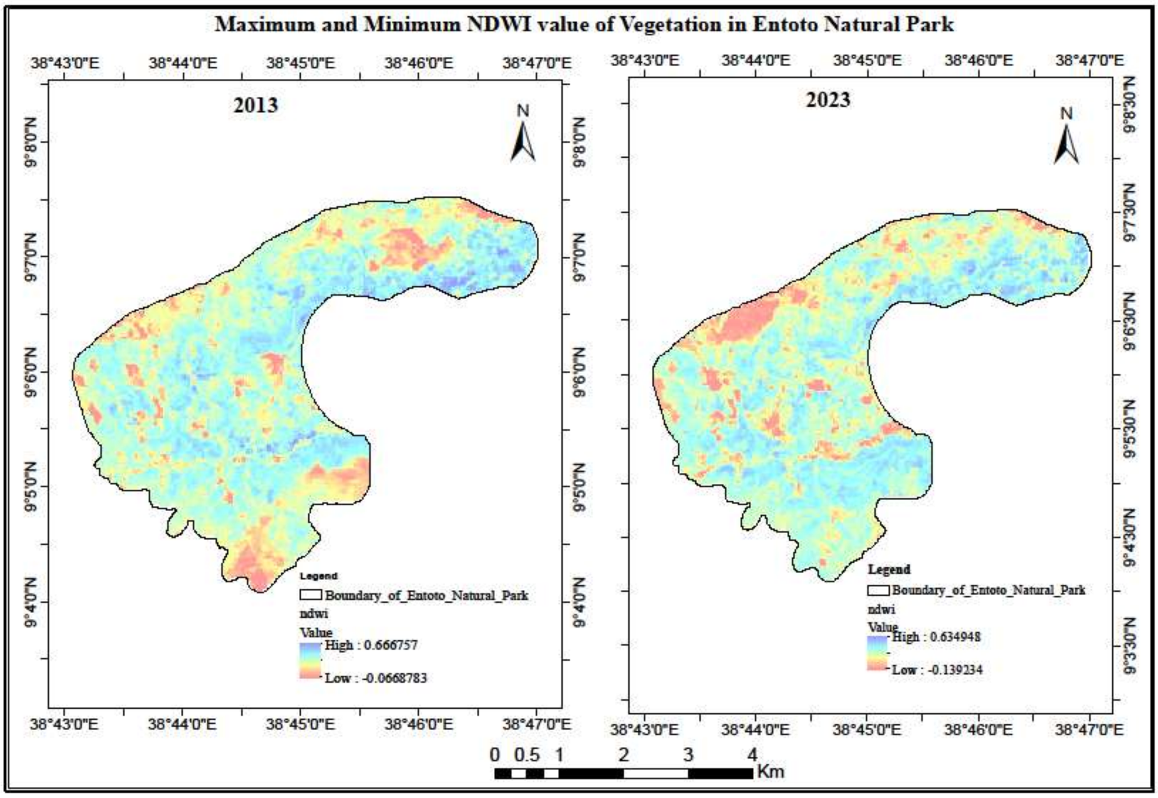
Leaf water content is one of the most common physiological parameters limiting the efficiency of vegetation productivity, including Eucalyptus trees. Based on the wet season Remote Sensing data and NDWI, the leaf moisture of vegetation during the wet season has been investigated in Entoto Natural Park. The leaf moisture content for Eucalyptus trees in the wet season was analyzed by calculating the NDWI spectral index from satellite imagery, and the results of the study have been discussed in this section.

Vegetation leaf water content is a very important parameter in determination of vegetation drought, because water stress restricts transpiration including closure of stomata and water evaporation from leaf surface. Water stress also affects crop photosynthesis and productivity. The analysis aimed to understand the water stress condition of Eucalyptus trees and other vegetation during wet season. The results show that Eucalyptus trees in the study area have relatively high leaf moisture during the wet season. The analysed leaf water stress in Entoto Natural Park clearly showed the leaf water condition of Eucalyptus trees and other planted seedlings during Green Legacy Campaigns. Please refer to figure 4-5, which shows the minimum and maximum NDWI values of vegetation in the study area during the wet season.

The results of the study indicate that the derived NDWI values during the wet season vary for each observed year (see figure 4:1). The calculated minimum and maximum values of the NDWI spectral index during wet season for the year 1993 are -0.074 and 0.630, respectively. A high value of NDWI indicates Eucalyptus trees with high moisture content or less water stress, while a low NDWI represents Eucalyptus trees with low leaf moisture or high-water stress. The minimum and maximum NDWI spectral index values of vegetation during wet season for the year 2003 are -0.165 and 0.745, respectively. The maximum NDWI value of vegetation calculated for 2003 is relatively higher than that of 1993, indicating that the vegetation leaf moisture content in 1993 was relatively lower than in 2003. This progression suggests an increase in vegetation leaf water content or decrease in vegetation water stress in 2003. Please refer to the maps in figure 4-5, which indicate the maximum and minimum NDWI values of vegetation in the study area during the wet season.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-8: NDWI values of vegetation during wet season.

The values of the NDWI spectral index during the wet season for all observed years were varied. In 2013, the minimum and maximum NDWI were -0.067 and 0.667 respectively, and for the year 2023, the calculated minimum and maximum values of NDWI were -0.139 and 0.634. This shows that the leaf water content of Eucalyptus trees in 2013 was relatively higher than that of 2023, indicating a decreased amount of Eucalyptus tree leaf moisture with increased leaf water stress in 2023. The following Table 4-3 shows the NDWI values of vegetation from the year 1993 to 2023 in the study area during the wet season. The values of the spectral index were calculated from spectral bands of satellite data during wet season. The variation of NDWI values for each year demonstrates the variability of vegetation leaf water content or water stress condition for different periods of time in Entoto Natural Park.

Table 4-3: The NDWI values of vegetation in Entoto Natural Park during wet season

Year	NDWI Values	
	Minimum	**Maximum**
1993	-0.074	0.630
2003	-0.165	0.745
2013	-0.067	0.667
2023	-0.139	0.634

For the calculated spectral index values, three decimal places were considered to accurately compare leaf moisture. NDWI values close to +1 indicate higher leaf moisture content with less water stress, while values close to -1 indicate lower vegetation leaf moisture content with high water stress in Entoto Natural Park during the wet season. The minimum and maximum NDWI values of Eucalyptus trees and other varieties of vegetation during the wet season were mapped to show the spatial variation of leaf moisture or leaf water stress condition. The minimum NDWI values of Eucalyptus trees and other vegetation were calculated for each observed year, and the analysis results show that the lowest NDWI value during the wet season was recorded in 1993 (See Figure 4-6). Additionally, the maximum NDWI values of vegetation in the study area during the wet season were determined for all observed years, and the analysis results show that the highest NDWI value was recorded in 1993 (See Figure 4-7).

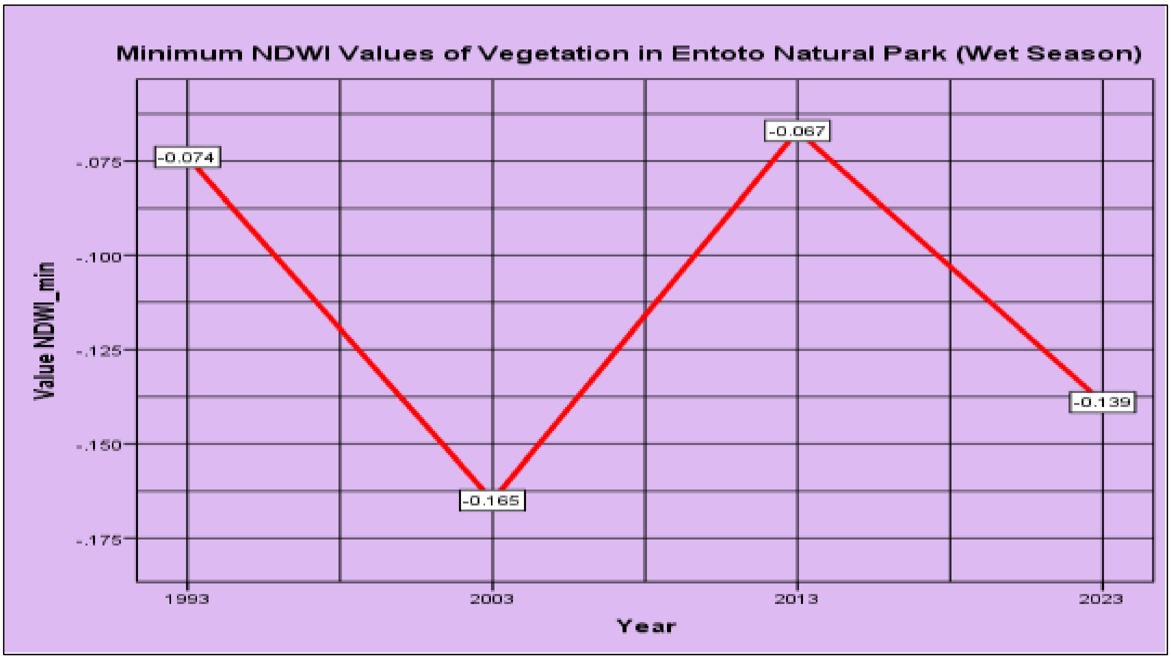


Figure 4-9: Minimum NDWI values of vegetation during wet season

The graph below illustrates the maximum NDWI values of vegetation from 1993 to 2023, with a 10-year interval. These values were calculated using multispectral satellite imagery of vegetation in Entoto Natural Park during the wet season. The analysis results indicate that the highest NDWI value was recorded in 1993.

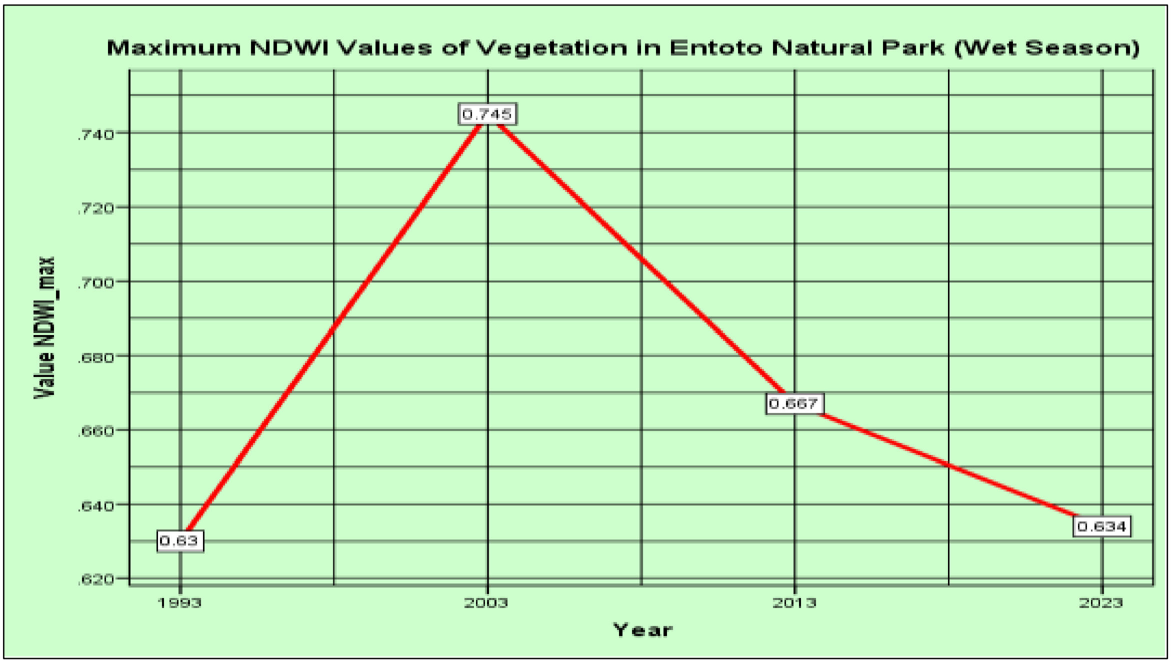
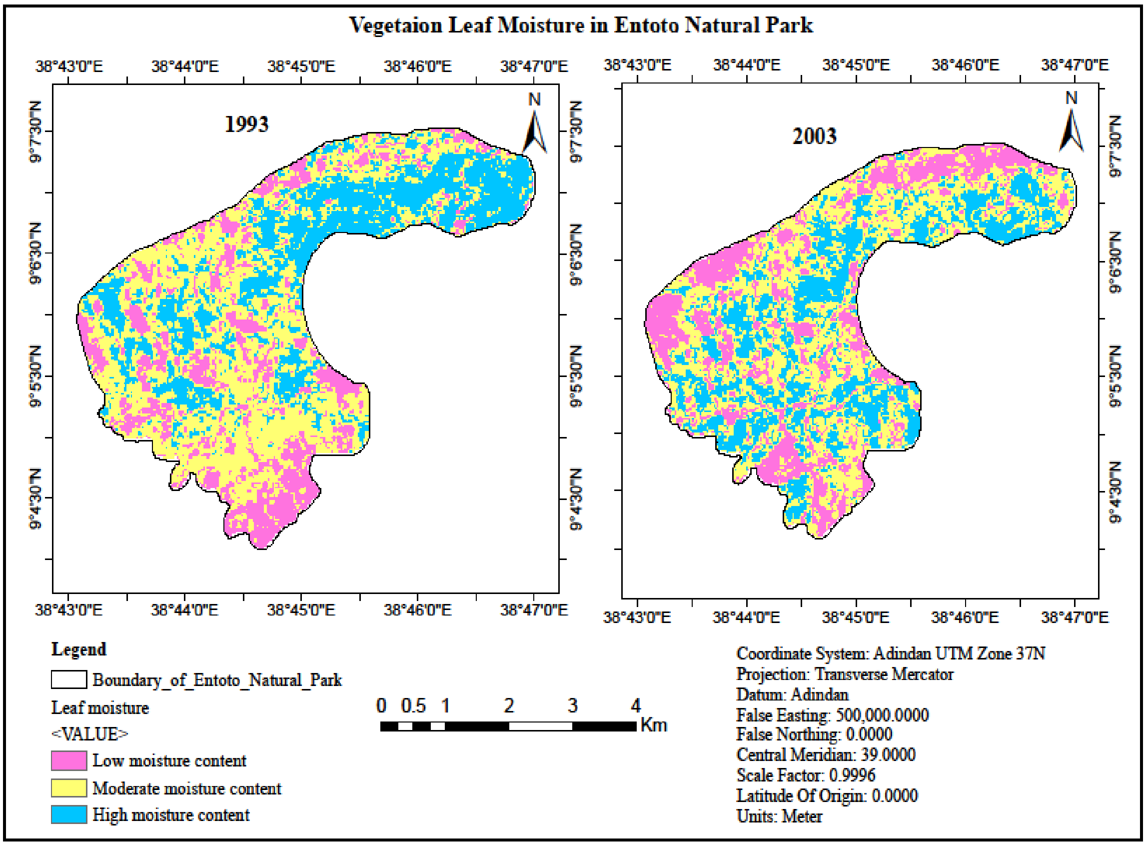
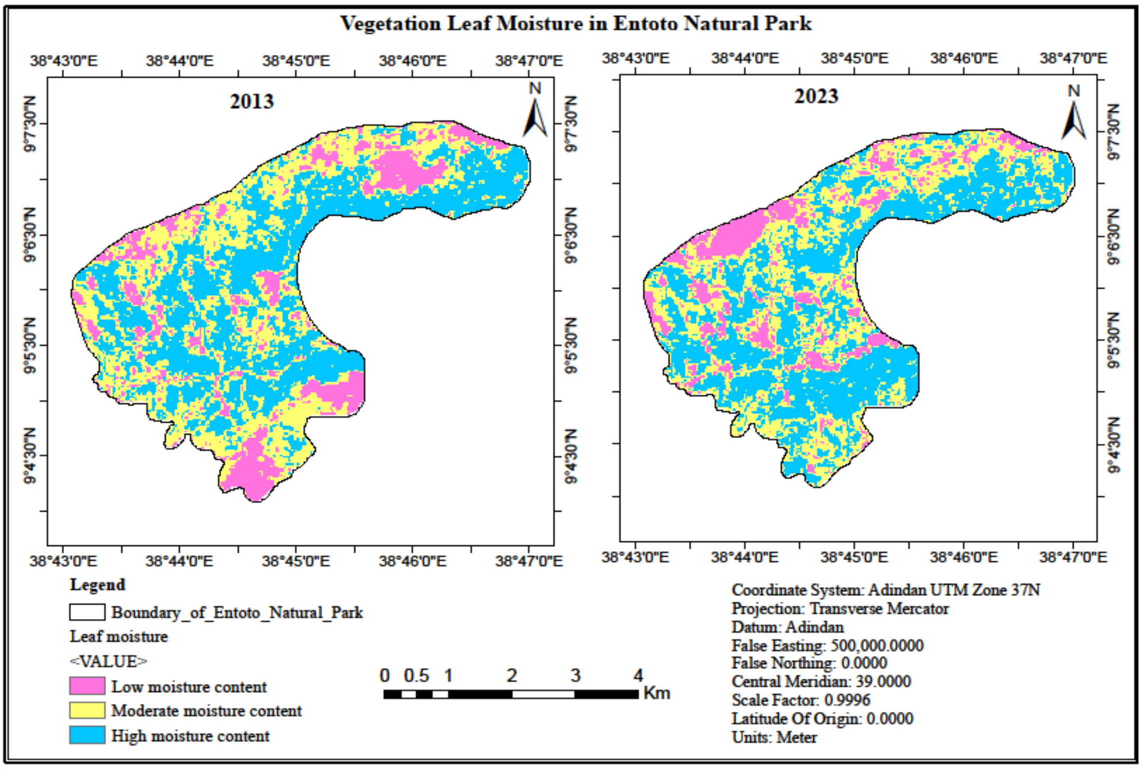


Figure 4-10: Maximum NDWI values of vegetation during wet season



a). 1993 & 2003



b). 2013 & 2023

Figure 4-11: Vegetation leaf moisture in Entoto Natural Park during wet season

During the wet season in Entoto Natural Park, the NDWI (Normalized Difference Water Index) values of the vegetation showed an increase. This indicates that the leaf moisture content of the vegetation in the study area is relatively high during this period. The increased NDWI values suggest that the vegetation in Entoto Natural Park has a higher water content in its leaves during the wet season. This is primarily due to the availability of sufficient rainfall, which provides a consistent supply of water to the plants. As a result, the plants are able to maintain their leaf moisture levels, leading to healthier and more vibrant vegetation.

Having adequate leaf moisture is crucial for the well-being of plants as it supports various physiological processes. It allows for efficient photosynthesis, the process by which plants convert sunlight into energy. Sufficient leaf moisture enables the plants to open their stomata (tiny openings on the surface of leaves) to take in carbon dioxide for photosynthesis while minimizing water loss through transpiration.

Furthermore, high leaf moisture content helps to regulate temperature within the plant tissues, preventing overheating and reducing the risk of heat stress. It also contributes to the overall resilience of the vegetation, making it more resistant to drought conditions that may occur later in the dry season. Overall, the increased NDWI values during the wet season indicate that the vegetation in Entoto Natural Park is well-adapted to the seasonal changes and able to thrive in the presence of abundant moisture, resulting in healthier and more robust plant growth

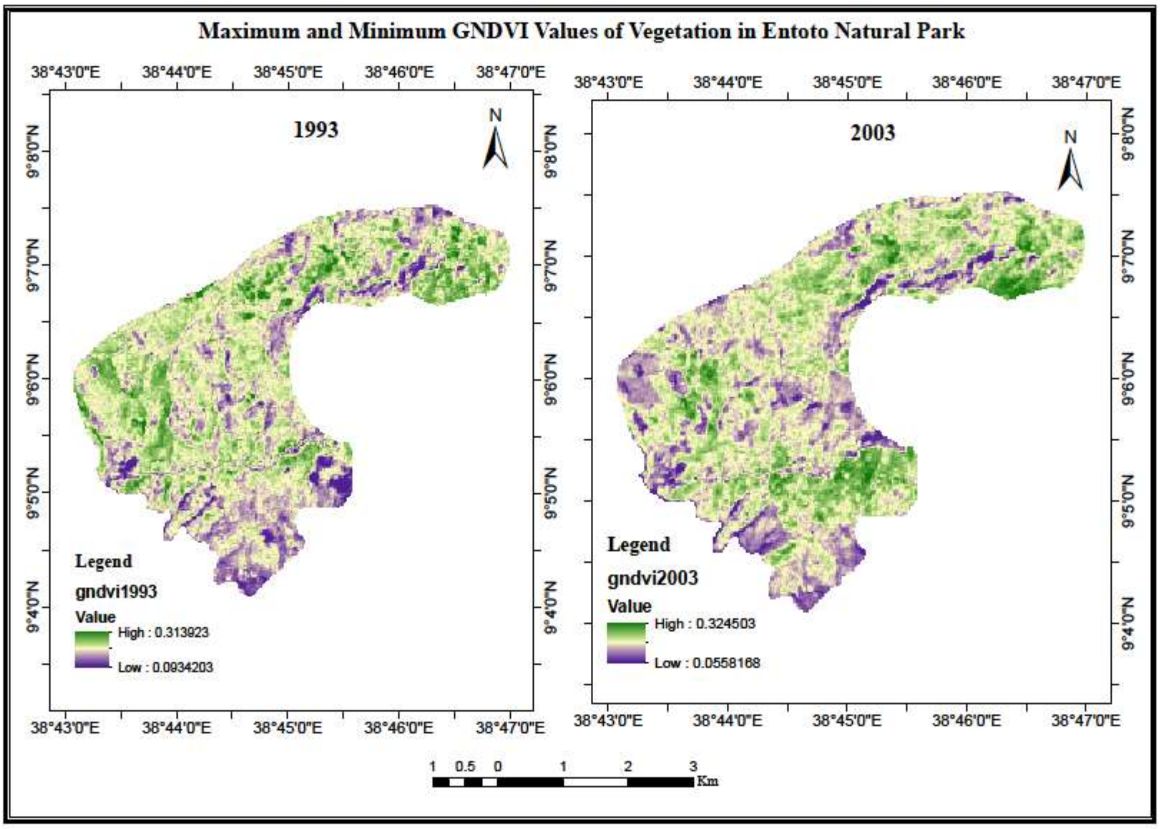
4.5. Chlorophyll Concentration of Vegetation in Dry and Wet Season

4.5.1. Chlorophyll Concentration of Vegetation in Dry Season

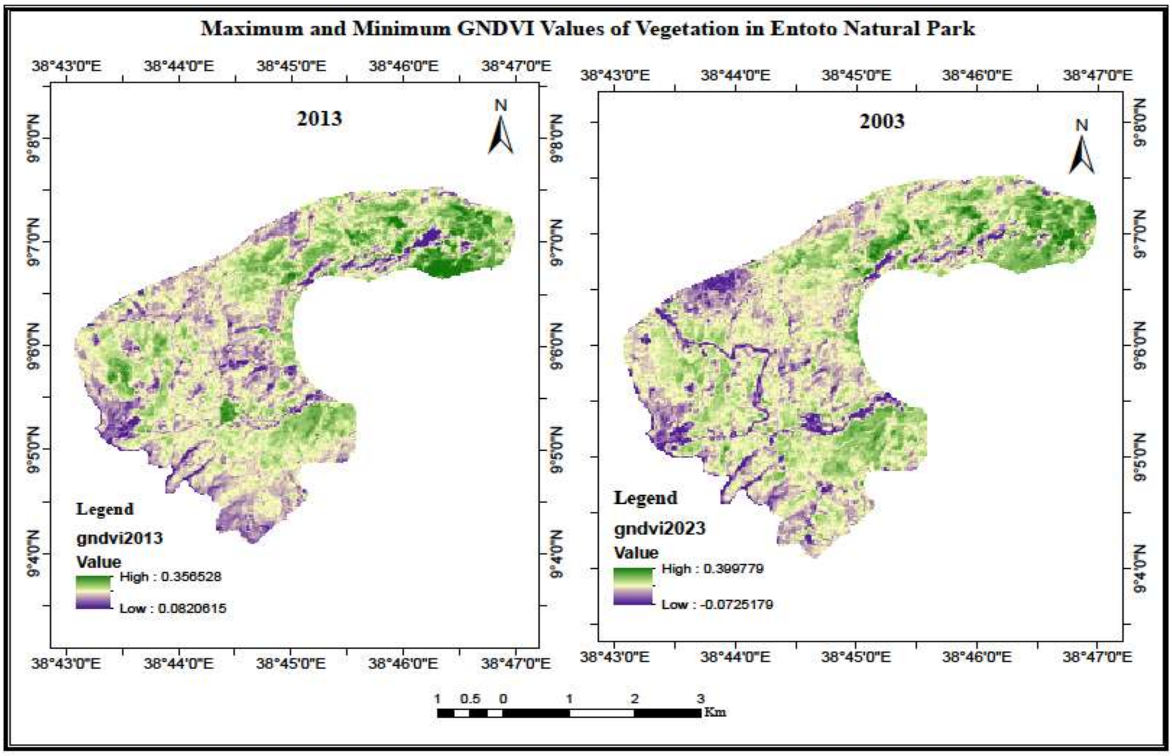
The chlorophyll concentration of vegetation in Entoto Natural Park during the dry season was analyzed based on the GNDVI spectral index. The results reveal that the dominant vegetation in the study area has relatively low chlorophyll concentration. Since the dominant vegetation in Entoto Natural Park is Eucalyptus trees, the analyzed vegetation chlorophyll concentration characterizes the chlorophyll concentration of the trees. Refer to figure 4-9 for the minimum and maximum GNDVI values of vegetation during the dry season in Entoto Natural Park.

There is some variation in GNDVI values from 1993 to 2003 in Entoto Natural Park. The minimum and maximum values of GNDVI for 1993 are 0.093 and 0.314, respectively. A high GNDVI value indicates an area of vegetation with high chlorophyll concentration, while a low GNDVI represents an area of vegetation with low chlorophyll concentration. For the year 2003, the minimum and maximum GNDVI values of vegetation were 0.056 and 0.325, respectively. The maximum GNDVI value obtained in 2003 was relatively higher than that of 1993, indicating an increase in vegetation chlorophyll concentration in 2003.

Figure 4-9 also displays the maximum and minimum GNDVI values of vegetation for the observed years in Entoto Natural Park during the dry season. The values of the Green Normalized Difference Vegetation Index for all observed years were different. In 2013, the minimum and maximum GNDVI values were 0.082 and 0.325, respectively. For the year 2023, the obtained minimum and maximum GNDVI values were -0.073 and 0.4. This indicates that the chlorophyll concentration of vegetation in 2023 was relatively higher than that of 2013, suggesting an increase in chlorophyll concentration during the dry season in 2023.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-12: Map of the maximum and minimum GNDVI values of vegetation in Entoto Natural Park during dry season.

The values of the Green Normalized Difference Vegetation Index varied for all observed years. In 2013, the minimum and maximum GNDVI values were 0.082 and 0.357 respectively. In contrast, for the year 2023, the calculated minimum and maximum values of GNDVI were -0.073 and 0.4. This indicates that the chlorophyll concentration of vegetation in 2013 was relatively lower compared to that of 2023, suggesting an increased amount of vegetation chlorophyll concentration in 2023. Table 4-4 presents the maximum and minimum GNDVI values of vegetation from 1993 to 2023 during the dry season in Entoto Natural Park. These values were calculated using GNDVI from satellite imagery spectral bands. The variation of GNDVI for each year reflects the fluctuation in vegetation chlorophyll concentration over different time periods in Entoto Natural Park.

Table 4-4: Maximum and minimum GNDVI values of vegetation during dry season

Year	**GNDVI Value**	
	Minimum	**Maximum**
1993	0.093	0.314
2003	0.056	0.325
2013	0.082	0.357
2023	-0.073	0.4

To ensure accurate comparison, the GNDVI values were rounded to three decimal places. A GNDVI value close to +1 indicates a higher degree of vegetation chlorophyll concentration, while values close to -1 indicate a lower degree of concentration during the dry season in Entoto Natural Park. The spatial variation of minimum and maximum GNDVI values during the dry season was mapped to visualize the differences. The analysis revealed that the lowest GNDVI value during the dry season was recorded in 2023 (figure 4-10), while the highest GNDVI value was also observed in 2023 (figure 4-11).

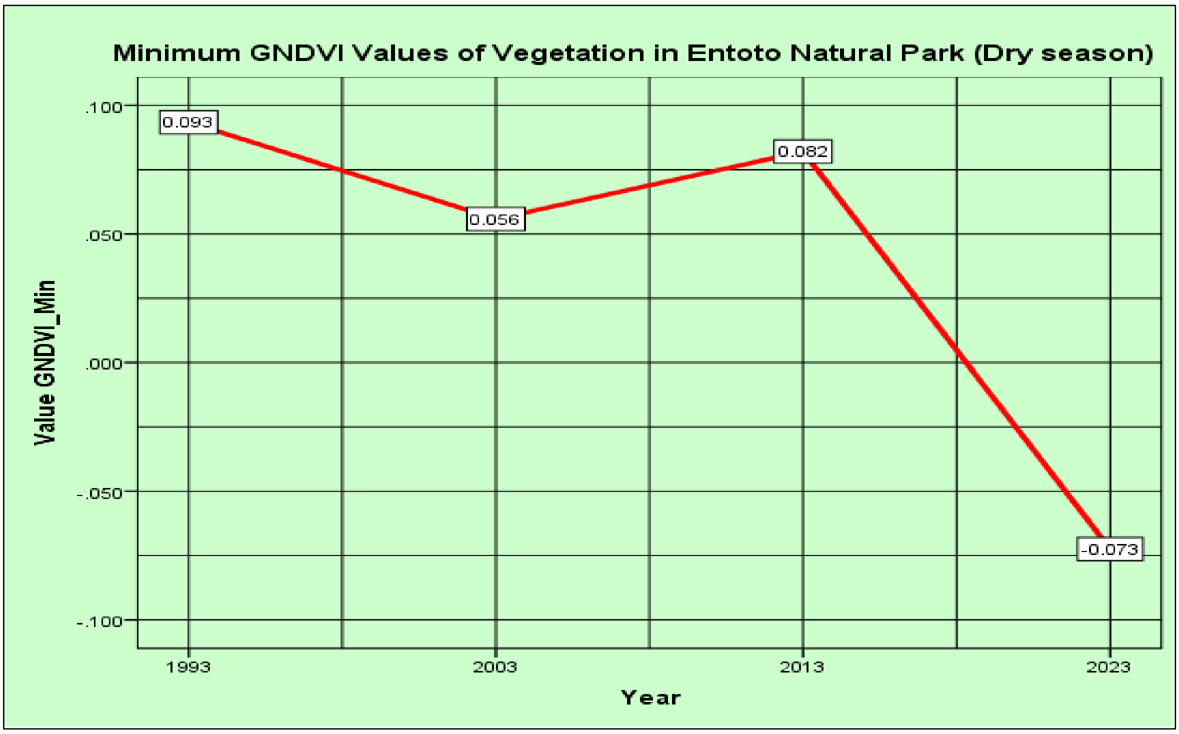


Figure 4-13: Graph of minimum GNDVI values of vegetation during dry season

The graph below illustrates the maximum GNDVI values of vegetation from 1993 to 2023 at 10-year intervals. The GNDVI spectral index values were calculated from multispectral satellite imagery of vegetation in Entoto Natural Park during the dry season. The analysis results indicate that the highest GNDVI value was recorded in 2023.

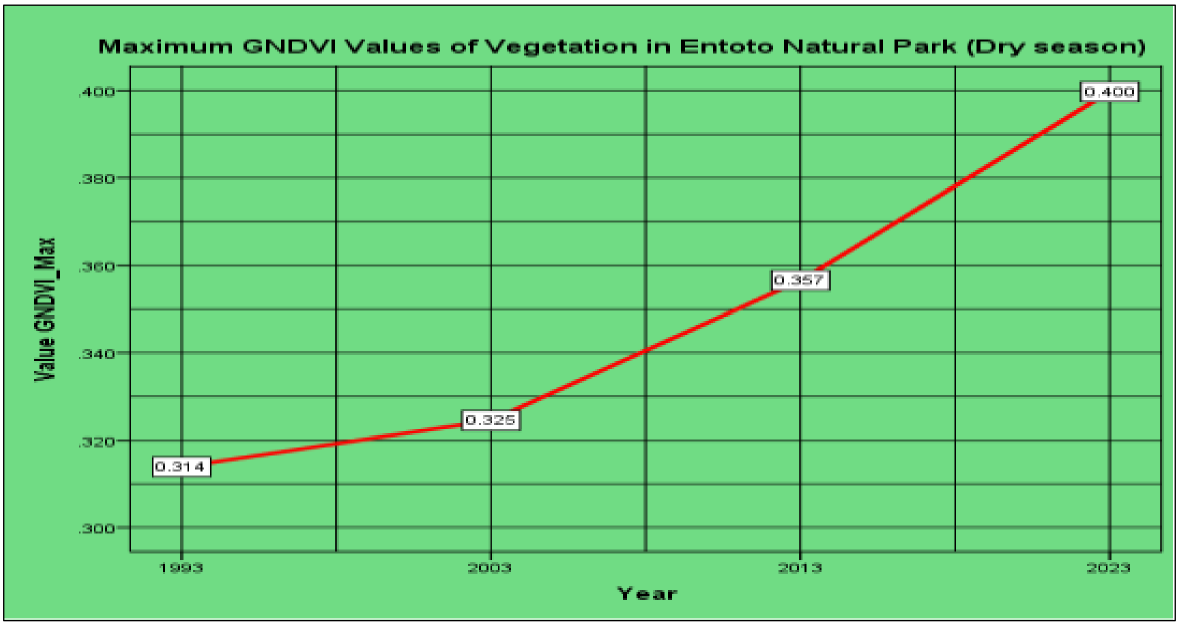
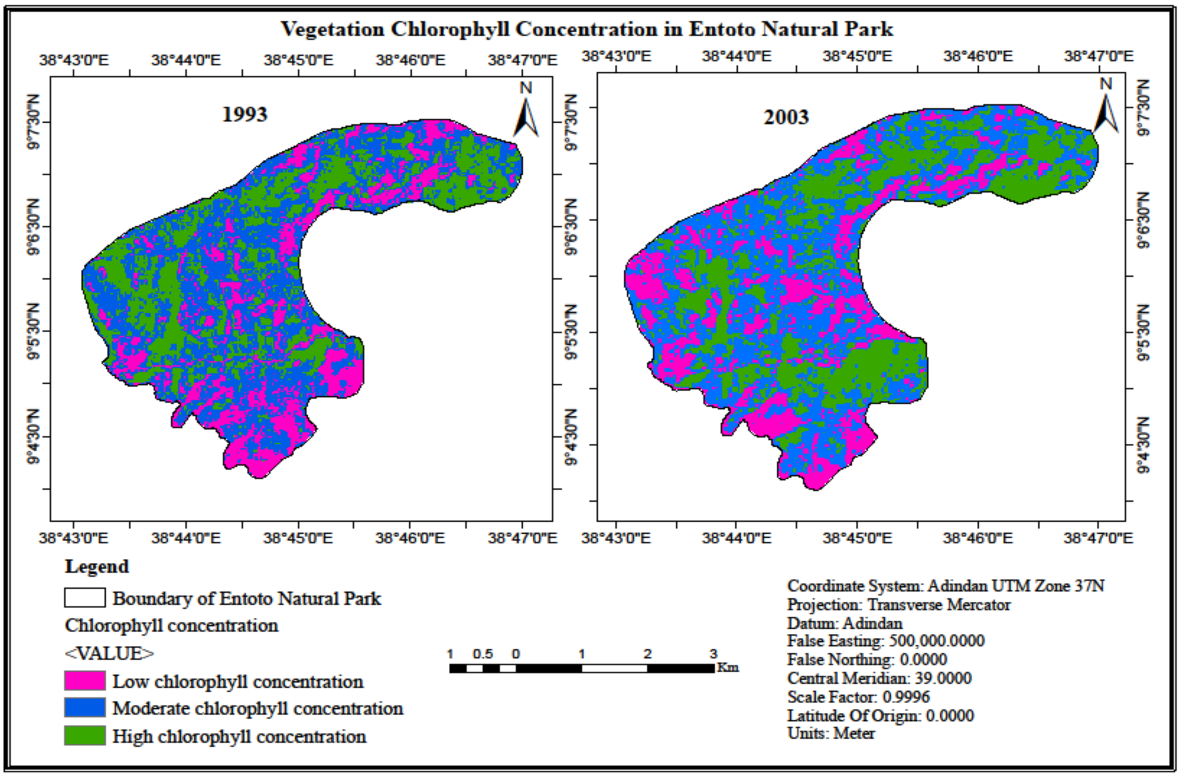
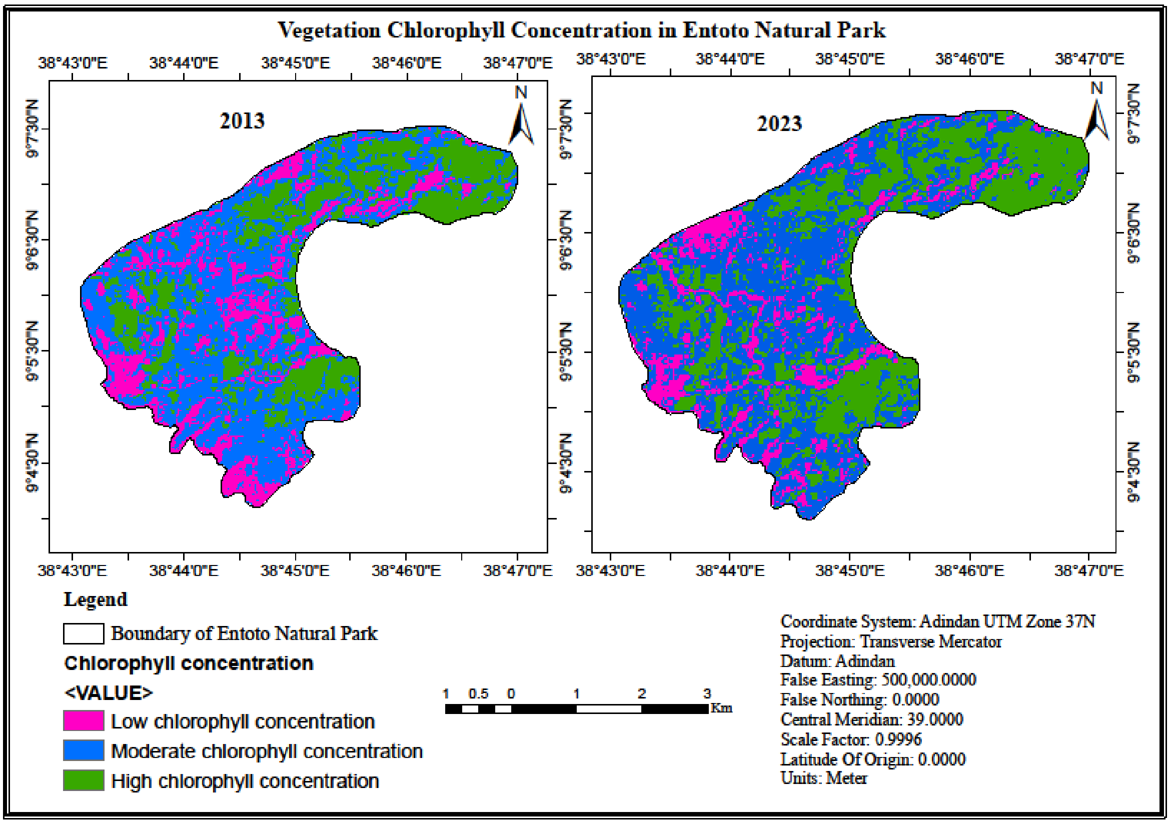


Figure 4-14: Graph of maximum GNDVI values of vegetation during dry season



a). 1993 & 2003



b). 2013 & 2023

Figure 4-15: Map of vegetation chlorophyll concentration in Entoto Natural Park during dry season

The findings revealed that the eucalyptus trees exhibited relatively low GNDVI values during the dry season, indicating a lower chlorophyll concentration compared to other vegetation types. Chlorophyll is a pigment essential for photosynthesis, the process by which plants convert sunlight into energy. Therefore, the lower chlorophyll concentration suggests reduced photosynthetic activity in the eucalyptus trees and other dominant vegetation during the dry season.

The decreased photosynthetic activity during the dry season can be attributed to the limited water availability in the environment. Water is crucial for various physiological processes in plants, including the production of chlorophyll and the efficient functioning of photosynthesis. When water is scarce, plants often undergo physiological adaptations to conserve water, such as reducing their photosynthetic activity and chlorophyll production.

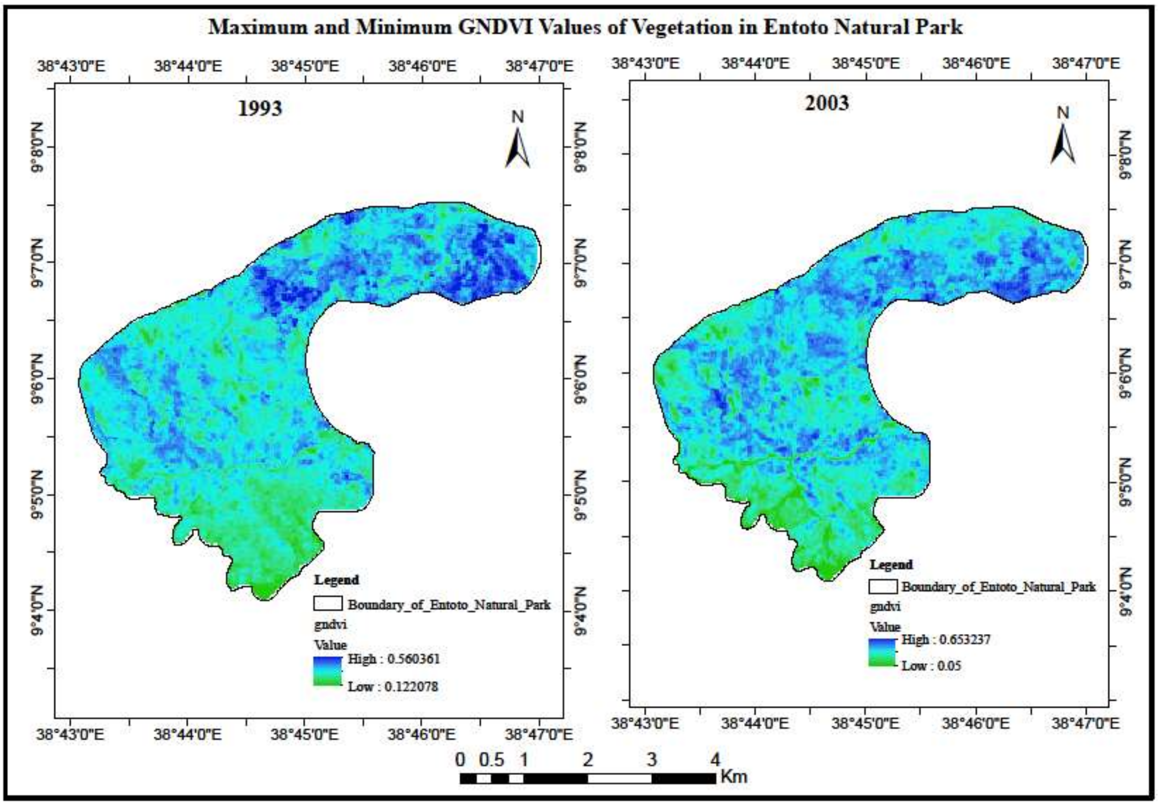
These findings provide valuable insights into the overall health and vitality of the vegetation in Entoto Natural Park during different seasons. They highlight the significant impact of water availability on plant physiology and emphasize the importance of understanding these dynamics for effective conservation and management of natural ecosystems. By considering the water requirements and adaptations of dominant vegetation, such as eucalyptus trees, land managers can make informed decisions to maintain and enhance the health of vegetation in the park, promoting its ecological stability and biodiversity.

4.5.2. Chlorophyll Concentration of Vegetation in Wet Season

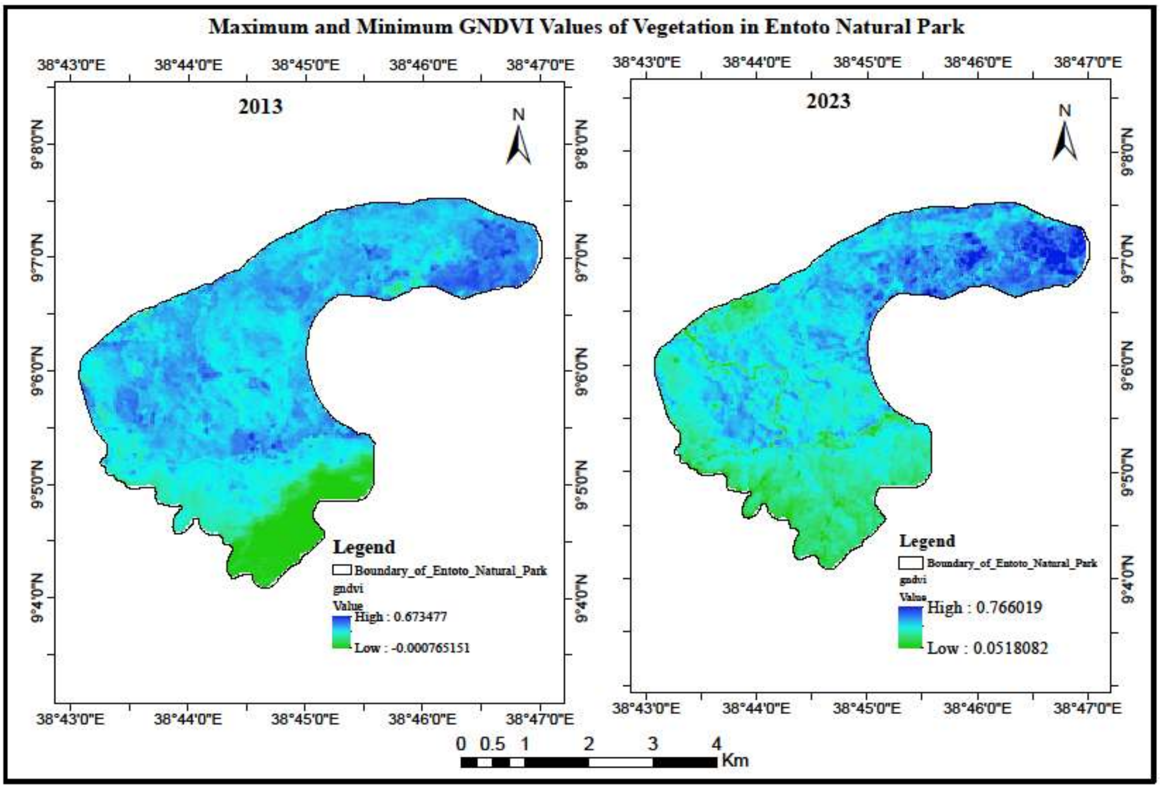
During the wet season, the chlorophyll concentration of vegetation was analyzed using the GNDVI index. The study focused on the dominant vegetation in Entoto Natural Park, which are Eucalyptus trees. The analysis of wet season satellite imagery and GNDVI values showed that Eucalyptus trees have relatively high chlorophyll concentration during this season.

The study analyzed the chlorophyll concentration of vegetation during the wet season by calculating GNDVI from multispectral satellite imagery. The results indicate that the dominant vegetation, Eucalyptus trees, have high chlorophyll concentration during the wet season. Figure 4-13 displays the minimum and maximum GNDVI values of vegetation during the wet season.

The study found variations in GNDVI values for each year during the wet season. For example, in 1993, the minimum and maximum GNDVI values were 0.122 and 0.560 respectively. The higher GNDVI value indicates vegetation with higher chlorophyll concentration, while a lower GNDVI value represents vegetation with lower chlorophyll concentration. In 2003, the maximum GNDVI value was relatively higher than in 1993, indicating an increase in chlorophyll concentration. Figure 4-13 includes maps showing the maximum and minimum GNDVI values of vegetation during the wet season.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-16: Map of the minimum and maximum GNDVI of vegetation in Entoto Natural Park during wet season

The GNDVI values during the wet season varied for all observed years. In 2013, the minimum and maximum GNDVI values were -0.001 and 0.673, respectively. For the year 2023, the calculated minimum and maximum GNDVI values were 0.051 and 0.766. This indicates that the chlorophyll concentration of vegetation in 2013 was relatively lower compared to 2023, suggesting an increased amount of chlorophyll concentration in 2023. Table 4-5 presents the maximum and minimum GNDVI values of vegetation from 1993 to 2023 in Entoto Natural Park during the wet season. These values were calculated using GNDVI from spectral bands of satellite imagery. The variation in GNDVI for each year reflects the changes in vegetation chlorophyll content over different time periods in Entoto Natural Park.

Table 4-5: The GNDVI values of vegetation in Entoto Natural Park during wet season

Year	**GNDVI Values**	
	Minimum	**Maximum**
1993	0.122	0.560
2003	0.050	0.653
2013	-0.001	0.673
2023	0.051	0.766

For accurate comparison, the calculated index values were rounded to three decimal places. A GNDVI value close to +1 indicates a higher degree of vegetation chlorophyll content, while values close to -1 suggest a lower degree of vegetation chlorophyll content in Entoto Natural Park during the wet season. The spatial variation of the minimum and maximum GNDVI values of vegetation during this period was mapped. The analysis revealed that the lowest GNDVI value during the wet season was recorded in 2013 (Figure 4-14). Additionally, the highest GNDVI value of vegetation in Entoto Natural Park during the wet season was observed in 2023 (Figure 4-15).

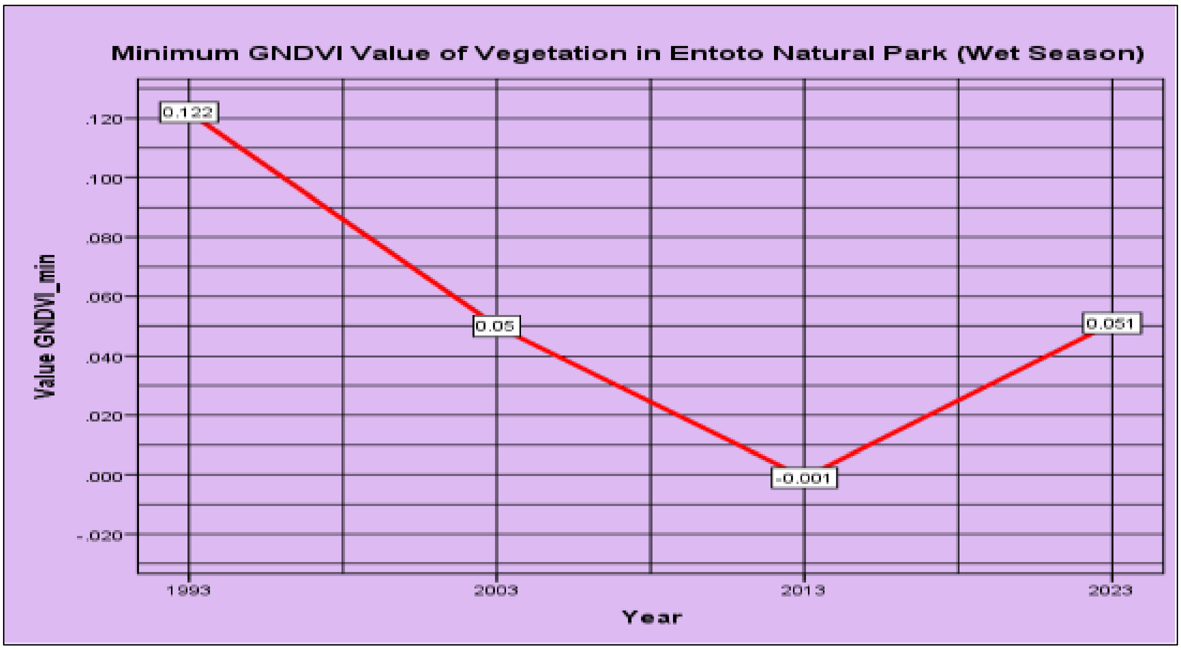


Figure 4-17: Graph of minimum GNDVI values of vegetation during wet season

The following graph shows the maximum GNDVI values of vegetation from the years 1993 to 2023 in 10-year intervals. The values of the GNDVI spectral index were calculated from multispectral satellite imagery of vegetation in Entoto Natural Park during the wet season. The analysis results indicate that the highest GNDVI value was recorded in 2023.

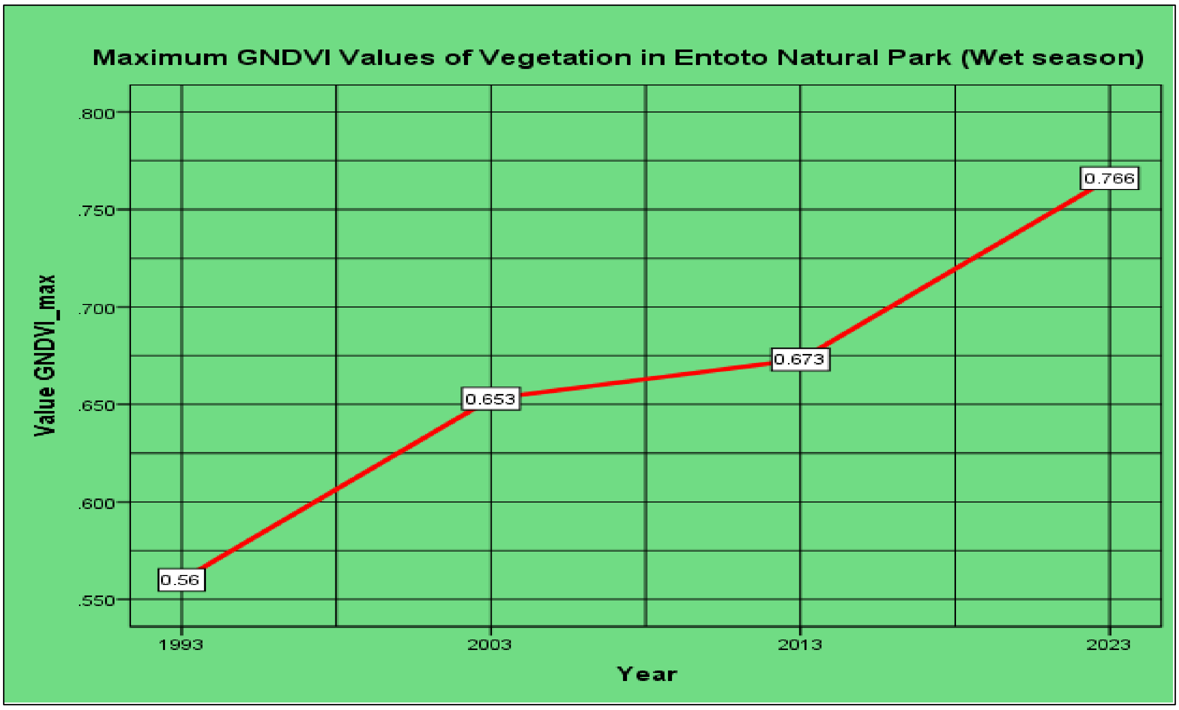
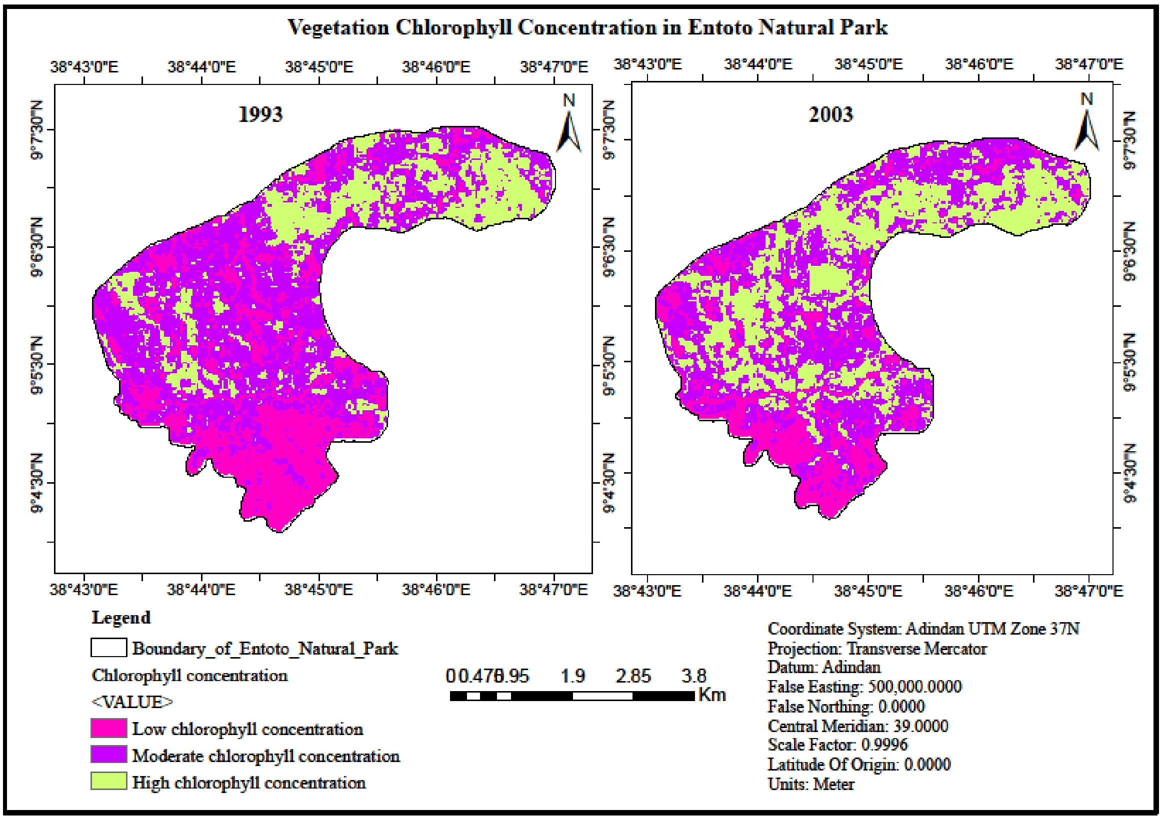
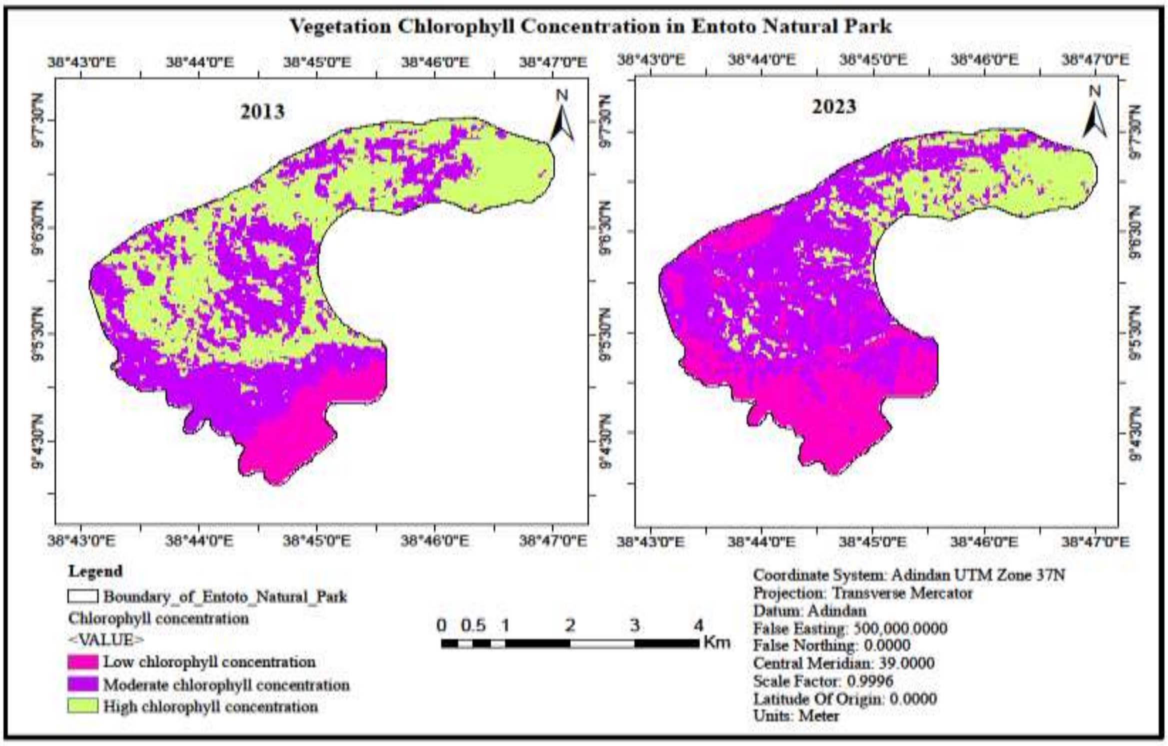


Figure 4-18: Graph of maximum GNDVI values of vegetation during wet season



a). 1993 & 2003



b). 2013 & 2023

Figure 4-19: Map of vegetation chlorophyll concentration in Entoto Natural Park during wet season

The lower chlorophyll concentration in eucalyptus trees suggests potential differences in their physiological characteristics compared to other types of vegetation in the park. Eucalyptus trees have unique adaptations that allow them to thrive in various environments, including their ability to tolerate drought conditions. However, this adaptation might come at the cost of reduced chlorophyll production, resulting in lower photosynthetic activity. Several factors could contribute to the lower chlorophyll concentration in eucalyptus trees. One possibility is that eucalyptus trees have evolved to allocate resources differently, prioritizing other physiological processes over chlorophyll production. This could be an adaptive strategy to cope with specific environmental conditions or to optimize resource utilization.

Additionally, the lower chlorophyll concentration in eucalyptus trees may also be influenced by their natural growth patterns and life cycle. Different species of vegetation have varying requirements for chlorophyll production, and it is possible that eucalyptus trees have naturally lower chlorophyll levels as part of their growth and development. The eucalyptus trees in Entoto Natural Park exhibited a lower chlorophyll concentration compared to other types of vegetation. Chlorophyll is a pigment found in plants that plays a crucial role in photosynthesis, the process by which plants convert sunlight into energy. It captures light energy and facilitates the production of glucose, which fuels plant growth and development. Understanding the differences in chlorophyll concentration between eucalyptus trees and other types of vegetation provides insights into the unique characteristics and adaptations of these trees. It highlights the diverse strategies that different plant species employ to survive and thrive in their respective environments.

4.6. Vegetation Health Status in Dry and Wet Seasons

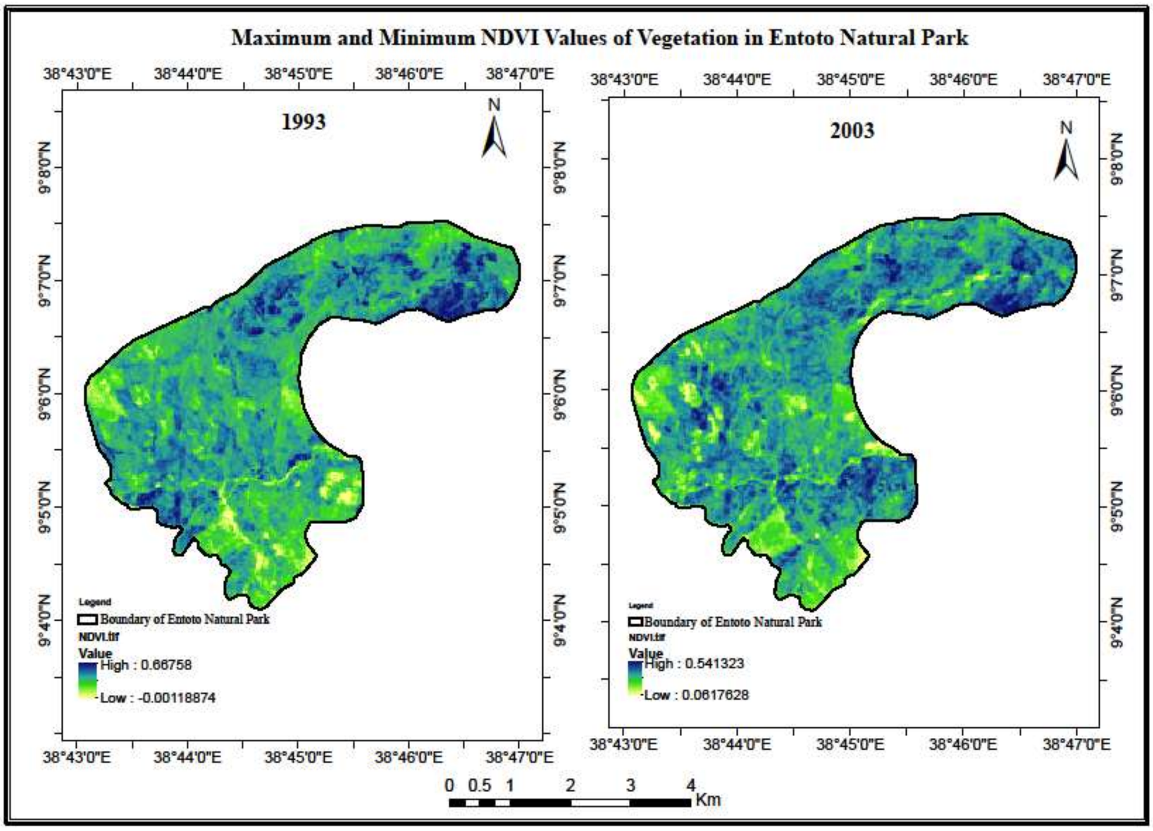
4.6.1. Vegetation Health Status in Dry Season

The vegetation health status in Entoto Natural Park was examined through driving NDVI (Normalized Difference Vegetation Index) from multi-spectral satellite imagery during dry season. The minimum and maximum value of NDVI was generated based on the spectral reflectance of vegetation to red and near infrared part of the electromagnetic spectrum. Healthy green vegetation has highly reflected the near infrared portion of electromagnetic radiation, and they absorb the red part of the spectrum.

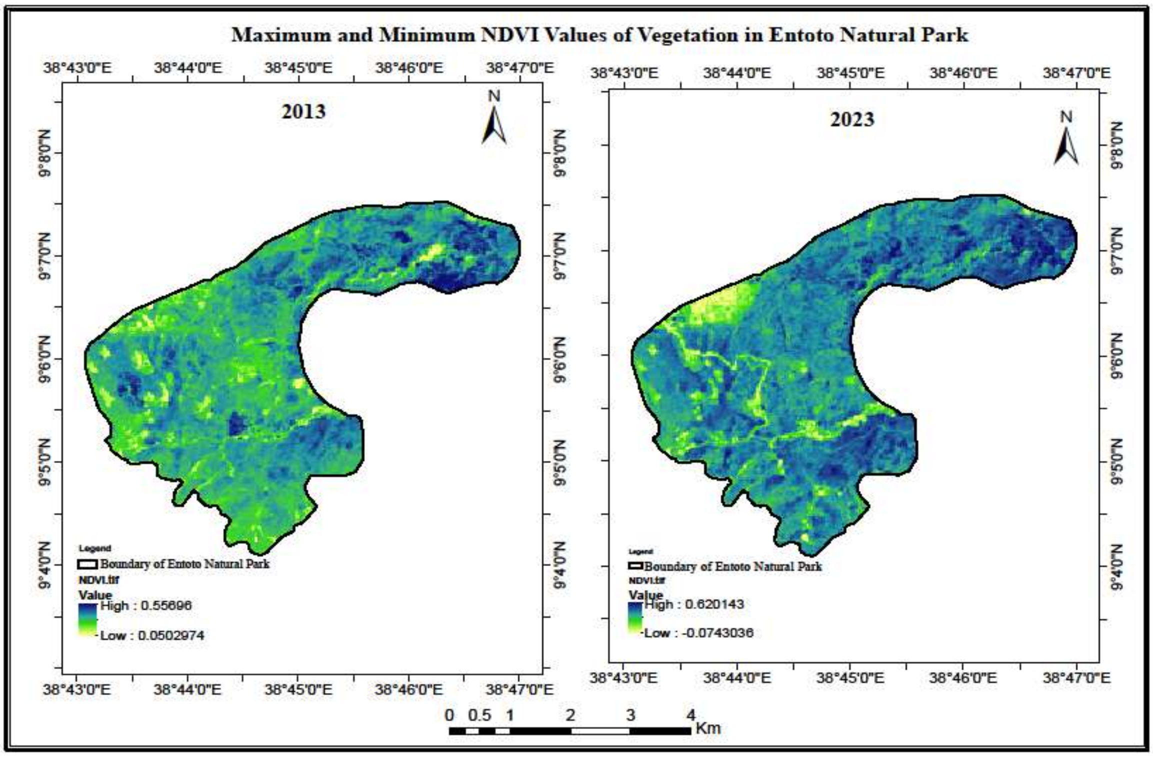
The result of the study reveals that the dominant vegetation in the study area has relatively low NDVI values during dry season. Since the dominant vegetation in Entoto Natural Park is Eucalyptus tree, the analysed vegetation NDVI value characterizes the Eucalyptus health status during dry season.

There is some variation of NDVI values from the year 1993 to 2003 in Entoto Natural Park during dry season. The minimum and maximum values of NDVI (Normalized Difference Vegetation Index) for the year 1993 are -0.001 and 0.668 respectively. The high value of NDVI shows the area of vegetation with good health status and low NDVI represents the area of vegetation with relatively low health status. The minimum and maximum NDVI values of vegetation for the years 2003 are 0.062 and 0.541 respectively. The maximum NDVI value of vegetation which was obtained in 1993 was relatively higher than that of 2003. This shows that vegetation health status in 1993 was relatively higher than vegetation health status in 2003 and the progress shows the decrease in vegetation health in the year of 2003.

Also, the following figure 4-17 shows the maximum and minimum NDVI values of vegetation during dry season in Entoto Natural Park. The values of Normalized Difference Vegetation Index for both years were different. In 2013, the minimum and maximum NDVI was 0.050 and 0.557 respectively and for the year 2023, the obtained minimum and maximum value of NDVI was -0.074 and 0.620. This indicates that the vegetation health status in 2023 was relatively higher than that of 2013. So, there is the increased healthy vegetation in 2023.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-20: Map of the maximum and minimum NDVI values of vegetation during dry season

The following table shows the maximum and minimum NDVI values of vegetation during dry season in Entoto Natural Park. The values were calculated from spectral bands of satellite imagery employing Normalized Difference Vegetation Index (NDVI). The variation of NDVI for each year indicates the variation of vegetation health status for different period of time in Entoto Natural Park.

Table 4-6: The NDVI values of vegetation in Entoto Naatural Park during dry season

Year	**NDVI Values**	
	Minimum	**Maximum**
1993	-0.001	0.668
2003	0.062	0.541
2013	0.050	0.557
2023	-0.074	0.620

For the calculated NDVI values, three decimal places were taken to increase the accuracy of comparison. The NDVI value close to +1 shows higher degree of vegetation health status and values close to -1 show the lower degree of vegetation health status in Entoto Natural Park. The NDVI values for live plants range from 0 to 1, with 1 indicating optimal health and 0 indicating poor health. The following graph shows minimum NDVI values of vegetation in Entoto Natural Park during dry season.

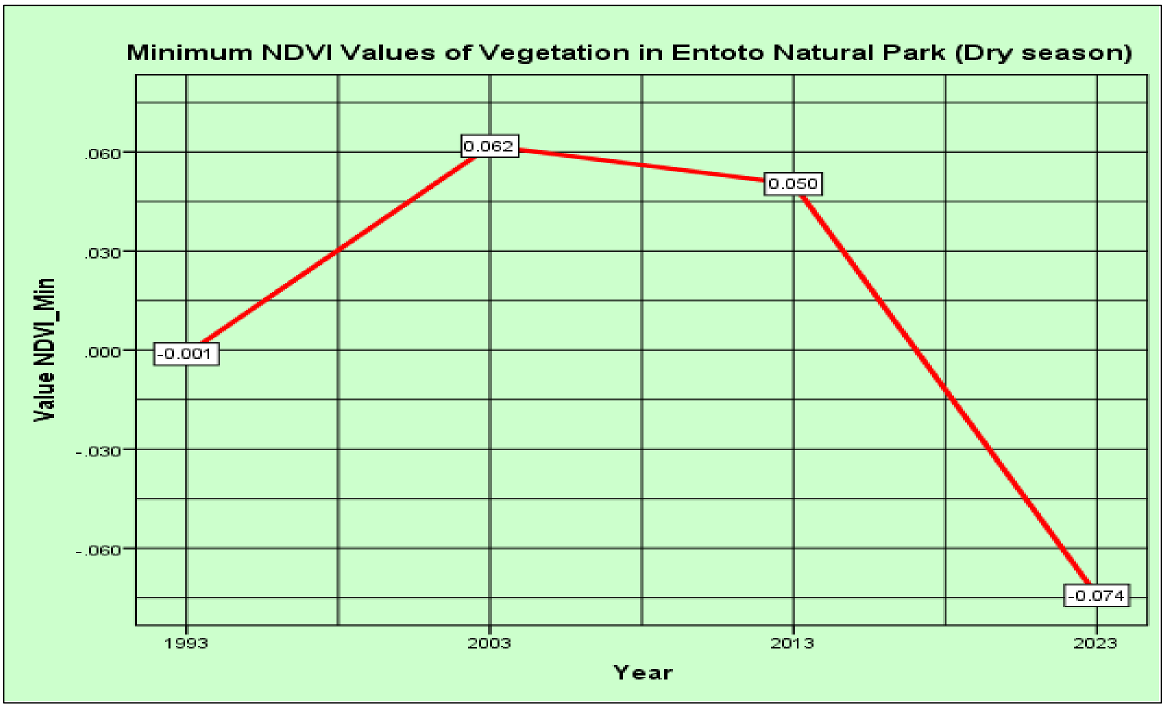


Figure 4-21: The graph of minimum NDVI values of vegetation during dry season

The following graph indicates the maximum NDVI values of vegetation from the years 1993 to 2023 in 10 years interval. The values of NDVI spectral index were calculated from multispectral satellite imagery of vegetation in Entoto Natural Park during dry season. The result of the analysis indicates that the highest value of NDVI was recorded in 1993.

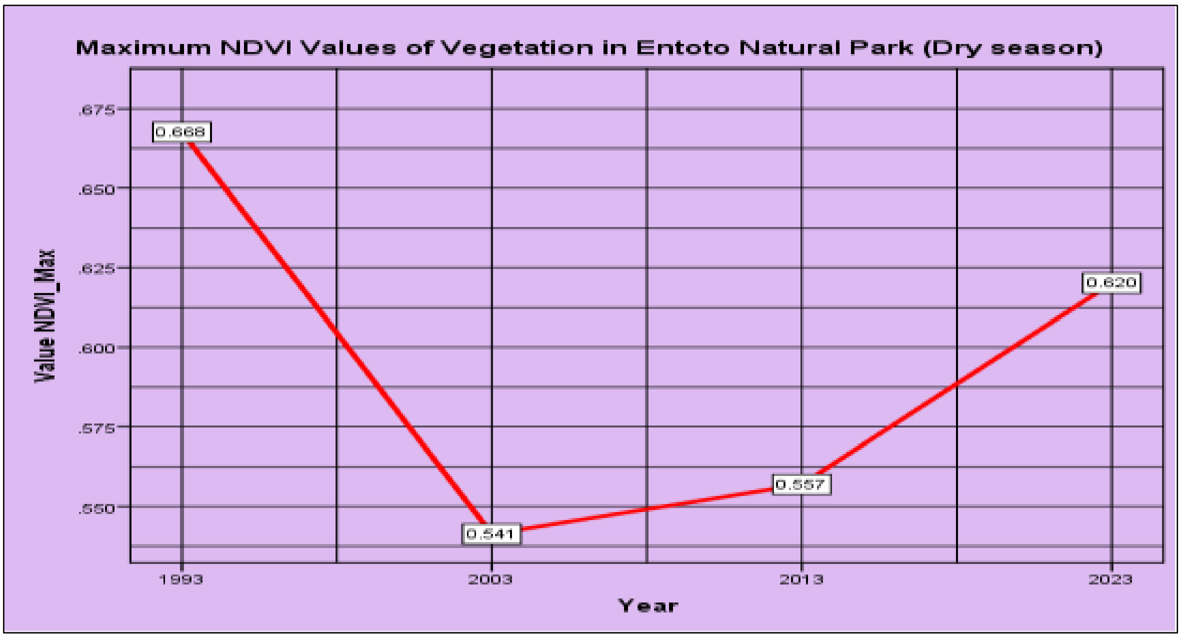


Figure 4-22: The graph of maximum NDVI values of vegetation during dry season

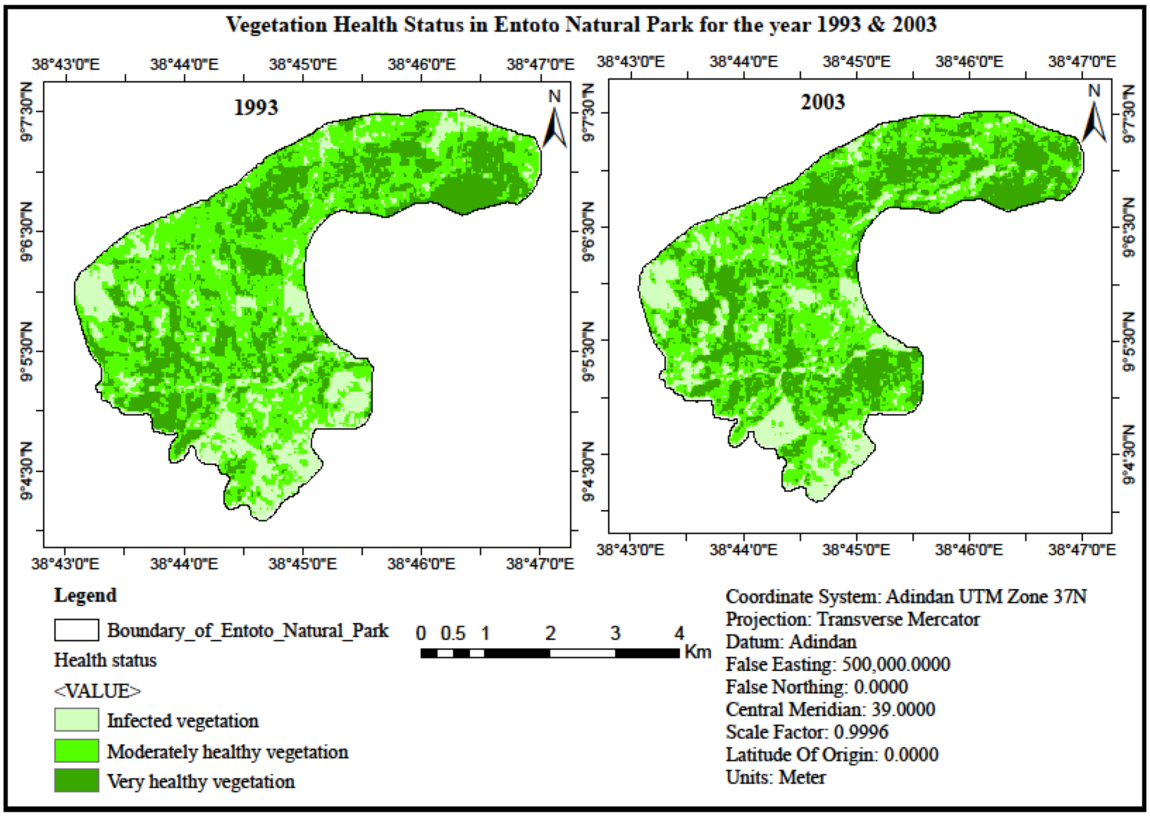
The maximum Normalized Difference Vegetation Index (NDVI) was calculated from different Landsat imagery for different period of time based on the spectral bands of the satellite imagery. There was the variation of NDVI values for each year and this variation indicates the variability of vegetation health status in Entoto Natural Park. Therefore, the result of the analysis showed that the highest NDVI value of vegetation was obtained in 1993 and its interpretation reveals that there was high healthy vegetation in 1993.

The following table shows the NDVI categories with its description. Different ranges of NDVI values show different level of vegetation health status. The level of vegetation healthy status was ranked as very healthy vegetation, moderately healthy vegetation and diseased or infected vegetation.

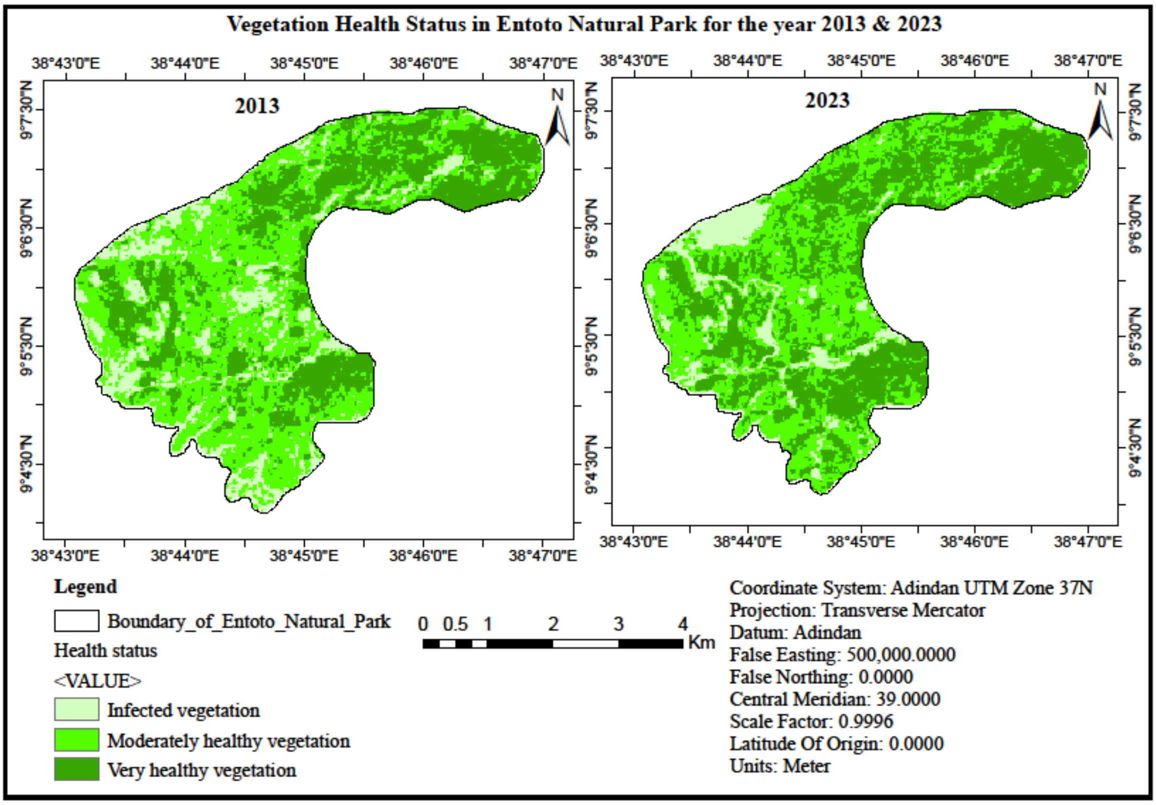
Table 4-7: Interpretation of NDVI values in differentiating vegetation health status

NDVI Values	Description
-1-0	Dead Vegetation
0-0.33	Diseased or infected vegetation
0.33-0.66	Moderately healthy vegetation
0.66-1	Very healthy vegetation

The vegetation health status for the years 1993 and 2003 were analysed based on the NDVI value of vegetation in Entoto Natural Park. The health status of the vegetation over the region was classified as very healthy vegetation, moderately healthy vegetation and diseased or infected vegetation. The dark green colour from the above map shows the area of land covered by dark green, very healthy vegetation. The colour nearest to dark green represents the area of land covered by moderately healthy vegetation in Entoto Natural Park. The dominant area is the land covered by moderately healthy vegetation for the year 1993 and 2003.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-23: Map of vegetation health status in Entoto Natural Park during dry season

The result of the analysis shows that the vegetation health status in North eastern part of Entoto Natural Park is relatively higher than the southern part of Entoto Natural Park for the year 2013 and 2023. Healthy green vegetation is found in large spatial coverage in North eastern part of Entoto Natural Park. Relatively less health vegetation is found in central and southern part of Entoto Natural Park for the year 2013. Also, for the year 2023, healthy green vegetation is found in large spatial coverage in North eastern and south eastern part of the study area while moderately healthy vegetation widely covers the central and southern part of Entoto Natural Park.

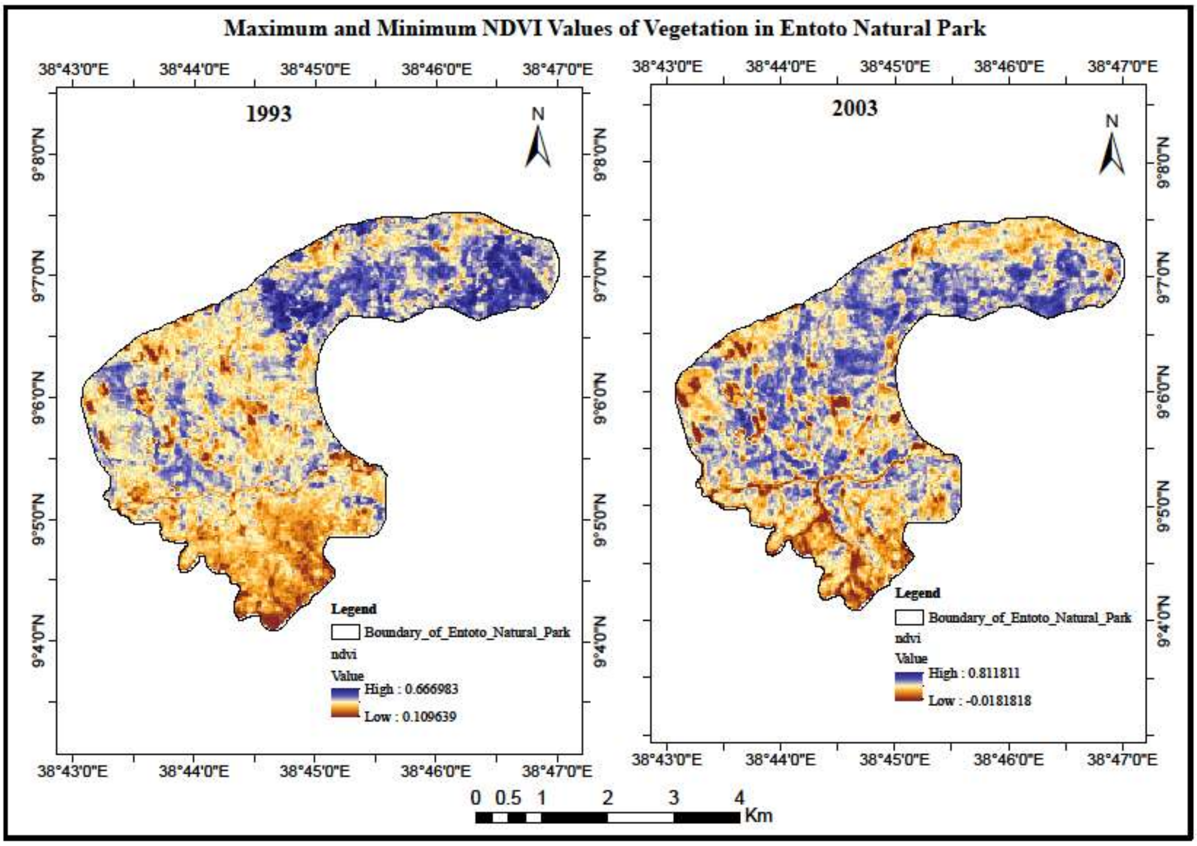
4.6.2. Vegetation Health Status in Wet Season

The analysis of spectral indices revealed that vegetation in Entoto Natural Park is healthier during the wet season compared to the dry season. This is because the wet season provides excess moisture in the soil, atmosphere, and vegetation leaves. The dominant vegetation in the park, Eucalyptus trees, showed good health during the wet season. However, there are still some infected Eucalyptus trees with low health status.

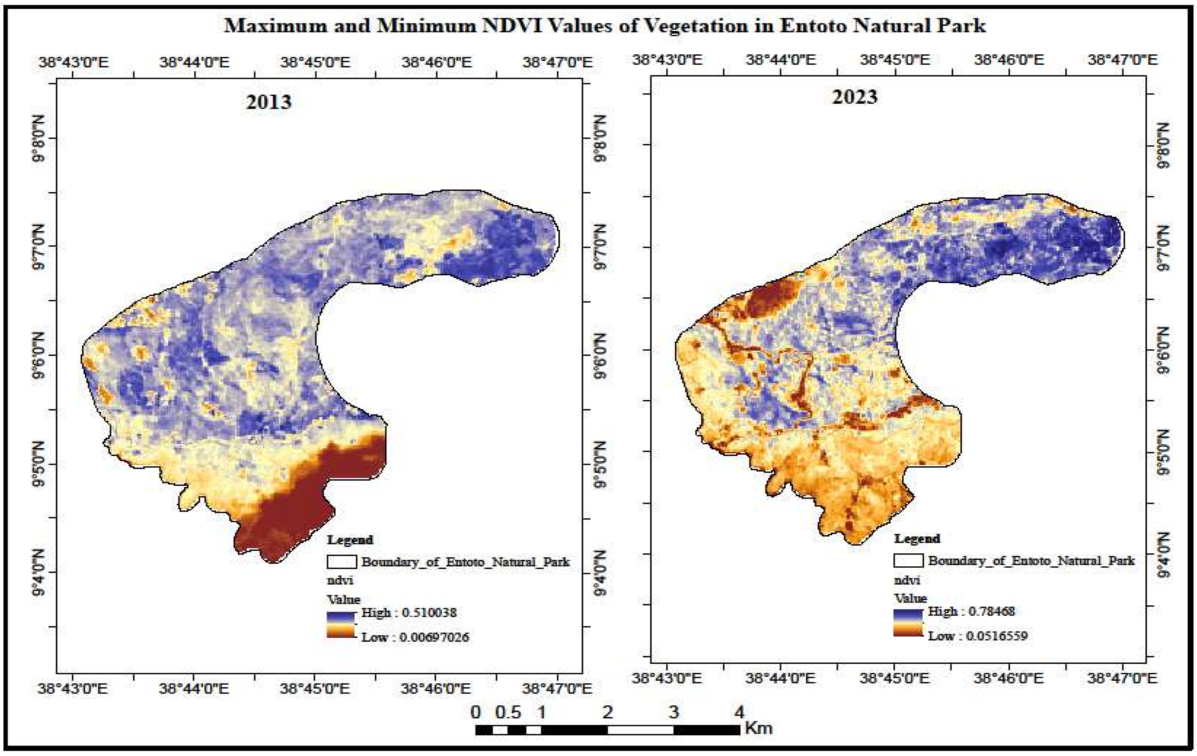
The study determined the minimum and maximum values of the Normalized Difference Vegetation Index (NDVI) based on the spectral reflectance of vegetation in the red and near infrared parts of the electromagnetic spectrum. The analysis showed an increase in NDVI values during the wet season. Healthy vegetation exhibits good spectral reflectance in the near infrared region while absorbing the red part of the electromagnetic radiation.

During the wet season, the NDVI values of vegetation in Entoto Natural Park varied from 1993 to 2003. The minimum and maximum NDVI values for 1993 were 0.109 and 0.667 respectively. A high NDVI value indicates good vegetation health, while a low NDVI represents areas with poor health. For the year 2003, the minimum and maximum NDVI values were -0.018 and 0.811 respectively. The maximum NDVI value obtained in 2003 was relatively higher than that of 1993, indicating an improvement in vegetation health.

Figure 4:8 illustrates the maximum and minimum NDVI values of vegetation during the wet season for the years 1993, 2003, 2013, and 2023 in Entoto Natural Park. In 2013, the minimum and maximum NDVI values during the wet season were 0.006 and 0.510 respectively. For the year 2023, the calculated values for the minimum and maximum NDVI were 0.051 and 0.784. This indicates that vegetation health status in 2023 was relatively higher than that of 2013, reflecting an increase in healthy vegetation.



a). 1993 & 2003



b). 2013 & 2023

Figure 4-24: Map of the maximum and minimum NDVI values of vegetation during wet season

The table below displays the maximum and minimum NDVI values of vegetation during the wet season for the years 1993, 2003, 2013, and 2023 in Entoto Natural Park. These values were obtained by analyzing satellite imagery using the Normalized Difference Vegetation Index (NDVI). By comparing the NDVI values for each year, we can observe the changes in vegetation health status over different time periods in Entoto Natural Park.

Table 4-8: The NDVI values of vegetation in Entoto Natural Park during wet season

Year	**NDVI Values**	
	Minimum	**Maximum**
1993	0.109	0.667
2003	-0.018	0.811
2013	0.006	0.510
2023	0.051	0.784

To ensure accurate comparison, the calculated values of the Normalized Difference Vegetation Index (NDVI) were rounded to three decimal places. A higher NDVI value close to +1 indicates a greater degree of vegetation health in Entoto Natural Park during the wet season, while values close to -1 indicate a lower degree of vegetation health. The graph below illustrates the minimum NDVI values of vegetation during the wet season in Entoto Natural Park for the years 1993, 2003, 2013, and 2023. The minimum NDVI values were determined for each year and visualized in Figure 4-22.

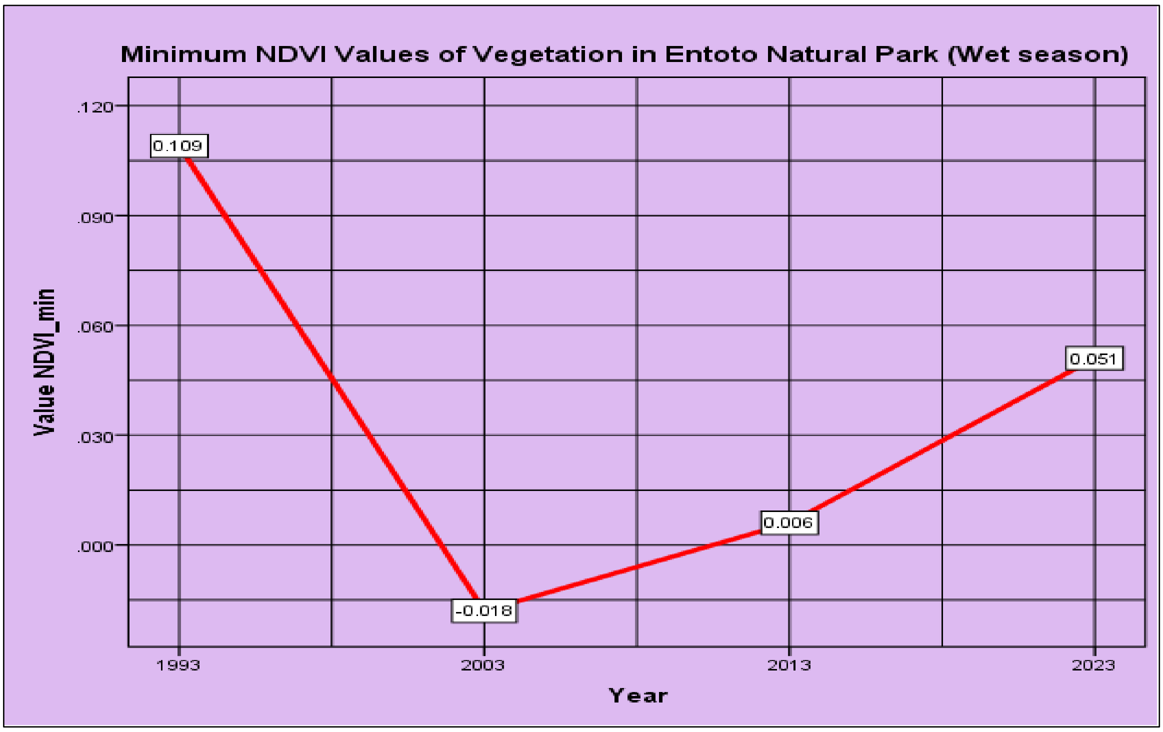


Figure 4-25: The graph of minimum NDVI values of vegetation during wet season

The following graph indicates the maximum NDVI values of vegetation from the years 1993 to 2023 in 10 years interval. The values of NDVI spectral index were calculated from multispectral satellite imagery of vegetation in Entoto Natural Park during wet season. The result of the analysis indicates that the highest value of NDVI was recorded in 1993.

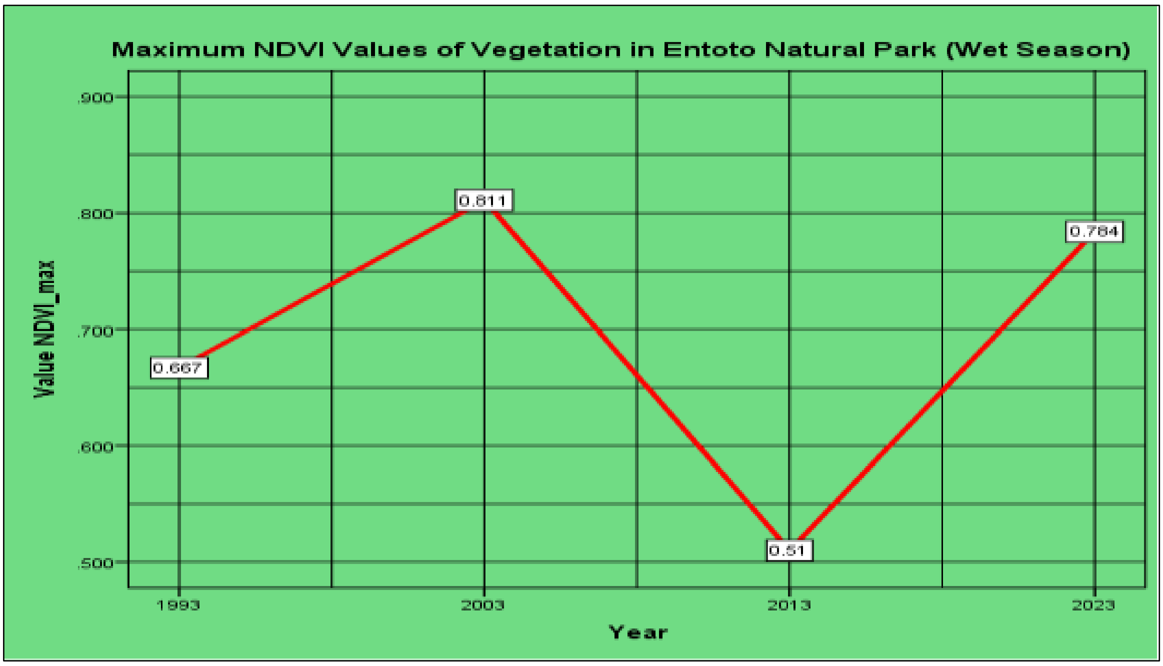
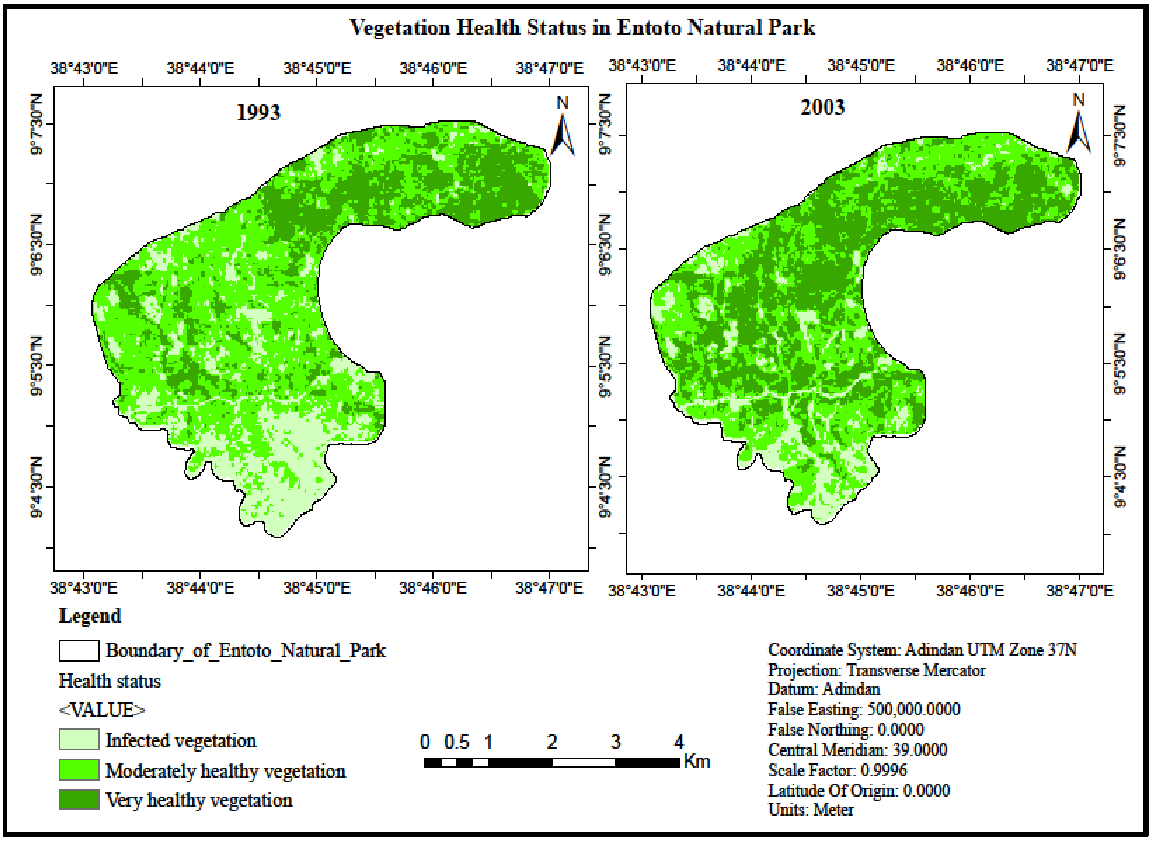
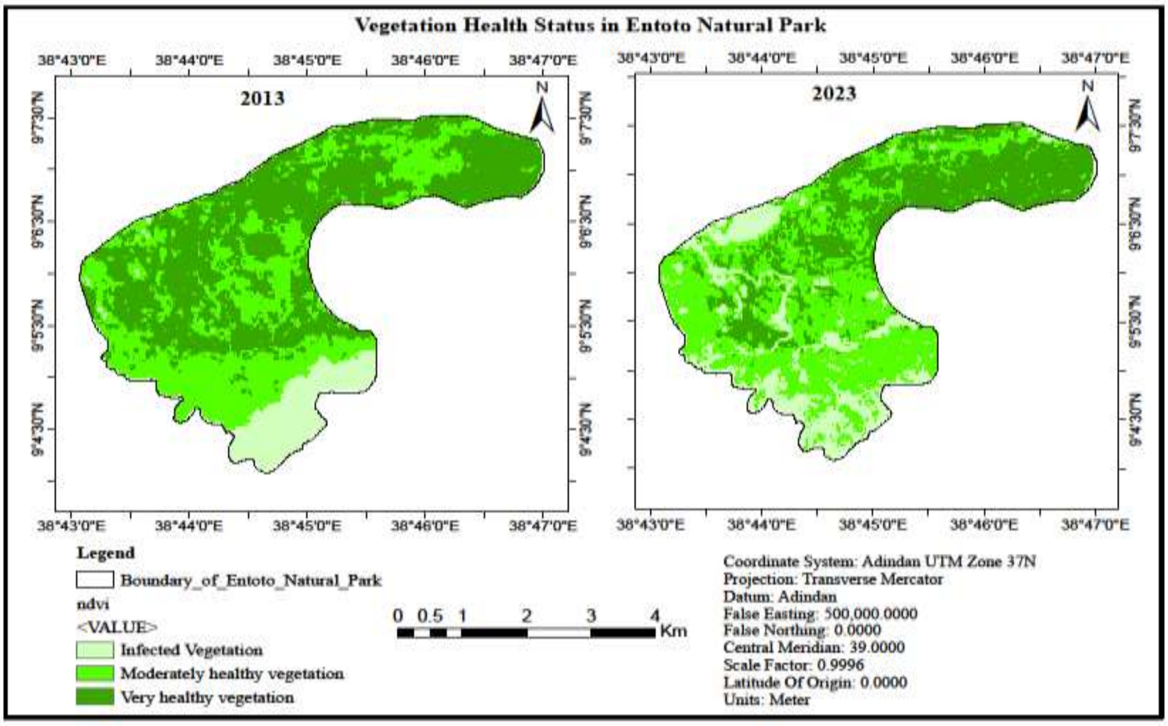


Figure 4-26: The graph of maximum NDVI values of vegetation during wet season



a). 1993 & 2003



b). 2013 & 2023

Figure 4-27: Map of vegetation health status in Entoto Natural Park during wet season

The findings of the study conducted in Entoto Natural Park revealed that the dominant vegetation, specifically the eucalyptus trees, exhibited relatively high health status during the wet season. This was determined by employing the NDWI (Normalized Difference Water Index) spectral index, which is commonly used to assess vegetation health status. The wet season is characterized by increased rainfall, resulting in higher soil moisture levels. This ample water supply ensures that plants have sufficient access to water, reducing water stress and promoting healthy growth.

The wet season often brings milder temperatures and diffuse light, creating favorable conditions for photosynthesis. These conditions enhance the vegetation' ability to capture sunlight and convert it into energy, promoting robust growth and overall plant health. The presence of adequate soil moisture during the wet season helps plants maintain proper hydration. This reduces water loss through transpiration, allowing plants to conserve water and allocate resources more efficiently.

By employing the NDWI spectral index, the study observed that not only the eucalyptus trees but also other vegetation in the study area exhibited relatively good health status during the wet season. This indicates that the overall ecosystem in Entoto Natural Park benefits from the increased water availability and favorable environmental conditions during this time, leading to healthier and more vibrant vegetation.

CHAPTER V: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study evaluated vegetation conditions for sustainable green legacy in Entoto Natural Park during dry and wet seasons. It was conducted employing multispectral satellite imagery and spectral indices such as Normalized Difference Water Index (NDWI), Green Normalized Difference Vegetation Index (GNDVI) and Normalized Difference Vegetation Index (NDVI). The objective of the study was to analyze the leaf water content, chlorophyll concentration, and overall health status of the vegetation during the dry and wet seasons in Entoto Natural Park.

The findings of the study revealed that the dominant vegetation in Entoto Natural Park, namely the Eucalyptus tree and Juniperus procera, exhibited very low leaf water content and moderate chlorophyll concentration during dry season. By employing the NDWI spectral index, it was observed that the Eucalyptus trees and Juniperus procera in the study area had relatively lower leaf water moisture.

Additionally, the Eucalyptus trees and Juniperus procera in Entoto Natural Park exhibited relatively low GNDVI values during the dry season. This suggests a lower chlorophyll concentration of Eucalyptus trees and Juniperus procera in the study area. Consequently, the photosynthetic activity of the dominant vegetation in the study area is relatively low during the dry season. This information provides insights into the overall health and vitality of the vegetation in Entoto Natural Park during different seasons, highlighting the importance of water availability and its impact on plant physiology.

The analysis of vegetation health status in Entoto Natural Park using the NDVI spectral index revealed interesting findings. The higher NDVI values during the wet season compared to the dry season indicate that the overall health and vitality of the vegetation, including eucalyptus trees and Juniperus procera, is significantly better during the wet season in the study area. This observation can be attributed to several factors. Firstly, the availability of water plays a crucial role in supporting plant growth and development. During the wet season, there is an abundance of water resources, including rainfall and soil moisture, which promotes optimal plant functioning and photosynthetic activity. This leads to higher chlorophyll content and healthier vegetation.

Additionally, the wet season provides favorable environmental conditions such as cooler temperatures and reduced water stress, allowing plants to thrive and allocate more energy towards growth and reproduction. These results in denser foliage, increased biomass production, and improved vegetation health. On the other hand, the lower NDVI values observed during the dry season suggest that the vegetation, including eucalyptus trees and Juniperus procera, faces challenges in maintaining optimal health and productivity. Limited water availability during this period can lead to water stress, reduced chlorophyll content, and decreased photosynthetic activity. As a result, the vegetation may exhibit signs of stress, such as sparse foliage and lower biomass production.

Understanding the seasonal variations in vegetation health is crucial for effective park management and conservation efforts. By recognizing the importance of water availability and its influence on vegetation health, appropriate measures can be taken to ensure the sustainable management and preservation of Entoto Natural Park's diverse ecosystem. This may include implementing water conservation strategies, monitoring and managing vegetation during periods of water scarcity, and promoting sustainable land use practices to maintain the overall health and resilience of the park's vegetation throughout the year.

5.2. Recommendation

The findings of this study highlight the valuable role of Multispectral Remote Sensing and Spectral indices in assessing vegetation conditions, including leaf water content, chlorophyll concentration, and overall vegetation health. Based on these results, the following research recommendations are suggested:

- It was observed that the Eucalyptus tree and Juniperus procera had lower leaf water moisture compared to other vegetation types. This implies that the contribution of Eucalyptus trees and Juniperus procera to environmental protection and climate change mitigation is relatively limited. Therefore, it is advisable to consider planting other plant species that can retain higher leaf water moisture and exhibit better photosynthetic activity to effectively absorb a significant amount of CO_2 from the surrounding environment.
- Given the relatively low impact of Eucalyptus trees and Juniperus procera in combating global warming and climate change, it is recommended to introduce different plant species in Entoto Natural Park to address the challenges associated with these issues and promote sustainable green legacy.
- Further research should be conducted in other areas to explore and gain new insights into evaluating vegetation conditions for achieving sustainable green legacy.

Overall, these research recommendations aim to enhance our understanding of vegetation conditions and contribute to effective strategies for environmental conservation and combating climate change.

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APPENDICES

Appendix 1: Band Specifications for Landsat 5 TM (Thematic Mapper)

Landsat 5 TM		
Bands	**Wavelength (micrometres)**	**Resolution (meters)**
Band 1 - Blue	0.45-0.52	30
Band 2 - Green	0.52-0.60	30
Band 3 - Red	0.63-0.69	30
Band 4 - NIR	0.76-0.90	30
Band 5 - SWIR 1	1.55-1.75	30
Band 6 - Thermal	10.40-12.50	120 (30)
Band 7 –SWIR 2	2.08-2.05	30

Appendix 2: Band Specifications for Landsat 7 ETM+ (Enhanced Thematic Mapper Plus)

Landsat 7 ETM+		
Bands	**Wavelength (micrometres)**	**Resolution (meters)**
Band1-Blue	0.45-0.52	30
Band 2-Green	0.52-0.60	30
Band 3-Red	0.63-0.69	30
Band 4-NIR	0.77-0.90	30
Band 5-SWIR1	1.55-1.75	30
Band 6-TIR	10.40-12.50	30/60
Band 7-SWIR2	2.09-2.35	30
Band 8-Panchromatic	0.52-0.90	15

Appendix 3: Band specifications for Landsat 8 OLI (Operational Land Imager)

Landsat 8 OLI		
Bands	**Wave length (micrometre)**	**Resolution (meters)**
Band 1- Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3-Green	0.53-0.59	30
Band 4-Red	0.64-0.67	30
Band 5- Near Infrared	0.85-0.88	30
Band 6 –SWIR1	1.57-1.65	30
Band 7-SWIR 2	2.11-2.29	30
Band 8-Panchromatic	0.50-0.68	15
Band 9-Cirrusus	1.36-1.38	30
Band 10- TIRS1	10.6-11.19	100
Band 11 -TIRS2	11.50-12.51	100

Appendix 4: Spectral indices of vegetation in Entoto Natural Park during dry season

Spectral Indices	Observed Years							
	1993		2003		2013		2023	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
NDWI	-0.081	0.618	-0.138	0.438	-0.136	0.450	-0.148	0.503
GNDVI	0.093	0.314	0.056	0.325	0.082	0.357	-0.073	0.4
NDVI	-0.001	0.668	0.062	0.541	0.050	0.557	-0.074	0.620

Appendix 5: Spectral indices of vegetation in Entoto Natural Park during wet season

Spectral Indices	Observed Years							
	1993		2003		2013		2023	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
NDWI	-0.074	0.630	-0.165	0.745	-0.067	0.667	-0.139	0.634
GNDVI	0.122	0.560	0.050	0.653	-0.001	0.673	0.051	0.766
NDVI	0.109	0.667	-0.018	0.811	0.006	0.510	0.051	0.784

Appendix 6: Mean of spectral indices for dry and wet seasons in Entoto Natural Park

Spectral Indices	Observed Years							
	1993		2003		2013		2023	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
NDWI	-0.078	0.624	-0.150	0.5915	-0.102	0.559	-0.144	0.569
GNDVI	0.108	0.437	0.053	0.489	0.041	0.515	-0.011	0.583
NDVI	0.054	0.668	0.022	0.676	0.028	0.534	-0.012	0.702