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Quantification of above ground forest carbon dynamics using Sentinial-2 imageries and InVEST Model in Triyuga Municipality of Chure Region

by

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Master of Science (Geographical Information Science and Systems) – MSc (GISc)

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Kathmandu

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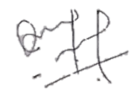
Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

September, 2023 Kathmandu



Signature

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DECLARATION

I am Deepa Dahal, hereby declare that this report entitled with "**Quantification of above ground forest carbon dynamics using Sentinial-2 imageries and InVEST Model in Triyuga Municipality of Chure Region**" is a based on primary work done by me and all the sources of information used in the work are duly acknowledged. This work has not been submitted to any other instruction for any academic award.

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Abbreviations

AGB	:	Above Ground Biomass
CFM	:	Collaborative Forest Management
CFUGs	:	Community Forest User Groups
CO_2	:	Carbon Dioxide
DBH	:	Diameter at Brest Height
ICIMOD	:	International Center for Integrated Mountain Development
InVEST	:	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	:	Intergovernmental Panel on Climate Change
LUCC	:	Land Use Cover Change
LULC	:	Land Use Land Cover
MLC	:	Maximum Likelihood Classification
NDVI	:	Normalized Difference Vegetation Index
REDD+	:	Reducing Emissions from Deforestation and Forest Degradation
UNFCCC	:	United Nations Framework Convention on Climate Change

Abstract

At the national and international levels, one of the most important issues is global climate change. The results of numerous studies indicate that both the global mean temperature and the global mean precipitation have been rising. According to IPCC (2018) estimates, between 2030 and 2052, the average global warming would likely approach 1.5°C if greenhouse gas emissions continue at their current rate. Due to its geography, Nepal has a complicated climate that varies widely. Climate change has an impact on Nepal in a number of areas, including biodiversity, agriculture, cattle, water resources, soil, tourism, and health. Both deforestation and forest degradation have a considerable impact on greenhouse gas emissions. These actions directly affect the amount of carbon sequestered. These actions have an immediate effect on the carbon sequestered. On the other hand, there is a substantial global potential for carbon storage in terrestrial ecosystems when damaged forests and soil are restored. According to estimates, between 18 and 20 percent of the world's greenhouse gas emissions are attributable to land use change, mainly the conversion of forestland to non-forestland and irresponsible forest management. REDD+ is a strategy that enables farmers and members of rural communities to take part in adaptation and mitigation efforts. By producing carbon credits, REDD+ has the potential to significantly increase revenue in developing nations. However, for successful application, accurate and verifiable methodologies to calculate biomass stocks and carbon sequestration rates must be developed. The literature on the deterioration of forests has a research vacuum since no study has been done to determine how much carbon has been lost from this region as a result of forest degradation or forest land being converted to other land uses throughout time. The purpose of this study is to close the knowledge gap in Triyuga Municipality about the relationship between LULC change and the mitigation of climate change through carbon sequestration.The objectives of study included the pattern of LULC in the study area during the period 2010 to 2023 and impacts of changes in LULC on carbon dynamics. The accuracy assessment of prepared LC was done using confusion matrix Kappa,s coefficient calculation. Sentiniel-2A image was used to prepare the land cover map of 2023 and ICI mode LC map of year 2000 and 2010 was used to extract Land cover map of Triyuga municipality. Using the InVEST 3.13.0 Workbench carbon sequestration model was used to estimate carbon storage in the year 2000 and 2010 with the IPCC 2006 carbon pool value. Carbon value for year 2023 was calculated by using Sharma and Pukala 1990 allometric equation. The above Ground carbon value for year 2000, 2010 and 2023 was 7887360.87 T of C, 7795346.07 T of C and 5233311.076 T of C, respectively. The reason for such a huge decrease in forest carbon is because of huge increase in cropland area 7107.07 ha which 76.48 % from 2000 to 2023 is. In regards with LULC change, built-up areas has increased from 0.07 % to 2.16, Crop land also has increased from 17 % to 30.02 %, OWL from 1.51 % to 3.88 %. However, bare lands, water bodies and forest land reflected decreasing trends. Bare land, forest land water bodies decreased statistics from 2000 to 2023 was 3.85% to 1.22%, 77.42 % to 62.53% and 0.33 % to 0.19%, respectively. From this study we concluded that major drivers of carbon stock decrease was massive increase of crop lands and built-up areas and decrease in forest land in Triyuga municipality. Nevertheless, this study has provided new insight into the changing LULC pattern and carbon stock change rate about the past 23 years. The findings will be helpful for decision- and policy-makers in the Triyuga Municipality in preserving natural ecosystems to support mitigation goals for climate change as well as preserving habitat quality for biodiversity preservation.

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1. Chapter Introduction

1.1. Background

Global change is one of the greatest challenges of our generation (Iyer et al., 2015) and is one of the major issues at both national and international levels (Khadka and Pathak, 2016). Various studies have concluded that the global mean temperature and global mean precipitation has been increasing (Field, 2012; Gu and Adler, 2015). Climate change due to human activities have caused about 1°C of global warming above pre-industrial levels with range of 0.8° to 1.2°C (IPCC, 2018). According to estimates from the Intergovernmental Panel on Climate Change (IPCC), if greenhouse gas emissions keep increasing at the current rate, the world will probably warm by 1.5°C between 2030 and 2052. Though the major contributors of greenhouse gases (GHGs) are developed countries the consequences of climate change are most felt by developing countries i.e. those who are most vulnerable (Devkota, 2014; Mahahrjan et al., 2011). Nepal is a country which has complex climate that varies greatly due to its topography (McSweeney and Lizcano, 2008). Nepal has lowland regions with warm and humid sub-tropical climate while high altitude regions are cold and temperature which can reach below zero during winter (PAN, 2009). Similarly, major monsoon in Nepal is dominated by south-easterly monsoon while winter monsoon by westerly (PAN, 2009; McSweeney and Lizcano, 2008). Nepal is ranked fourth most vulnerable country to the impact of climate change and the seventh most affected country due to climate change in Climate Risk Index (Kreft et al., 2016). Similarly, MoSTE (2014) have identified Nepal as one of the four global hotspots for climate change risk due to its complex and extreme topography. This implies that though Nepal's contribution to greenhouse gases is negligible compared to developed countries, its risk to climate change is very high (Shrestha et al., 2000). The impact of climate change in Nepal is seen in various sectors like biodiversity, agriculture, livestock, water sources, soil, tourism, health, and some others. (MoPE, 2017). The main impact of climate change is on water resources and deglaciation can change the hydrological characteristics of glacial fed rivers (MoPE, 2017).

Forests absorb and store more carbon dioxide (CO_2) than any other terrestrial ecosystem (Gibbs et al., 2007). Forests have a CO_2 storage capacity of roughly 4,500 Gt, which exceeds atmospheric carbon dioxide levels of 3,000 Gt (Prentice et al., 2001). However, as Lal (2005) demonstrated, the amount of carbon retained in trees varies dramatically among latitudes. High latitude forests account for around 49% of terrestrial carbon store, while mid-latitude forests account for 14% and low latitude forests account for 37%. (et al., 1994). Forests provide the added benefit of carbon sequestration, making sustainably managed forests valuable as reliable GHGs sinks (Levy et al., 2004).

Forest carbon dynamics are determined by factors such as succession stage and management practices, which determine whether forests function as carbon sources or sinks (Masera et al., 2003). Disruptions to forest ecosystems, such as clearing, degradation, or conversion to other land uses, result in the release of previously stored carbon from above-ground and below-ground biomass, as well as the soil, eventually contributing to atmospheric CO_2 levels (Gibbs et al., 2007). Deforestation and forest degradation both contribute significantly to greenhouse gas emissions (Gibbs et al., 2007; Masera et al., 2003). These activities have a direct impact on the carbon stored in trees' living biomass (Gibbs et al. 2007). Restoration of degraded forests and soil, on the other hand, has significant global potential for carbon storage in terrestrial ecosystems, with the potential to compensate for 50-75% of historical carbon losses (Lal, 2005, Upadhyay et al., 2005). Agriculture and forestry are important sectors in Nepal, accounting for 36.56% of the country's total GDP (MOF 2012). Agriculture is the primary source of employment and livelihood for more than two-thirds of Nepal's population, and it is frequently supplemented by livestock activities (MOF 2012). Forests provide many resources to rural communities, including firewood, fodder, timber, and non-timber forest products (WECS 2010). Therefore, community forestry in

Nepal is important for more than just carbon sequestration; it is also important for increasing livelihood diversification and strengthening socio-ecological resilience in the face of climate change (Joshi et al. 2010). Currently, over 15,353 community forest user groups (CFUGs) representing 1.8 million households have been allocated approximately 30% of the national forest land, totaling approximately 1.3 million per hectares (MOF 2012). Forests managed under the community forestry scheme are regularly harvested for biomass, making it critical to monitor carbon sources and sinks in order to understand the overall carbon balance (Stinson and Freedman 2001; Mandal and Laake 2007). Biomass volume, in particular, is an important indicator of a forest's ability to sequester carbon (Dixon et al. 1994; Brown 2002; Masera et al. 2003; Lal 2005; Gibbs et al. 2007; Mandal and Laake 2007).

Land use change, particularly conversion of forestland to non-forestland and unsustainable forest management, is estimated to account for 18-20% of global greenhouse gas emissions (IPCC 2007). This increase in emissions is regarded as a significant contributor to global climate change. To address this issue, the REDD+ initiative (reducing emissions from deforestation and forest degradation, as well as the role of conservation, sustainable forest management, and carbon stock enhancement in developing countries) was launched in 2007 at the Conference of Parties (COP 13) in Bali. It was formally adopted as a measure to help mitigate climate change. The REDD+ mechanism requires the participating countries to measure and monitor CO_2 emissions caused by deforestation and degradation within their borders. The global debate on climate change mitigation recognizes REDD+ as an approach that allows rural communities and farmers to participate in mitigation and adaptation activities (Dietz and Kuyah 2011). REDD+ has the potential to generate significant income in developing countries by creating carbon credits. However, the development of accurate and verifiable methods to estimate biomass stocks and carbon sequestration rates is required for successful implementation. Various payment schemes are currently being developed to reward afforestation and reforestation activities as part of climate change mitigation efforts. As a result, the significance of carbon stored in tree biomass has grown, as trees are recognized as significant carbon sinks capable of sequestering atmospheric CO_2 in both temperate and tropical regions (Fang et al., 2001; Houghton et al., 2001).

The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have recognized the importance of reducing emissions from deforestation and forest degradation (REDD) in developing countries which focuses on preserving and sequestering carbon in forests (Staddon, 2009). The authors advocate for community-based forest management (CBFM) as a successful forest management model, particularly in developing countries (Masera et al., 2003; Staddon, 2009). Nepal, one of the world's least developed countries, has emerged as an innovator in implementing CBFM, which has a well-documented history of community forestry (Gautam et al. 2004; Staddon 2009). Nepal's community forestry exemplifies effective operations, progressive legislation, and evolving decentralized forest management practices (Giri and Ojha, 2010). Notably, Nepal's community forestry has made major advances in terms of strengthening social cohesion and improving forest ecology (Gautam et al., 2004). Decentralized and participatory forest policies in the country have been critical in restoring many degraded ecosystems (Bajracharya and Mool, 2009).

Changes in land use and land cover have implications for carbon dynamics, influencing carbon sequestration and emissions. Forest loss, conversion to agriculture, and urban expansion can result in carbon stock reduction, while reforestation and conservation efforts can enhance carbon sequestration potential (Sharma et al., 2018). This research has added valuable insights into the carbon dynamics and Land Use Land Cover change in Triyuga Municipality from 2000 to 2023. It has covered various aspects, including carbon stock assessment, land use change analysis, and the impacts of land use change on carbon dynamics. Further exploration of these papers will provide a more comprehensive understanding of the research background in this field of carbon valuation and LULC change impact analysis.

1.2. Literature Review

1.2.1. Significance of forest in Carbon sequestration

Forests play a crucial part in the global carbon © cycle (Denman et al., 2007) and as countries strive to understand and influence global changes, a thorough understanding of forest carbon dynamics is essential. Forest managers, policymakers, and governments need reliable methods to assess historical carbon stocks and changes, as well as to investigate potential future forest and land-use policies. As, relying solely on field measurements would be impractical and costly, tools developed to meet these needs typically include significant modeling components to generate estimates of carbon stocks and changes across vast landscapes. Modeling is also the only viable method for simulating future scenarios. Given the inherent heterogeneity of forest ecosystems, gathering sufficient field measurements to accurately characterize all types of forests under various conditions is not feasible (Running et al., 1999).

Approximately two-thirds of terrestrial carbon is sequestered in standing forests, understory plants, forest debris, and forest soils, excluding carbon stored in rocks and sediments (Sedjo et al., 1998). Agricultural and grassland soils are also capable to store significant amounts of carbon (Lal et al., 1998). Currently, Asia's forests are estimated to be net CO_2 emitters, owing primarily to deforestation and forest degradation (Dixon et al., 1994). The study by Post and Kwon (2000) shows that changes in land use and vegetation types have a significant impact on carbon fixation, flux, and soil respiration. According to Lal (1999), worldwide restoration of degraded forests and soils has the potential to sequester carbon in terrestrial ecosystems, compensating for 50-75% of historical carbon losses.

In recognition of the significant role of forests and soil in mitigating the greenhouse effect, an agreement was reached during the Kyoto Protocol to include carbon sequestration in forests and soil as acceptable offsets (UNFCCC, 1997). The primary reason for the increased interest in forestry is the flexibility it provides in increasing carbon stocks in forests, particularly in light of the uncertainties surrounding the effects of global warming (Solberg, 1997). If human activities are ultimately found to be the cause of global climate change, carbon accumulation in wood biomass will have a long-term positive impact on lowering atmospheric CO2 levels. Even if global warming is not as bad as predicted, increased stock of timber is likely to have a positive impact on forest products and other environmental benefits. (Hoen and Solberg, 1994). Similarly, increased soil productivity due to carbon sequestration has the potential to improve local agricultural production and contribute to the long-term livelihoods of millions of people living in biomass-based subsistence economies.

1.2.2. Carbon sequestration

Carbon sequestration refers to the process of removing and storing carbon dioxide from the atmosphere, typically through changes in land use (Mandal and Laake, 2005). It is regarded as a critical environmental concern in the twenty-first century and has been intensively research topic in recent years (Jaiswal et al., 2014). Forest-based carbon sequestration has enormous promise for solving global environmental concerns such as GHGs accumulation in the atmosphere and climate change (Girma et al., 2014). Trees act as carbon sinks by absorbing CO2 during photosynthesis and storing excess carbon as biomass (Jana et al., 2009).

The carbon contained in forest trees is known as tree or forest biomass. The CO2 (IPCC) has identified five carbon pools in the terrestrial biosphere, one of which is biomass. Aboveground biomass, belowground biomass, litter, woody debris, and soil organic matter are all examples of these pools. Among all the carbon pools, aboveground biomass accounts for a significant amount of the carbon stored (Vashum and Jayakumar, 2012). Forests trap and store more carbon than any other land-based ecosystem, making them a key natural mechanism for mitigating climate change. When forests are cut down or degraded, the carbon contained in them is released into the atmosphere as carbon dioxide (CO2) (Gibbs et al., 2007). Plants continue to retain carbon indefinitely, primarily in the form of live biomass.

1.2.3. Biomass

Assessing terrestrial biotic carbon stocks and their changes is difficult, and current estimates are frequently uncertain because carbon stock and flux are calculated using average biomass values. Simultaneously, chronic disturbances and fragmentation, both natural and man-made, pose serious threats to the Himalayan region's forests and biodiversity (Singh et al., 2005). Deforestation, forest disturbances, and topographic variations can cause forest biomass values to deviate significantly from average values, resulting in biased estimates. Estimating biomass typically relies on applying a common equation over a large area (Houghton 2003), and estimates can vary depending on stand age, species composition, and topography. Furthermore, Houghton (2003) stated that errors in biomass stock estimates are attributed to a lack of species-specific allometric equations for trees of various diameter classes, particularly large and small diameter trees. Because tree architecture and wood density vary significantly among species, it is preferable to use species-specific allometric equations that account for all diameter classes to estimate above and below ground biomass of a forest stand (Sundriyal et al. 1994; Sundriyal and Sharma 1996; Rai et al. 2002). While directly weighing tree biomass in the field is the most precise method for biomass estimation, it is time-consuming and destructive, making it only feasible for small areas and sample sizes. However, by utilizing allometric equations and existing knowledge on tree allometry, the accuracy of current biomass and forest carbon stock estimates can be increased. Recent applications and estimates of tropical forest biomass are included in scientific papers (Brown and Lugo 1982; Rawat 1983; Uhl et al. 1988; Brown et al. 1989; Rana et al. 1989; Bargali et al. 1992; Brown 1997; Lodhiyal et al. 2002; Chettri et al. 2002; Chettri and Sharma 2007; Chettri and Sharma 2009; Singh et al. 2011). Hence, using allometric equations is an important step in estimating above and below ground biomass (Crow 1978a, 1978b; Brown et al. 1989).

1.2.4. Carbon sequestration through community forest

Community forestry is a method of managing forest resources those benefits nearby communities by preserving and restoring the areas that have suffered from resource depletion and social decline in the past (Brendler and Carey, 1998). The strategy aims to prevent deforestation and degradation by implementing protective measures (Banskota et al., 2007), while also promoting decentralized forest administration and empowering local people (Karky et al., 2005). Community forestry involves multiple stakeholders and actors, including the state, private enterprises, and local forest users, all of whom are seeking to meet their economic, political, and social needs (Hobley and Malla 1996). Local forest users are organized into groups called CFUGs to help with this process who are in charge of managing forests, harvesting forest products, and determining market prices under the supervision of an executive committee chosen by the CFUG assembly (Chhetri et al., 2012). The failure of existing institutions, which had led to the gradual degradation of Nepal's hill forests, prompted the implementation of community forestry policies (Chhetri et al., 2012, Ojha et al. 2009). In the 1970s, the Nepalese government began to reconsider the involvement of local users in forest management, recognizing the effectiveness and benefits of common property management (Chhetri et al., 2012; Pokharel, 2012). This resulted in the legal establishment of community forest management (CFM) via the Forest Act of 1993 and the Forest Rules of 1995. The implementation of collaborative forest management (CFM) is dependent on the collaboration of Forest Department Officers and CFUGs (Satyal Pravat and Humphreys, 2013). CFM has been shown to be effective in increasing forest cover, conserving biodiversity, and providing forest products to support local livelihoods (Karky and Skutsch, 2010). Community managed forests in Nepal encourages natural regeneration and protects seedlings to promote the sustainable use of forest resources (Moss 2012). According to research by Patel et al. (2013), CFM has a positive impact on forest condition, making it an effective model for controlling deforestation and forest degradation. Local communities now have better access to firewood, timber, fodder, litter, and grass resources thanks to community forest conservation and management (Banskota et al. 2007).

1.2.5. InVEST Model

Several international scientific organizations have advocated for the use of the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model as a modern approach to evaluating ecosystem services (ESs) (Keller et al. 2015; Leh et al. 2013; Redhead et al. 2016; Sánchez-Canales et al. 2012). Researchers have also conducted research to quantify and map carbon storage and sequestration, which is a well-studied regulating service (Nackoney 2003; Stringer et al. 2012; Kanime et al. 2013; Jiang et al. 2017; Wang and Qie 2018; White, R.P.; Yang et al. 2020). However, the majority of these studies have concentrated on urban areas, coastal ecoregions (Zhao et al. 2016), mountainous regions (Zhao et al. 2018), and floodplains (Lininger et al. 2019), with arid agro-urban ecosystems receiving less attention (Favretto et al. 2016; Lu et al. 2018) when it comes to quantifying the ES value of carbon sequestration using the InVEST model. Four carbon pools were employed in recent research to assess and forecast climate change: above- and below-ground biomass, soil organic carbon, and dead organic matter.. Similar studies focused on changes in carbon storage in the soil organic carbon pool (Egoh et al. 2011) and the belowground biomass pool (Shangguan et al. 2014), from the past to the present.

1.2.6. LULC change

Land use and land cover (LULC) are constantly changing as a result of natural and human activity. Natural processes and human actions have both resulted in major changes in LULC (Houghton 2003). Many initiatives have been made to analyze and quantify the amount of anthropogenic changes in land cover. The principal source of human-induced land use changes has been the conversion and modification of natural ecosystems for agricultural uses (Ramankutty and Foley 1999). Human activities' impact on the environment is not a new problem, as historical records describe instances of damaging human influence on the Earth's (Marsh 1864). However, breakthroughs in ideas, methods, tools, and strategies targeted at mitigating the negative effects of LULC alterations have occurred in recent decades. Extensive research have been conducted to document these historical changes globally (Ramankutty and Foley 1999; Pongratz et al. 2008) or nationally (LRMP 1986; Uddin et al. 2015). The process of land use and land cover change is complex and takes numerous forms, with the differences in rate and magnitude. The dynamics also vary according to its scale (Keyser and Kaiser 2010).

Nepal, a predominantly mountainous country, encompasses two thirds portion of the Himalayan range (Rokaya et al. 2012), where agriculture is an essential component of the country's economy. Nepal is divided into five distinct physiographic regions: the High Mountain, the Middle Mountain, the Hill, the Shiwalik range, and the Tarai (LRMP 1986). When compared to the low-lying Tarai region, the Middle Mountain and High Mountain areas are more vulnerable to land use and land cover change (LUCC) and suffer more severe consequences even from minor changes (Khanal 2002). Because of the steep slopes of Nepal's mountainous terrain, the impact of LUCC is not limited to the specific regions where changes occur; it can easily extend its effects to the plains and low-lying areas (Becker and Bugmann 2001).

1.2.7. Three tier approach of carbon sequestration

There are two methods for estimating changes in forest carbon stocks that meet Tier 3 guidelines. The first method is known as the "inventory change" approach, which involves calculating the difference in carbon stocks by comparing detailed inventories taken at different time points (IPCC, 2003). Based on these inventories, models such as FORCARB and Heath and Birdsey (1993) can be used to estimate carbon stocks, providing a highly accurate assessment of total carbon stock changes as it integrates all relevant factors like natural disturbances, management, land-use change and climate. This method, however, does not provide information on year-to-year variations during the observation period and necessitates additional data to estimate non-CO2 emissions from factors such as fires and land-use changes. The fact that the inventories are based on field measurements taken in a portion of all inventory plots each year further complicates the technique. The second option, advised by the Good Practice Guidance (GPG), is the "one inventory plus change" method. Detailed models for calculating growth rates, decomposition, and non-CO2 emissions are required for this strategy, together with information on land-use changes, forest management activities, natural disturbances, and inventories of forests and other areas. This method has the benefit of allowing for flexible timing of the inventory as long as the information required to align the inventory with the analysis's start year is provided. The tier 3 approach is being used in this paper to compute the carbon value.

1.2.8. Carbon pools

The biomass of the tree or forest refers to the carbon that has been captured or stored on the forest trees. In the terrestrial ecosystem containing biomass, the CO2 identified five carbon pools: the aboveground biomass, belowground biomass, litter, woody debris, and soil organic matter. The aboveground biomass makes up the majority of the carbon pool out of all the carbon pools (Vashum, 2012). More than any other terrestrial ecosystem, forests store and sequester large amounts of carbon, acting as a natural "brake" on global warming. When trees are destroyed or deteriorate, the carbon they have stored is released as CO2 into the atmosphere (Gibbs et al., 2007). As measured by living biomass, plants store carbon for the duration of their lives.

1.3. Objectives of Study

The main objectives of the study includes the change of LULC in the study area during the study period 2000 to 2023, their impacts on carbon dynamics and to analyze the major drivers of LCC.

- Preparation of LULC map of the study area for year 2023
- To detect the change in LULC from 2000 to 2023
- Above Ground Forest Biomass Calculation of Triyuga municipality
- Effects of land cover change in carbon dynamics

1.4. Problem of statement

Reducing emissions from deforestation and forest degradation (REDD+) is an initiative that aims to protect existing forests while also encouraging forest expansion. It encourages developing countries to increase their forest cover in exchange for carbon credits, providing incentives for local communities to preserve forests rather than engage in deforestation for economic gain. The ability of a country to establish a baseline for forest carbon stocks and emissions, as required by the UNFCCC, is used to assess the success of REDD+ implementation. To meet this requirement, comprehensive forest inventories covering all forest types and including carbon stock estimation are required. Essentially, REDD+ is concerned with accurately estimating carbon stocks in various carbon pools, including above- and below-ground components for sustainable forest development.

Land use and land cover (LULC) changes are increasing significantly in both developing and developed countries, owing to the pursuit of economic growth and development. These rapid and dynamic activities raise concerns about the ecosystem's potential capacity to store carbon. Similarly, Nepal, as a developing country, has seen significant changes in land use and land cover over the last three decades (specifically, from 1990 to 2019) (FAO, 2017).

The literature on the deterioration of forests has a research vacuum since no study has been done to determine how much carbon has been lost from this region as a result of forest degradation or forest land being converted to other land uses throughout time. The prospective focus of my research is on how much carbon we can sequester in the future if we maintain the current land use pattern. Additionally, my study closes this knowledge gap regarding studies in Triyuga Municipality and thus adds to the body of knowledge in this area. Additionally, it raises the research question of figuring out the area's overall maximum capacity for carbon sequestration. As a result, the study makes connections between LULC modification and aspects of mitigating climate change through carbon sequestration.

The absence of baseline data on forest resources from the local to the regional level is another significant barrier to effective forest AGB estimation in Nepal. The inability of the forest personnel to undertake an inventory continues to be one of the key problems. The cause could be linked to a dearth of technical support and an overreliance on conventional field data collection methods. To the best of our knowledge, this is the municipality of Triyuga's first attempt at a research study.

2. Chapter Methodology

In this research, Geospatial Technology was used in order to acquire the dataset and those data was analyzed using the InVEST model and field data. The field data was collected and analyzed using Microsoft Excel, Arc Map 10.8 and google earth pro to measure carbon amount.

The steps that are followed to attained objectives of our research is briefly described successively along with flow chart and other necessary tables and figures

2.1. Study Area

The Chure region is a significant geographical area in Nepal, encompassing 37 out of 77 districts. It stretches from east to west, covering 13.6% of the country's total landscape and is home to approximately 60% of Nepal's population (DHM, 2017).

Triyuga is one of the eight municipalities within Udayapur district, located in Province No. 1 of Nepal. It is the third largest municipality in Nepal and the largest in Province No. 1 in terms of area, spanning 547.43 square kilometers. The initial population of the municipality, according to the 2021 Nepal census, is 104,375. It is divided into 16 wards, with Gaighat serving as the municipality's headquarters. Surrounded by the Mahabharat hills to the north and the Churey hills to the south, Triyuga encompasses the Inner Tarai, which consists of flood plains formed by the Triyuga River and its tributaries. To the north of the municipality are Udayapurgadhi and Rautamai, while Khotang District lies to the northeast and Chaudandigadhi Municipality to the east. Saptari District is situated to the south of Triyuga Municipality. The municipality is located within the Udayapur Valley, the largest valley in eastern Nepal, and boasts natural attractions such as the Triyuga River and Baruwa River flowing through the town (Triyuga Municipality, 2018).

2.1.1. Geography

Triyuga Municipality is situated within the geographical coordinates of 26°41'17" to 26°56'42" North latitude and 86°32'11.5" to 86°50'29" East longitude. Previously, it consisted of separate municipalities known as former Triyuga Municipality, Jalthal, Khadu, Saune, and Jogidaha villages. However, these entities have now merged to form a single municipality called Triyuga Municipality. The newly formed municipality encompasses both the Terai (flat) and hilly regions. Its strategic location serves as a central commercial hub and facilitates connectivity between the Tarai (plain) and hilly areas. This region has been proposed as the headquarters of the municipality. The expanded Triyuga Municipality now extends towards the vast Gaubihar region and is adjacent to the district headquarters, encompassing both the Terai and hilly regions (Triyuga Municipality Village Profile, https://triyugamun.gov.np/ne).

2.1.2. Soil

In this division, mostly sandy geranium soil is found, while red ocher is found in some places. Sand and gravel are more common on the banks of rivers that flow through the Churia range while on the banks of rivers that flow through the Mahabharat range loamy and clayey soil are commonly found. Due to the division's location in a flood-prone area, as well as increased erosion of the fertile soil and the annual decline in water level, the soil in this area is becoming drier.

2.1.3. Temperature and Rainfall

Under the jurisdiction of Division Forest Office, Gaighat, Udayapur, the temperature ranges from 18.82°C to 24.104°C. Under Division Forest Office, Gaighat, Udaipur all Triyuga, Chaudandigarhi and Belka municipalities have high temperature in southern part, central part has medium temperature and low temperature northern part. Triyuga municipality has lowest temperature in northern part. According to (ICIMOD, 2022), Triyuga municipality has average annual temperature ranging from lowest 18.82^{0}C to highest 24.1^{0}C.

Rainfall under the jurisdiction of Division Forest Office, Gaighat, Udayapur is 1523.37 mm. from 1792.73 mm. According to analytical study the rainfall is increasing as we go from west to the east of the working area, while the western parts of Triyuga municipality have relatively less rainfall. Triyuga municipality has annual rainfall ranging from 1523.37mm to 1654.68 mm.

2.1.4. Forest type

2.1.4.1. Forest groups based on climate

(a) Temperate forests

This type of forest is 88 m above sea level to 1000 m. It is spread widely over the division Churia and Bhawar area. 99,522.7 ha (84.8%) of the total area is occupied by this type of forest. Shorea robusta, Khair and Terai hardwood forests are found here, and every year important firewood is produced from this part. About 80 % forest were Shorea robusta dominate forest in Municipality.

b) Subtropical broad-leaved forest

This type of forest occupies 1000m- 2000m above sea level. It is spread in the Mahabharata region such as north-east Saune, Babla, Chaudandi. 18861.5ha (15.1%) of the total area is occupied by this type of forest. Shorea robusta, Hadu, Bothdhangero, Saj, Harro, Burro, Chilaune, Katus, Tuni, Lampate etc. species are found in this type of forest.

2.1.4.2. Forest based on the species

The altitude of this division forest is from 88 m to 1923 m. This division is a rich in terms of biological diversity. Staiton (1972) divided the forests of Nepal into 35 divisions according to the altitude, in this division the forests can be classified into 7 types based on the altitude and species.

a. Shorea robusta Forest- below 1000m
b. Sissoo-Khair Forest
c. Tropical Deciduous Riverine Forest
d. Tropical Evergreen Forest- below, 1000m
e. Sub-Tropical broad-leaved Forest, 1000-2000m

2.1.5. Major rivers, streams and watersheds

The main watershed of the areas flows from Mahabharata towards chure, whereas their branches and sub-watershed areas include Hadia, Kang, Lohale, Triyuga, Baruwa, Deodhar and Murtikhola and many other sub-watershed. Triyuga contains watershed area namely Baruwa Khola, Triyuga, Lohakhola and kangkhola where are studied by Chure Uplifting Project. River included in Chure Terai Madhesh Conservation and Management Master Plan in Triyuga river system 1 are Triyuga dwar, kali Khola, Bhalmanti Khola, Bagaha, Letey lama Khola, Baruwa Khola and in Triyuga river system 2 are Triyuga, Shivae Khola, Hadiya Khola, Kang Khola, Babiya Khola, Lohale Khola.

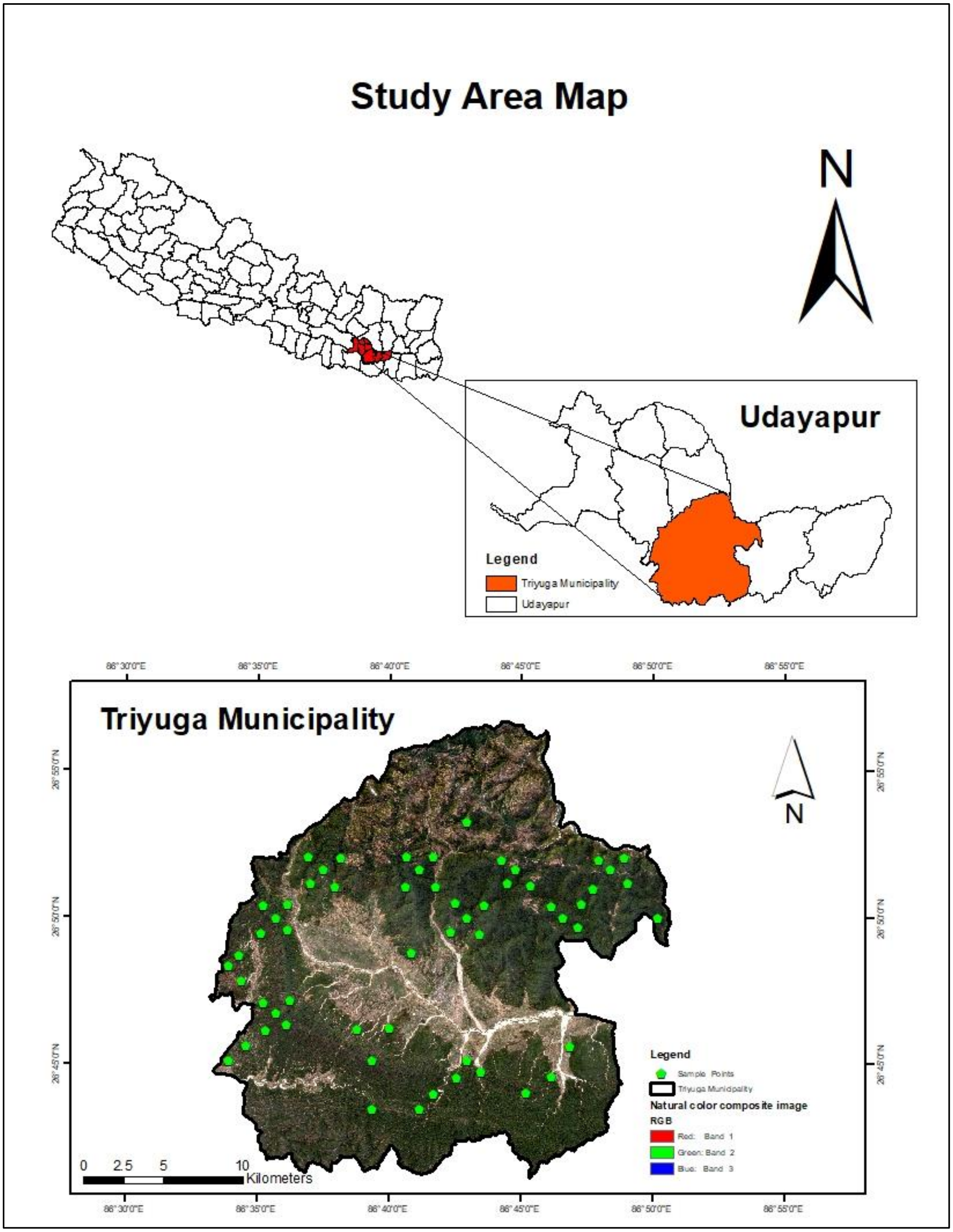

Figure 1: Location map of Triyuga Municipality

2.2. Software and instruments used

LULC Chure Map was extracted using ArcGIS Pro to analyze the raster picture. In this work, the carbon stock was estimated using the InVEST model created by the Natural Capital Project and LULC obtained from ICI mod data. The InVEST model makes use of maps of LULC as well as stocks of carbon pools (soil organic carbon, belowground biomass, above ground biomass, dead organic matter) to estimate how much carbon is now fixed in a landscape or how much is being sequestered.

Table 1: Showing the list of software used during thesis work

S.N.	Software used	Used for	Type
1.	QGIS/ArcGIS pro	Spatial Analysis and Data Management and Final Map composition	Enterprise
2.	ERDAS Imagine	Pre-processing, Image Classification	Enterprise
3.	Google Earth	For getting fair about the study area and also verifying the features on ground	Free and Open
4.	InVEST 3.12.0	Used for mapping carbon sequestration and calculation	Free and Open
5.	MS-office	For Analysis, Report writing, Preparation and Presentation	Free and Open
6	MS-Excel	For tables and contents keeping, analysis and calculations	Free and Open
7	Zotero	For Analysis, Report writing, Preparation and Presentation	Free and Open

2.3. Preprocessing of image

Before studying a satellite image, preparation is necessary to prevent data tampering or distortion. In order to establish a direct connection between data and biophysical processes, preprocessing is also required (Coppin et al., 2004). We do picture enhancement, radiometric correction, and scan-line corrector (SLC) gap filling as part of the image preprocessing process.

Atmospheric correction and topographic normalization are required to improve the classification results (Hale and Rock, 2003; Song et al., 2001). Atmospheric correction primarily includes the removal of haze, which originates from fractions of water vapor, fog, dust, smoke, or other minute atmospheric particles (Makarau et al., 2014). Image enhancement is the modification of pixel values to improve visual interpretation by increasing the distinction between features (Lillesand et al., 2015). Histogram equalization (HE), one of the most widely utilized techniques, was applied here. The fundamental goal of HE-based approaches is to completely uniformize the intensity distribution by reassigning the pixel intensity values (Cheng and Shi, 2004).

2.4. Classification Procedure

A mix of supervised and unsupervised classification in pixel-based image classification yields a more precise strategy for classifying land use. In this work, we developed six primary land use classes using a hybrid classification approach in order to be compatible with the classes often established for Nepal, as shown in table 2. Our hybrid strategy consists of first classifying photos unsupervised, then classifying them supervised.

Table 2: Land use/land cover classes.

Land Use/Cover Class	Land Uses and Land Covers Included in Class
Urban/Built-up area	Structures of all types: residential, industrial, commercial, airports, and roads/highways
Crop Lands	Croplands and temporary grasslands used for agriculture
Forest Lands	Forest, parks and permanent tree covered area
Other Wooded Lands	Shrub lands, Grasslands and Riverbed areas
Bare Lands	Vacant lands, open area, and fallow lands
Water Bodies	River and associated areas

The unsupervised Iterative Self-Organizing Data Analysis (ISODATA) grouping into 75 clusters served as the foundation for the hybrid categorization of land uses in this study. Because the precise number of spectral classes in the data set was not yet known (Cihlar, 2000), hyper clustering, which employs a significantly greater number of clusters than the intended classes, was chosen (Bauer et al., 1994). From the Google Earth observation and other land use maps of the study location, these clusters were assigned the labels of built-up areas, crop lands, forest lands, other woody regions, barren lands, and water bodies. Classes of the same type of land use that were spectrally similar were combined. The complete set of the spectral class signature was utilized as training data for supervised classification in the second stage (Kuemmerle et al., 2016).

For each class, we then chose at least 50 training examples. These spectral characteristics were only deemed acceptable where there was little overlap in the land use (Gao and Liu, 2010). The maximum likelihood classifier (MLC) technique was then used for supervised classification. Thematic raster layers from the classification were made available for use in post-classification and change detection.

2.5. Data collection

2.5.1. Primary data Collection

A. 2013 and use land cover data of Nepal was downloaded from the ICIMOD data portal (https://rds.icimod.org/) and from this land use land cover of Triyuga Municipality was extracted by using the ArcGIS pro software.

B. The Natural Capital Project developed the InVEST 3.12.0 model carbon storage and sequestration model software natural capital project, which was used to calculate the carbon stock in the research area.

C. The Sentinel-2 data of year 2023 was downloaded from the website https://scihub.copernicus.eu/dhus/#/home.

D. Field Measurements

For the purpose of gathering primary data, we created a field performance and devised a sampling strategy utilizing Arc Map. The details and instruments used for this process can be found in the annex section. However, due to time constraints during our field visits, obtaining an adequate amount of data proved to be a challenging endeavor, yet it remained a vital component of our study. Consequently, we managed to collect both primary and secondary data during our fieldwork.

Table 3: Instrument used during filed work

S.N.	Instruments	Functions
1	DBH tape	For measuring the diameter of tree at Breast Height
2	Vertex	For measuring tree Height and horizontal distance
3	Soil Augur	For digging the pit to take soil sample
4	Garmin GPS and Android phone	For finding and recording the spatial point or GCP
6	Topo Map and Guide Map	For verifying and locating the features in field as well as in newly classified LULC map
7	Measuring Tape	For measuring horizontal distance and delineating boundary
8	ZIP lock Bags	For Collecting Soil samples
9	Stationaries	For Keeping records in the fields

2.5.2. Secondary Data Collection

Government statistics: Government organizations frequently gather and publish data on a range of subjects, including population demographics, economic indicators, forest statistics, carbon sequestration, and more. Examples include census information, forest types, land use patterns, and deforestation rates, among others. The primary government organizations whose reports were used to assess this research include DFO Udayapur, Gaighat, the Ministry of Forest and Environment, the REDD Implementation Center, the Ministry of Land Management, etc.

Research articles: Secondary data can be found in academic journals, conference proceedings, and research reports, among other places. These papers are available to researchers for the purpose of obtaining information, conclusions, and insights from earlier investigations undertaken by other experts in the subject.

Other organizations' surveys and studies: Numerous public and private organizations conduct surveys and studies on various facets of land use planning and forest statistics. Some organizations, like ICI MOD, have contributed more to my study than others.

Online databases and repositories: downloaded satellite images from Copernicus using an online database, and collected important information about geography, demography, and climatology using the Triyuga Municipality village profile.

2.6. Data analysis

2.6.1. Sampling strategy and sample plot determination

The sample plot was chosen depending on the research objectives. The sample plot's location was established using Stratified Random sampling methods in areas that were covered in forestlands. For the purpose of validating the local land use cover, the chosen sampling plots had interviews by at least 15 key informant interviewees. The KII included ward chairpersons, district forest officers, division forest officers, CF chairpersons, and municipal officers.

Sampling plot determination was done by using the equation 1

Equation 1: No of sample plot

$$n = \frac{\mathbf{a}\ (\text{Area to be surveyed})}{500} \qquad \text{............................... (DoF 2014)}$$

Where,

n = number of sample plots to be surveyed

a = Area to be surveyed

500m2 is the area of the sample plot

Sampling intensity will be calculated by using the equation 2

Equation 2: Sampling Intensity

$$SI = \frac{a}{A} \times 100\% \quad \text{.............................. (DoF 2014)}$$

Where,

S.I = Sampling Intensity

a = Area to be surveyed

A = Total area of the study site

The study area was divided in to 3*3 km grid in ArcMap 10.8 and the grids were selected such that the selected grid represents the overall vegetation of the study area. For this study 0.1%, SI was used and the total number of sample plots to be surveyed was 70 plots, which was generated by stratified random sampling along with purposive sampling with the use of ArcMap

The sample plot was chosen depending on the research objectives. The sample plot's location was established using Stratified Random sampling methods in areas that were covered in forestlands. For the purpose of validating the local land use cover, the chosen sampling plots had interviews by at least 15 key informant interviewees. The KII included ward chairpersons, district forest officers, division forest officers, CF chairpersons, and municipal officers.

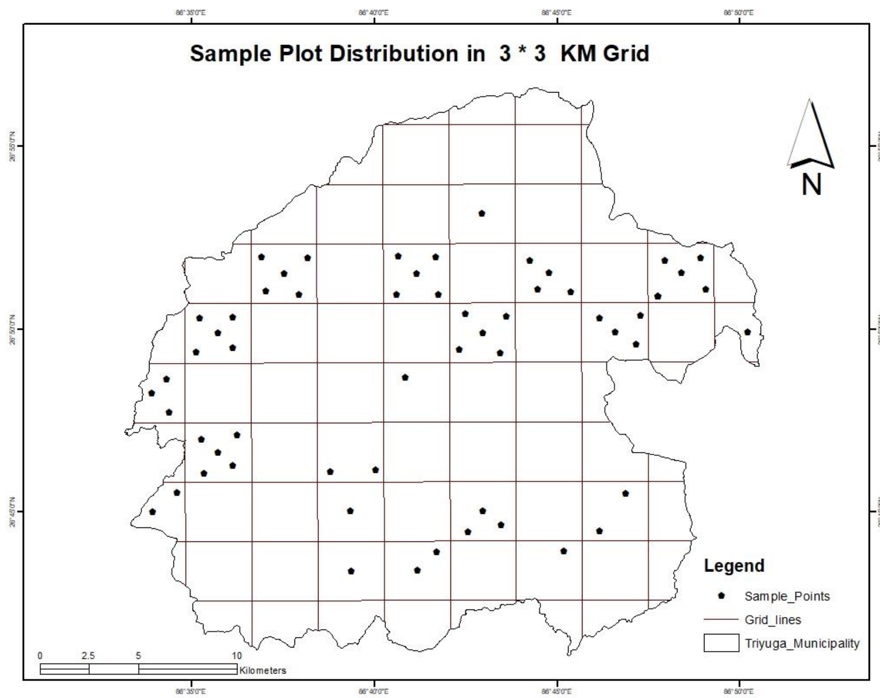

Figure 2: showing sample plot distribution

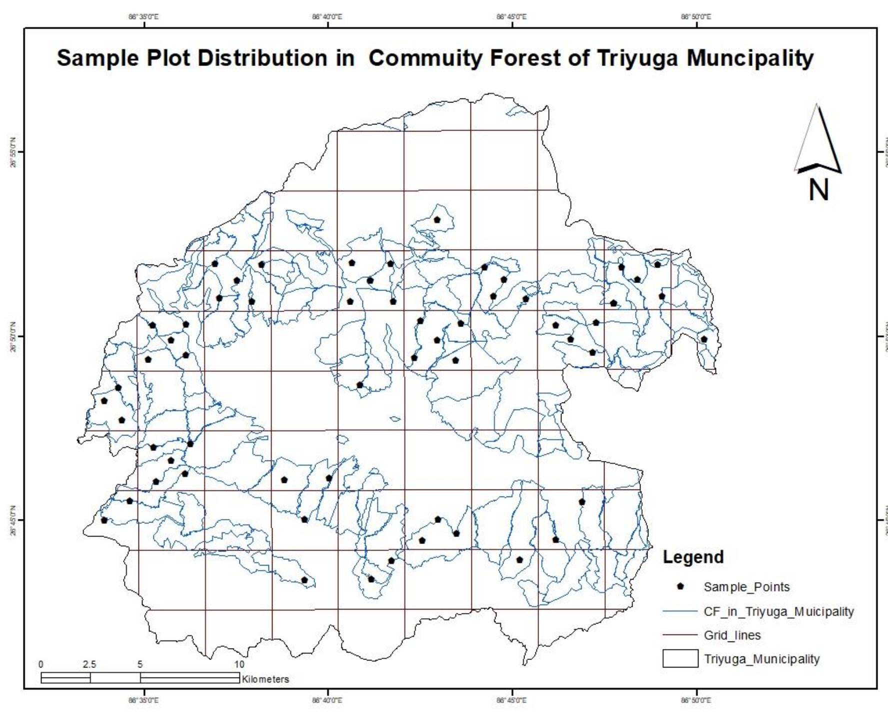

Figure 3: showing sample plot distribution within CF boundary

2.6.2. Sample Plot Design

Both circular and rectangular plots can be used for measuring forest carbon. Circular samples are still suggested for the study because they are reasonably simple to set up. The radius of each plot is determined by the forest's density, with a radius of 12.2 m for moderately dense vegetation, as was previously discussed. Several sub-plots are created within each plot, as shown in figure 5, for various purposes. For example, inside the 12.62 m radius plot, a sub-plot with a 5.64 m radius is created for saplings, one with a 1 m radius is created for counting regeneration, and one with a 0.56 m radius is created for sampling leaf litter, herbs, grass, and soil.

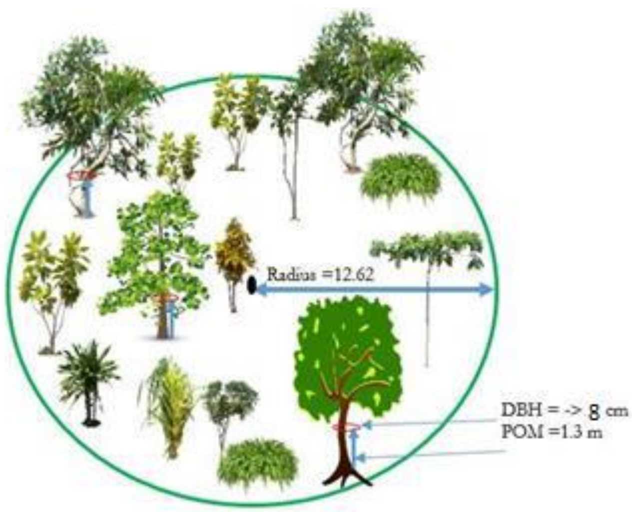

Figure 4: showing the sampling plot design for carbon measurement for 500m2 plot

(source: Sumareke, 2016)

2.7. Above Ground Biomass estimation using allometric equation

The volume equations developed by Sharma and Pukkala (1990) and the biomass models prescribed by the MoFSC (1988) were used to estimate the volume and biomass of standing trees. The air-dried biomass values obtained using these equations were then converted into oven-dried biomass values using a conversion factor of 0.91 (Chaturvedi, 1982; Kharal and Fujiwara, 2012) and a carbon-ratio factor of 0.47 (IPCC, 2006).

Equation 3: Allometric Equation

$\ln(v) = a + b \ln(d) + c \ln(h)$

Where,

ln = Natural logarithm to the base 2.71828.

V = Volume (dm3) = exp [a + b × ln(DBH) + c × ln(h)]

d = DBH in cm

h = Total tree height of tree in m

a, b and c are coefficients depending on species Values were divided by 1000 to convert them into cubic meters. The regression parameters of Equation 1 are presented in Annex 2

Tree stem biomass estimation: Tree-stem biomass was calculated using Equation 2 and species-specific wood-density values (Annex 1).

Equation 4: Stem Biomass

Stem biomass = Volume × Density

Where,

Volume = Stem volume in cubic meters

Density = Air-dried wood density

2.8. Invest Model for Carbon Calculation

Using a condensed version of the carbon cycle, the inVEST carbon module was utilized to calculate each cell's amount of static carbon storage and dynamic sequestration (Adelisardou et al., 2022; Tallis et al., 2008). The four carbon pools that are examined in this module are soil organic carbon, belowground carbon density, aboveground carbon density, and dead organic matter. Equation (5) was used to calculate the carbon storage $C_{m,i,j}$ in a specific grid cell (i, j) with land use type "m" (Adelisardou et al., 2022);

Equation 5: InVest carbon calculation

Cm,i,j = A * (Cam,i,j + Cbm,i,j + Csm,i,j + Cdm,i,j)

Where A is the actual area of each grid cell (ha) and Cam,i,j, Cbm,i,j, Csm,i,j, and Cdm,i,j are the above-ground carbon density (t per ha), below ground carbon density (t per ha), soil organic carbon density (t per ha), and dead organic matter carbon density for grid cell (i,j) with the land-use type m. Thus, carbon storage "C" across the whole region can be calculated as (Adelisardou et al., 2022).

Equation 6: Carbon Storage

$$C = \sum_{m=1}^{n} C_{m,i,j}$$

For preparing carbon sequestration map via InVEST model, the input data were as follows:

- Current land use/land cover (LULC) map – tiff format
- Carbon pools - CSV format
- Current land use/land cover – for expected sequestration rates

The values of four carbon pools for each classes was used the values from IPCC guidelines (IPCC, 2006) and previously published research articles of department of forest. The values was shown in table 4, source and citation can be see in annex 6.

Table 4: Showing carbon value per pixel for 6 land cover classes

LULC Name	C_above	C_below	C_soil	C_dead	C_total
Waterbody	0.1	-	-	-	0.1
Forest	97.69		31.44	0.32	129.45
Riverbed	3.6	4	-	-	7.6
Built-up Areas	5	-	-	-	5
Croplands	3.95	-	6.6	-	10.55
Grass lands	-	-	84.9	-	84.9
Other wooded lands	5.81	-	98.98	0.45	105.24

(Source: Rimal et al., 2019)

2.9. Accuracy Assessment for LC Map

Accuracy of change detection depends on many factors, including precise geometric registration and calibration or normalization, availability and quality of ground reference data, the complexity of landscape and environment, methods and algorithms used, the analyst's skills and experience, and time and cost restrictions (Lu et al., 2004). The classification error matrix, often known as a confusion table, is the most effective and popular assessment technique. The error matrix for the accuracy assessment of change detection was proposed based on this matrix by (Biging et al., 1999; Gong, 1993).Confusion matrix was utilized to measure the accuracy of each classified image. The confusion matrix is used for the following accuracy.

Equation 7: Overall Accuracy

$$\text{Overall Accuracy} = \frac{\text{Total number of classified pixels in the category (diagonal)}}{\text{Total number of reference pixels}} \times 100$$

Equation 8: User's Accuracy

$$\text{Users Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in the category (row total)}} \times 100$$

Equation 9: Producer's Accuracy

$$\text{Producer Accuracy} = \text{Accuracy}\ \frac{\text{Number of correctly classified pixels in each category}}{\text{Total Equation Number of classified pixels in the category}} \times 100$$

For accuracy comparison, the simulated and original land use were compared using the kappa coefficient (T). According to Lillesand et al. (2015), KAPPA Statistic may assess classification accuracy using absolute Classification 0 to 1 and random classification. The correctness of the supplied formula was used to generate the Kappa Coeffiicient(T) Statistic..

Equation 10: Kappa Coefficient

$$\text{KappaCoefficient (T)} = \frac{\text{Totals ample} \times \text{Total corrected sample)} - \Sigma(\text{columntotal} \times \text{Rowtotal})}{\text{Total sample2} - \Sigma(\text{columntotal} \times \text{Rowtotal})}$$

2.10. Methodological Framework

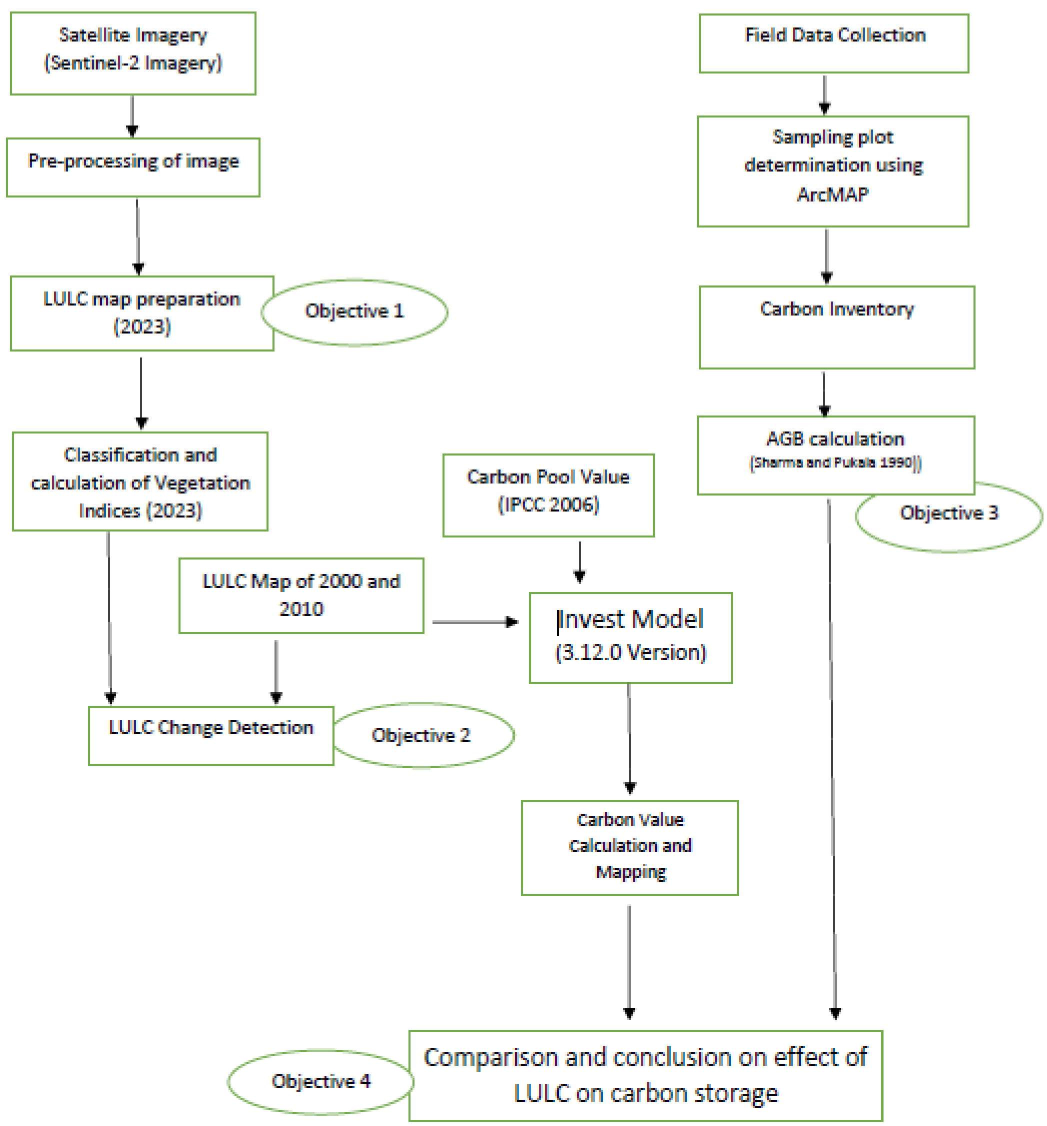

Figure 5: Showing methodological framework for thesis work

3. Chapter Results and Discussion

3.1. Preparation of Land cover map of 2023

Sentinel imageries from platform 2A was used to prepare LC map of Triyuga Municipality. ArcMap 10.8 was used to LC map preparation and analysis.

3.1.1. Visual interpretation

To correctly categorize LULCs, it is important to carefully consider factors including the spectrum properties of multiple LULC classes, the potential for spectral misunderstanding between related classes, and more. Sentiniel-2 uses a modified band configuration to make the feature in the image easier to understand.

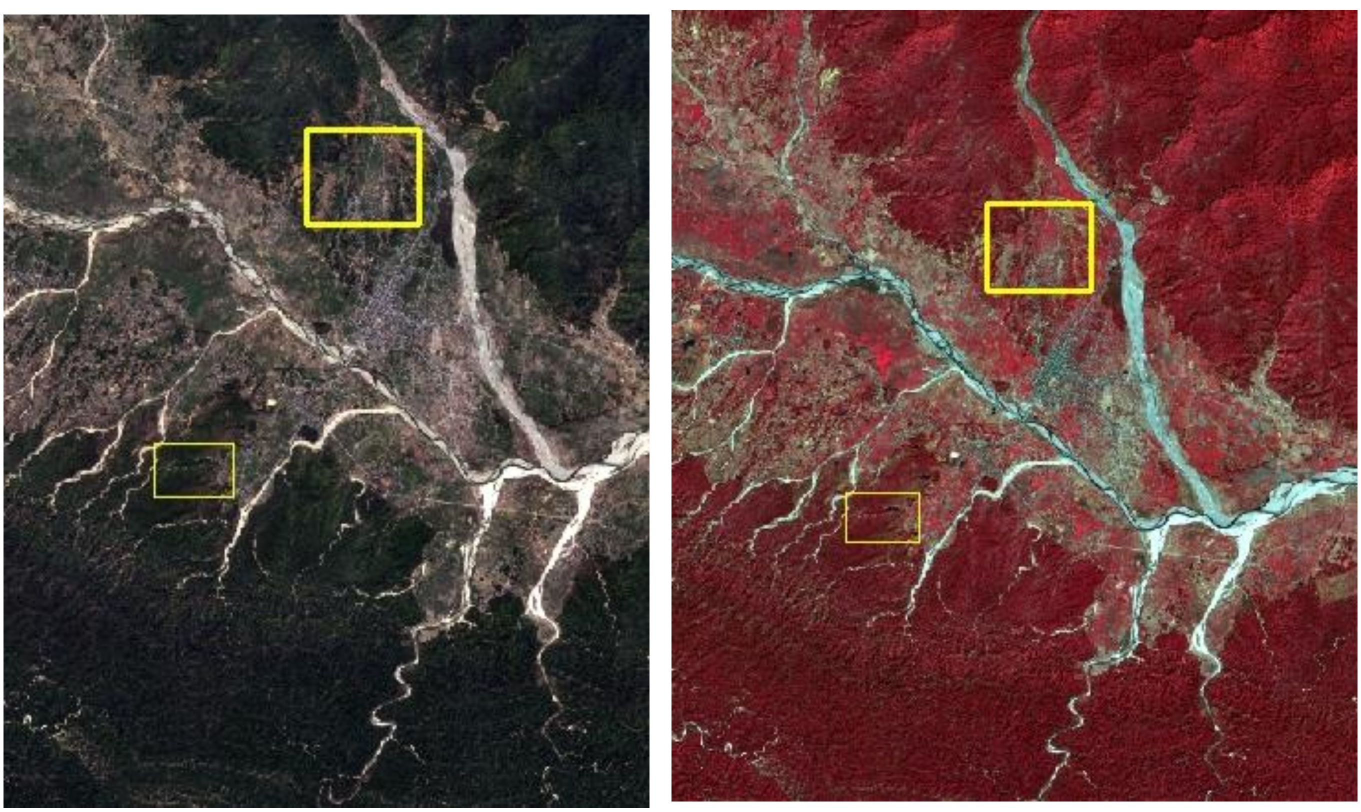

Figure 6: Showing Natural color Composite (left) and False color Composite (right) Sentinel-2 image of Triyuga Municipality

The color infrared band combination, sometimes known as a false color combination, is used to highlight vegetation such as forests, farmland, and other vegetative land cover. It excels at reflecting chlorophyll by utilizing the near-infrared (B8) band. Because of this, redder vegetation is seen in infrared images of color. Urban centers, however, are white.

Because to the low backscattering values of water, urban areas, and bare terrain, Sentinel - 2's portrayal in a false color (FC) composite makes it challenging to visually comprehend. Therefore, a natural or true color composite image was employed to examine Water, Built-Up Areas, and Bare Areas (left image). The red (B4), green (B3), and blue (B2) channels are used in the natural color band combination, often known as the true color combination. Its goal is to portray imagery in a manner similar to how our eyes perceive the environment. Healthy vegetation is green, much like what we see. Next, metropolitan characteristics frequently have a white and gray appearance. Lastly, the degree of cleanliness determines what colour of dark blue the water is.

3.1.2. Collecting samples for Pixel Based Classification

Land Cover classification totally based on the training sample: representative pixels or areas that you use to teach the classification algorithm about the spectral characteristics of different classes. Training samples were taken from the composite band image of Band 2, Band 3,Band 4 and band 8 having 10 * 10m resolution image. The maximm training samples were taken from the built-up lands as the built-up areas is very much sensative to take training sample because of its spectral properties as hoses have different shaded roofs like blue,red, zinc,etcs as well as have small coverage ascompared toother land cove types. Similaryly, in Triyuga municipality at the date of image, varities of agricultural lands were nooted: heavy croplands, bare croplands, recently crop planted lands,etcs. To meet all the spectral reflactance accoding to crop lands maximum training samples were taken. Forest lands, bare lands and water bodies do not have varities of reflactance as compared to built-up lands and Croplands therefore they bear similar pixel values as compared to built-up and crop lands.

Figure 7: Showing the training samples in composite band image of Triyuga Municipality

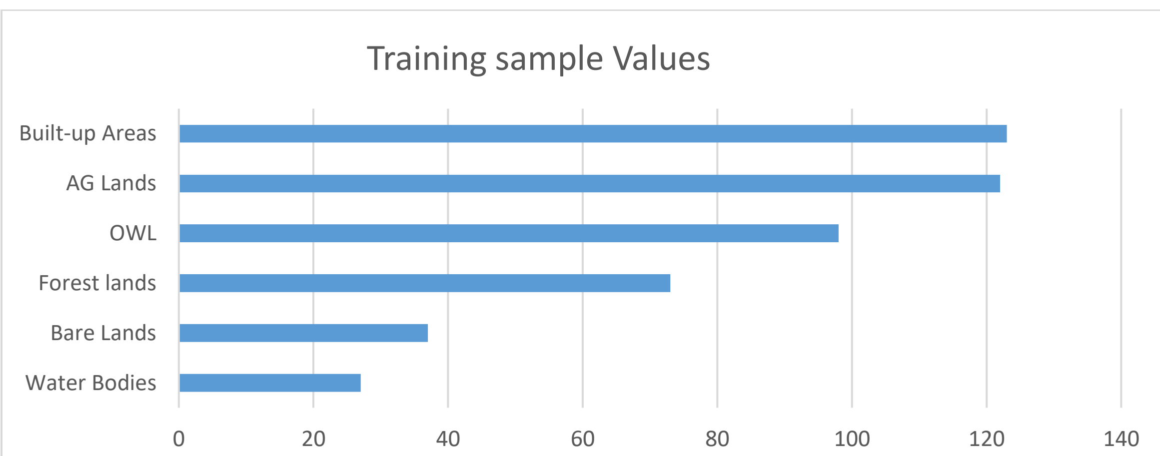

Figure 8: Showing training sample statistics according to land cover types

3.1.3. Classification of land cover classes

Maximum likelihood classification (MLC) was applied to classify the landcovers into six land cover types: water bodies, bare lands, forest lands, other woodedlands, croplands and built-up areas. MLC defines the algorithm from training sample spectral signature values for each pixel and assign the calss with maximum likelihood pixel values.

In Triyuga municipality, maximum area was covered by forest areas with 62.53%, followed by Crop lands 30.02%. As compared to forest and croplands, Water bodies and bare lands were insignificant with around 0.19% and 1.22%, respectively. Built-up areas also rakns with low volumw of 2.16% as whown in table below.

Table 5: Showing the resulted value of LC classes for 2023

Land Cover	COUNT	Area (ha)	Area %
Water Bodies	10369.00	103.69	0.19
Bare lands	66638.00	666.38	1.22
Forest lands	3415748.00	34157.48	62.53
Other Wooded lands	212158.00	2121.58	3.88
Crop Lands	1639966.00	16399.66	30.02
Built-up Areas	117975.00	1179.75	2.16

3.1.4. Post Classification

Post classification was done to obtain the smooth land cover map of Triyuga municipality. The Boundary clean tool in Arc Map 10.8 was used which ragged edges of class boundaries and clump the classes. Spetial coherency of ML classified map was increased. Regions that are adjacent and belong to the same class was connected and more precise map was created as shown in figure.

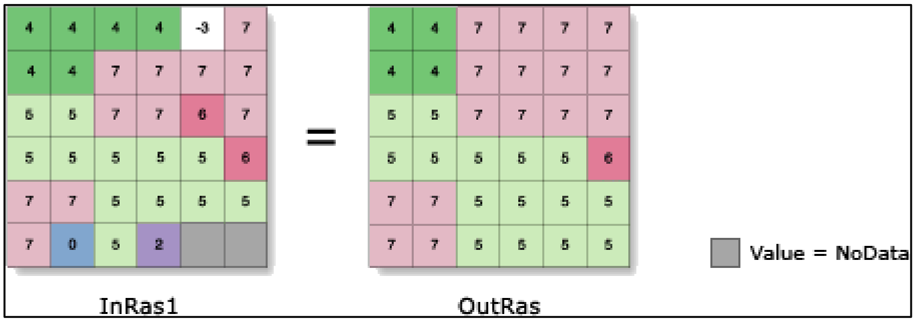

Figure 9: Showing the boundary tool working mechanism

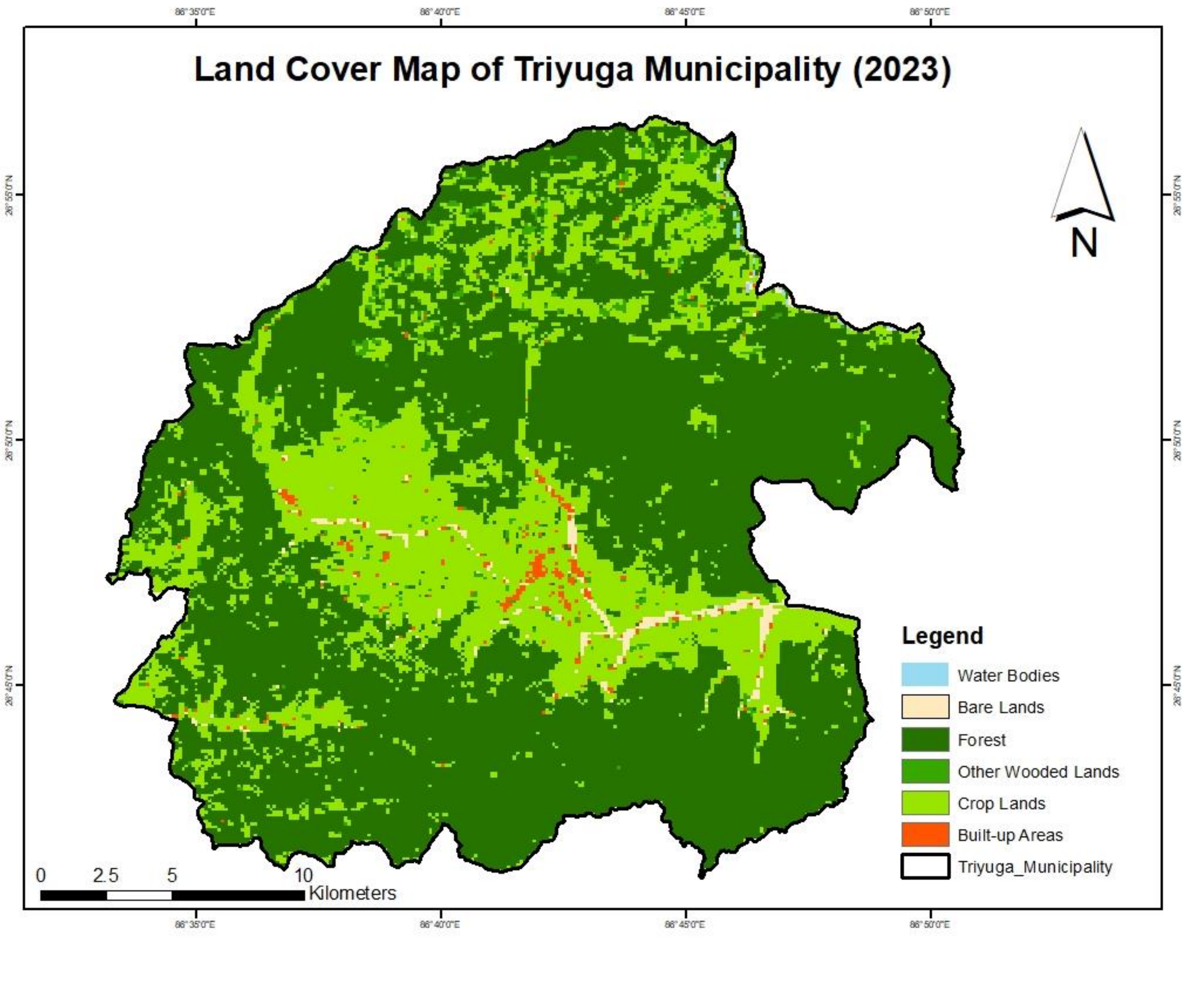

Figure 10: Showing the land Cover Map of Triyuga Municipality (2023)

3.1.5. Land Cover classification accuracy assessment

Aside from other variables, topography and atmospheric disturbances may also have an impact on how accurately LULC change detection works in mountainous areas. Accuracy evaluation can be used to gauge the classification's validity (Congalton and Green, 1993). In this investigation, a collection of 103 points chosen using stratified random sampling was used to evaluate the accuracy of each identified image. For each category in the study area, we collected at least 15 accuracy assessment points, as shown in figure 11. As illustrated in figure 12, the accuracy evaluation plot was further superimposed in Google Earth and confirmed. During a field visit, several of the Points were also validated.

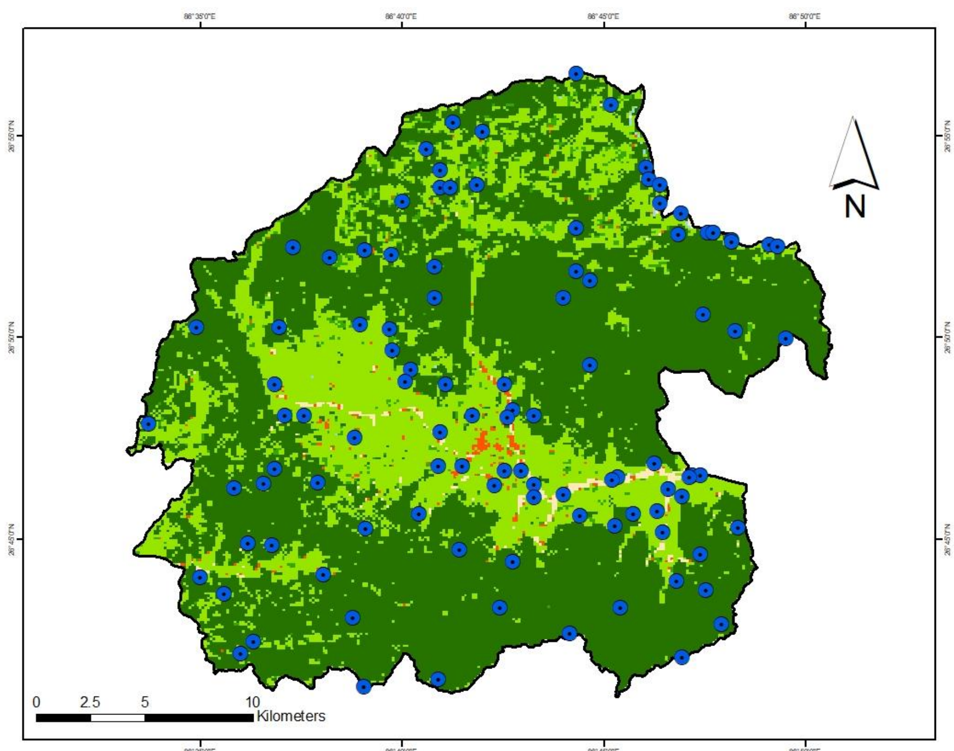

Figure 11: Showing accuracy points in arc map overlaid in LC map 2023

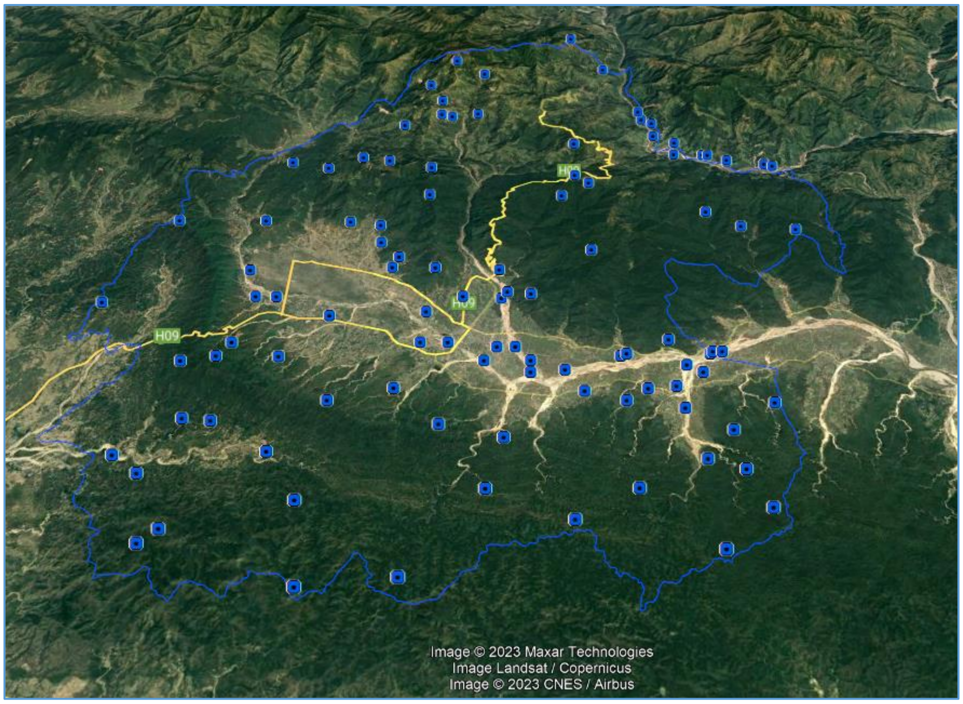

Figure 12:Showing accuracy points overlaid in google earth pro for verification

To evaluate classification accuracy, a cross-tabulation of the mapped class vs. reference class error matrix was used. The error matrix was used to derive the Kappa Coefficient, producers' accuracy, and users' accuracy. Table 6 contains an overview of accuracy evaluation results.

Table 6: Showing the LC accuracy assessment calculations

Classified Class	Water Bodies	Bare Lands	Forest	OWL	Crop Lands	Built-up Areas	Total	User Accuracy	Kappa
Water Bodies	10	0	0	0	0	0	10	1	0
Bare Lands	0	9	1	0	0	0	10	0.9	0
Forest	0	0	44	0	0	0	44	1	0
OWL	0	0	0	7	3	0	10	0.7	0
Crop Lands	1	0	1	3	14	0	19	0.73	0
Built-up Areas	0	4	0	0	2	4	10	0.4	0
Total	11	13	46	10	19	4	103	0	0
P_Accuracy	0.90	0.69	0.95	0.7	0.73	1	0	0.85	0
Kappa	0	0	0	0	0	0	0	0	0.80

3.2. Field Data Results

3.2.1. Descriptive statistics of field data

Forest parameters i.e. DBH, and height of the tree required for modeling were collected in the field. Individual tree data were fitted in the allometric equation and summed to plot level for obtaining plot-level data. A total of 830 different trees were collected from 70 sample plots, which shows that the mean height, DBH, AGB, and carbon stock were 14.7 m, 36.2176 cm, 198.834 per ha, and 93.4519tper ha respectively. More summary statistics were also assessed and shown in Table 6. All the plot wise data is presented in Annex 3

Table 7: Showing statistics of field data

	Mean	Std. Deviation	Std. Error
Height (m)	14.70	8.17	0.28
DBH (cm)	36.21	18.09	0.62
AGB (t/h)	198.83	555.91	19.29
C-stock (t/h)	93.45	19.29	9.06

3.2.2. Common species found in study area

With the aid of local experts, rangers, and forest officers, we were able to identify the species in the field. After the fieldwork, a scientific name was looked up. The data from 70 sample plots included 830 trees in total. There were a total of 17 distinct species identified, with Annex 5 providing descriptions of the most prevalent ones. Shorea robusta has the highest overall species occurrence rate (50.24%), followed by Lagerstroemia parviflora (10.48%), Terminalia tometosa (13.73%), 5.66%, Adina cordifolia (2.29%), Terminalia chebula (1.45%), Terminalia bellirica (3.86%), Syzygium cumini (5.66%), and other tree species (6.63%). Tatari, Kumvi, Piyari, Ashare, Tejpatta are among other tree species.

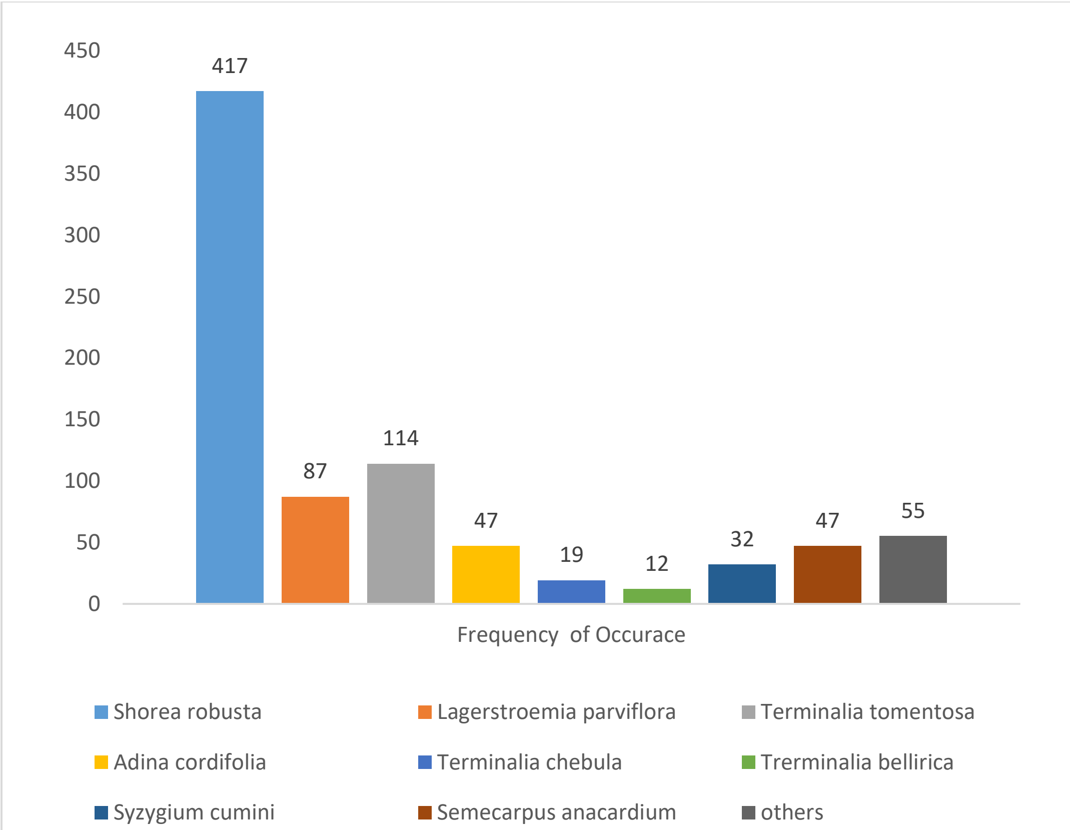

Figure 13: Showing species occurrence in 70 sample plots

3.2.3. Calculation of Vegetation Indices (NDVI)

NDVI values are interpreted to assess the health and density of vegetation. Healthy vegetation will have higher NDVI values, while stressed or sparse vegetation will have lower values. NDVI values ranges from -1 to 1 where Values near -1: represent non-vegetated surfaces like water bodies or barren land, values around 0: suggest bare soil or urban areas, values between 0 and 1: indicate varying levels of healthy vegetation, with higher values representing denser and healthier vegetation.

Calculation of NDVI was done using ArcMAP 10.8 tool raster calculator. In Triyuga Municipality NDVI value ranges from -0.185021 to 0.664313.

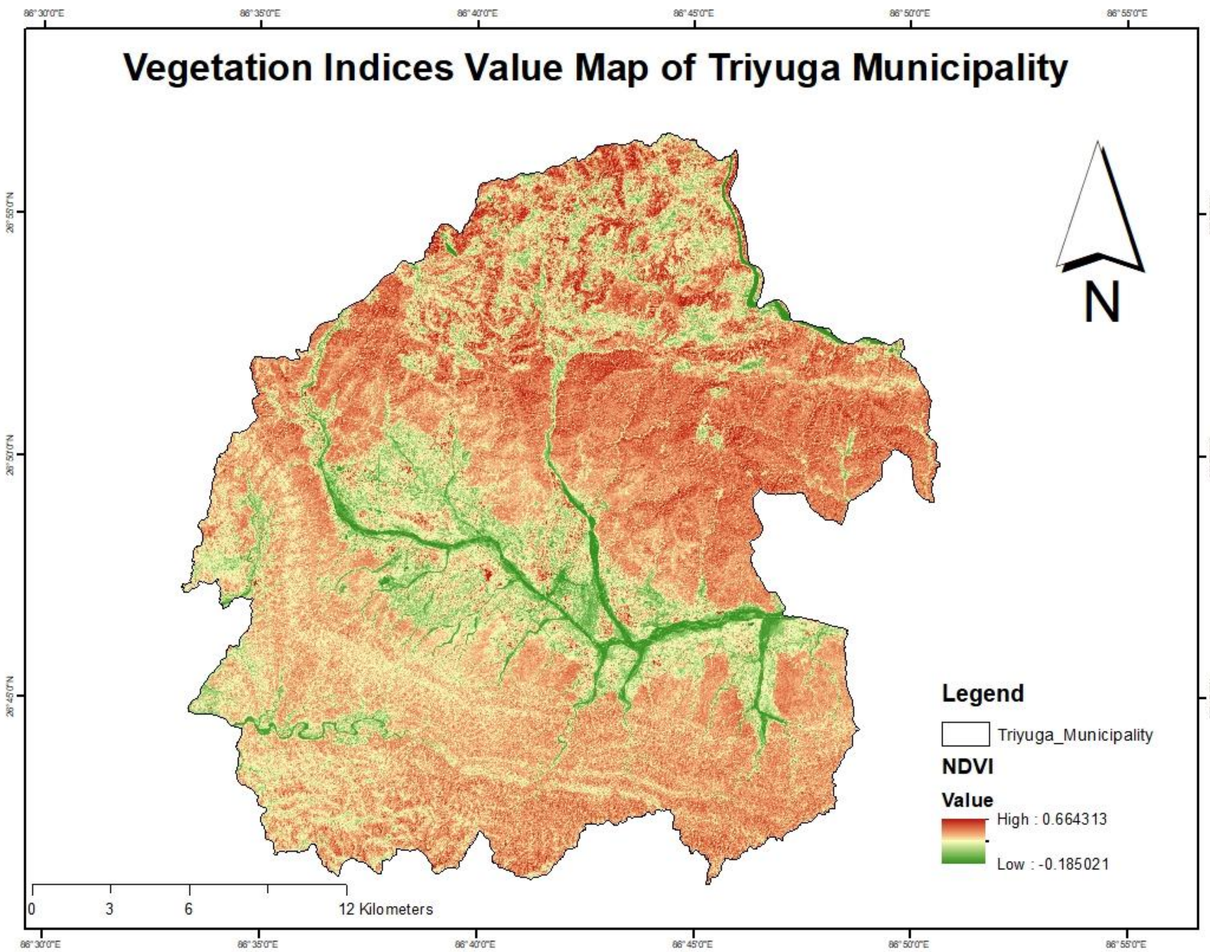

Figure 14: Showing 2023 NDVI map of Triyuga Municipality

3.2.4. Mapping AGB and carbon stock of study area

Estimation of AGB and carbon stock for the whole study was done using equation 4 in ArcGIS using the raster calculator tool. A carbon stock map was produced based on the conversion factor of 0.47 as 47% of forest biomass is stored as carbon. As per the result of the AGB map, a map with a white area represent 0 AGB as it represents the water bodies, bare lands, agricultural lands as well as built-up areas. It can be seen that the amount of AGB ranges from 4.14 to 286.76 t h- in table in Annex…. The lower biomass is highly present near river areas, agricultural lands, and built-up areas. The areas with undulating topography and the forest areas within the community forest had higher AGB as undulating areas are not easily accessible. Subsequently, the carbon

Given that the total amount of forest AGB was increased by 0.47 (47% of the AGB), the stock map exhibits a similar pattern to the AGB map. As a result, the carbon content is higher in those places where the AGB is higher. The research regions have carbon contents that range from 10.21 to 856.74 tons per hectare. In Triyuga Municipality, the total AGB and carbon quantity is 5233311.076 tons and 11134704.42 respectively. Finally, the AGB and carbon per ha in the research region are 206.198 T and 96.91 T, respectively.

3.3. Invest Model Application for Carbon quantification

3.3.1. Carbon pool values

According to the InVEST model, carbon sequestration was estimated (Daily et al., 2009; Bagstad et al., 2013; Ruckelshaus et al., 2015). It is a comprehensive tool for calculating the value of ecosystem services and analyzing the trade-offs associated with them. The carbon cycle is explained by the model using five carbon pools: soil, dead organic matter, above- and below-ground biomass, and harvested wood products. Only the first four carbon pools—as opposed to harvested wood products—were examined in this study. The carbon stocks of each grid cell associated with various land use categories can be efficiently output by the model.

We assume that carbon density has been maintained constant over time and that LUCC is the only factor causing changes in carbon stocks because this model is unable to capture the process of carbon transformation from one pool to another. For the carbon pools for the years 2000 and 2010, all figures were taken from the secondary article based on data from the IPCCC and department of forests.

Figure 15: Showing the IPCC carbon stock value per pixel

LULC Name	C_above	C_below	C_soil	C_dead	C_total
Waterbody	0.1	-	-	-	0.1
Forest	97.69		31.44	0.32	129.45
Riverbed	3.6	4	-	-	7.6
Built-up Areas	5	-	-	-	5

Croplands	3.95	-	6.6	-	10.55
Grass lands	-	-	84.9	-	84.9
Other wooded lands	5.81	-	98.98	0.45	105.24

3.4. Estimation of carbon storage for 2010 using InVEST

The same process with LC 2000 data was repeated to get the following results. Calculation of carbon stock for the study areas was done using ICI mod 2010 land cover map having 30 * 30 m resolution. Boundary map of the Triyuga Municipality was overlaid and extracted by mask in Arc Map 10.8 to get LC map of the study area.

3.4.1. Spatial distribution of LULC (2010)

The study area consisted of mainly 7 LULC classes namely, water body, forest, built-up area, crop land, shrub land. The area of each LULC classes were calculated based on the count of the pixel of particular LULC in ArcGIS. Area of per pixel is 900 m^2. According to the calculations, out of 7 LULC classes forest covered maximum area of 42028.74 ha (71.16 %) and crop land 9533.79 ha (16.14%). Similarly, grassland areas 4397.04 ha (7.44%), bare areas 1958.13 ha (3.32 %), built-up and waterbody covers 0.37% land area.

Table 8: Area covered by 6 land cover classes

	COUNT	**Area(ha)**	**Area %**
Water body	1823.00	164.07	0.28
Forest Area	418130.00	42028.74	71.16
Bare land	21757.00	1958.13	3.32
Built-up Area	564.00	50.76	0.09
Crop land	105931.00	9533.79	16.14
Grass land	48856.00	4397.04	7.44
Other wooded Land	10313.00	928.17	1.57

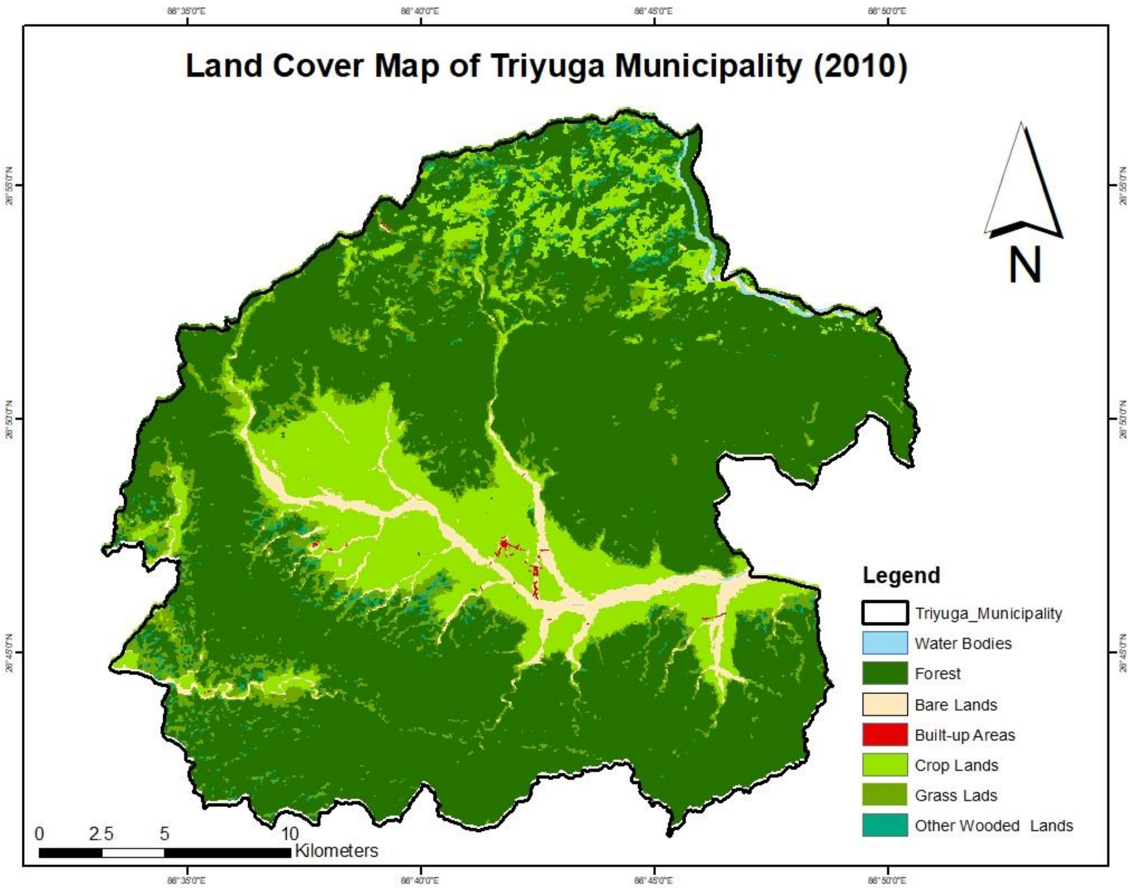

Figure 17: Land cover map of Triyuga Municipality of 2010

3.4.2. Carbon storage in different LULC classes (2010)

A raster output representing the spatial distribution of carbon storage in the research region was created using the results of the InVEST carbon storage model. Additionally, the findings showed that the Triyuga Municipality, with a geographical area 56000 per has, stored 7795346.07 T of carbon, although carbon storage differs within various LULC classes. Out of 7 LULC classes forest stores maximum amount of carbon i.e. (7129325.565 T) (91.45%). Rest of other class stored about 9 % of carbon like crop land stored 133473.06 T, grass land stored 434867.256 T, other wooded land stored 97680.61 T of carbon as shown in table no 8. The amount of carbon storage on overall study area ranged from 0 to 17.0505 ton per pixel represented in the figure 17.

Table 9: Carbon value of 6 land cover classes

LULC	**Total Pixel count for c (T)**	**carbon in each LULC area class % (T)**
Water bodies	0.00	0
Forest	189.45	7129325.56
Bare soil	0.00	0
Built-up area	0.00	0
Cropland	14.00	133473.06
Grassland	98.90	434867.25
Other wooded land	105.24	97680.61

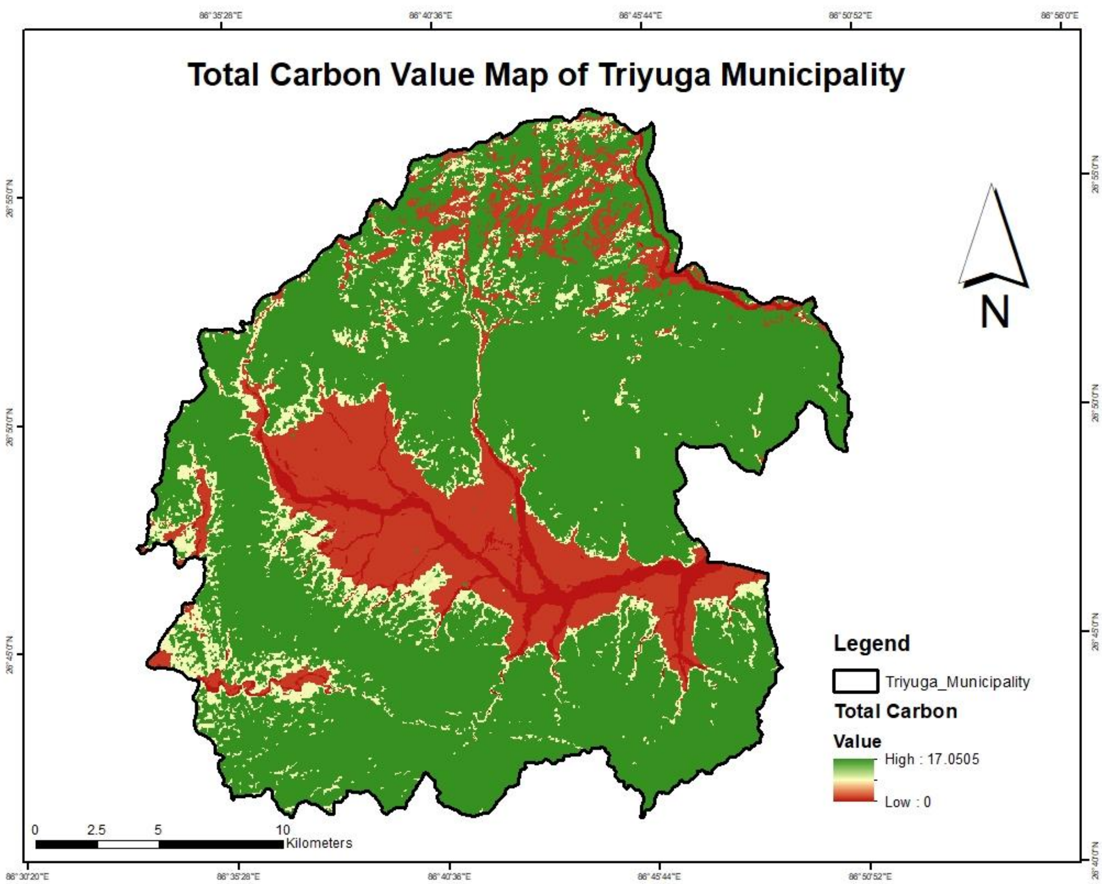

Figure 16: Showing total carbon map of Triyuga municipality for 2010

3.4.3. Carbon storages in different carbon pools (2010)

The spatial distribution of carbon storage in various carbon pools in the research region was compiled by the InVEST carbon storage and sequestration model into a raster output. The amount of carbon stored as an intermediate output of the InVEST carbon storage model ranges from 0 to 8.7921 tons per pixel above ground, 0 to 5.4 tons per pixel below ground, 0 to 8.9082 tons per pixel in organic soil matters, and 0 to 0.18 tons per pixel in organic dead matters, according to Figure 18.

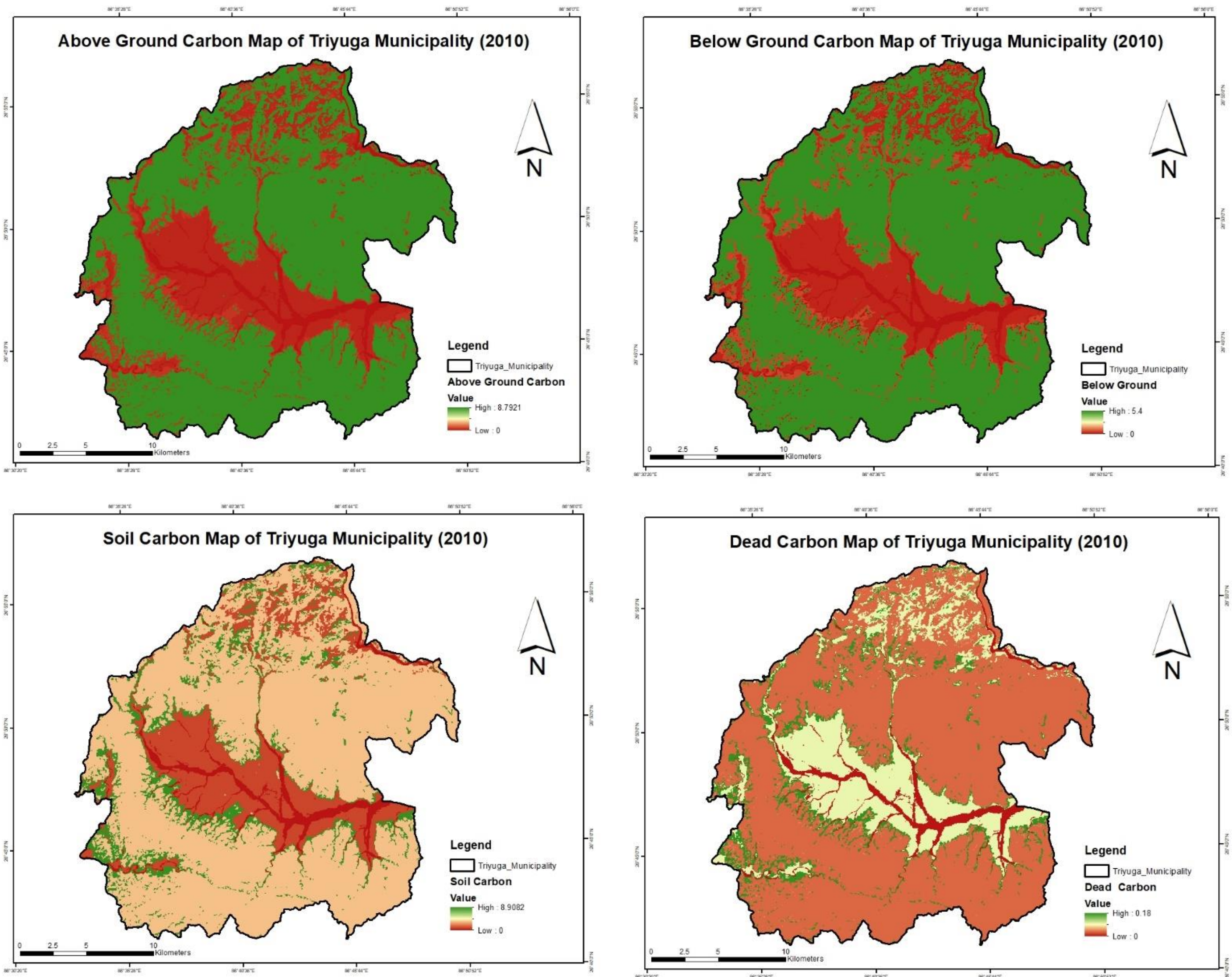

Figure 17: Showing four carbon pools of Triyuga Municipality (2010)

3.5. Estimation of carbon storage for 2000 using InVEST

The same process with LC 2000 data was repeated to get the following results. Process was done same as for 2010. Calculation of carbon stock for the study areas was done using ICI mod 2000 land cover map having 30 * 30 m resolution. Boundary map of the Triyuga Municipality was overlaid and extracted by mask in Arc Map 10.8 to get LC map of the study area.

3.5.1. Spatial distribution of LULC (2000)

LC map was extracted by using ICI mod 2000 land cover map. The study area consisted of mainly 7 LULC classes namely, water body, forest, bare land, built-up area, crop land, grass land and other wooded land. The area of each LULC classes were calculated based on the count of the pixel of particular LULC in ArcGIS. Area of per pixel is 900 m^2. According to the calculations, out of 7 LULC classes forest covered maximum area of 38592.54 ha (70.60 %) and crop land 9292.59 ha (17.00 %). Similarly, grassland areas 3628.17 ha (6.64%), bare areas 2105.19 ha (3.85 %), built-up and waterbody covered 0.4% land area.

Table 10: Area covered by 6 land cover classes

	COUNT	**Area (ha)**	**Area %**
Waterbody	2019.00	181.71	0.33
Forest	428806.00	38592.54	70.60
Bare land	23391.00	2105.19	3.85
Built-up Area	400.00	36.00	0.07
Cropland	103251.00	9292.59	17.00
Grass land	40313.00	3628.17	6.64
Other wooded land	9194.00	827.46	1.51

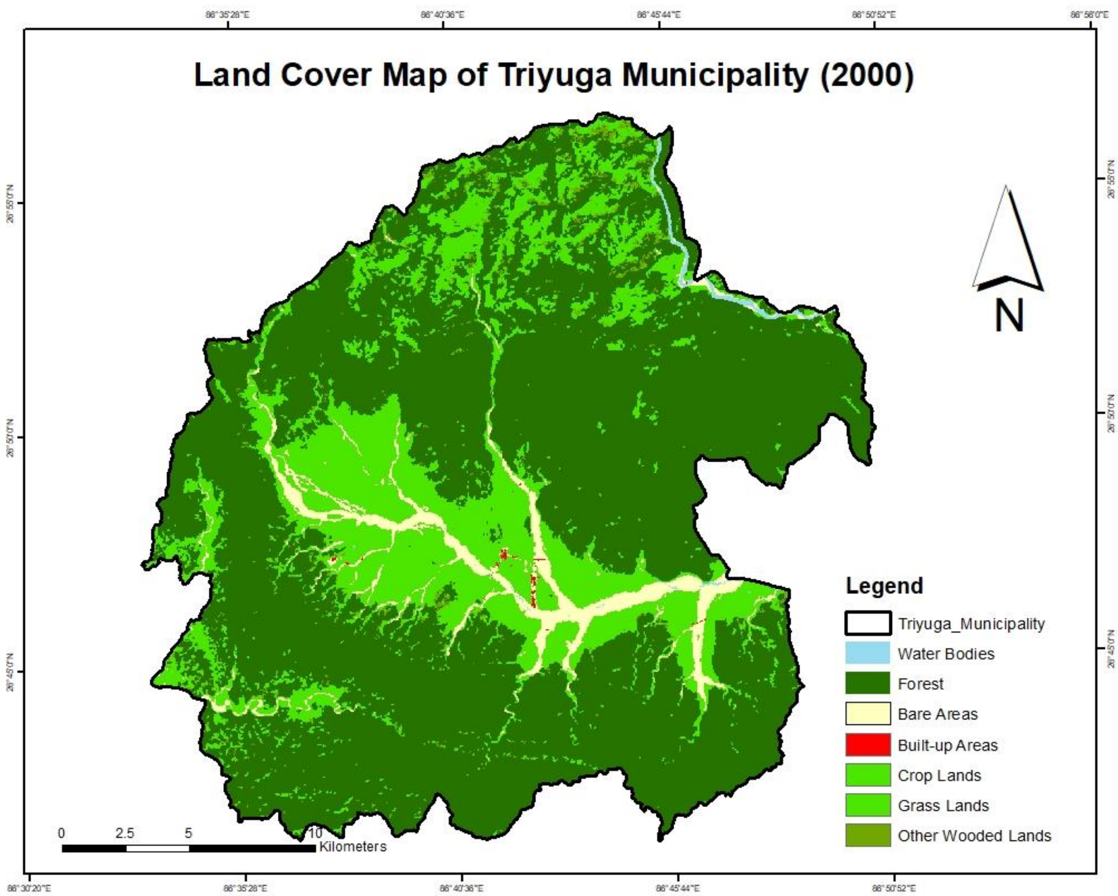

Figure 18: Land Cove Map of Triyuga Municipality (2000)

3.5.2. Carbon storage in different LULC classes (2000)

A raster output representing the spatial distribution of carbon storage in the research region was created using the results of the InVEST carbon storage model. Additionally, the findings showed that the Triyuga Municipality, with a geographical area 56000 per has, stored 7887360.43 T of carbon, although carbon storage differs within various LULC classes. Out of 7 LULC classes forest stored maximum amount of carbon i.e. (7311356.70 T) (92.07%). Rest of other class stored about 8 % of carbon like crop land stores 130096.26 T, grass land stored 358826.01 T, other wooded land stores 87081.89 T of carbon as shown in table no 10. The amount of carbon storage on overall study area ranged from 0 to 17.0505 ton per pixel represented in the figure 20.

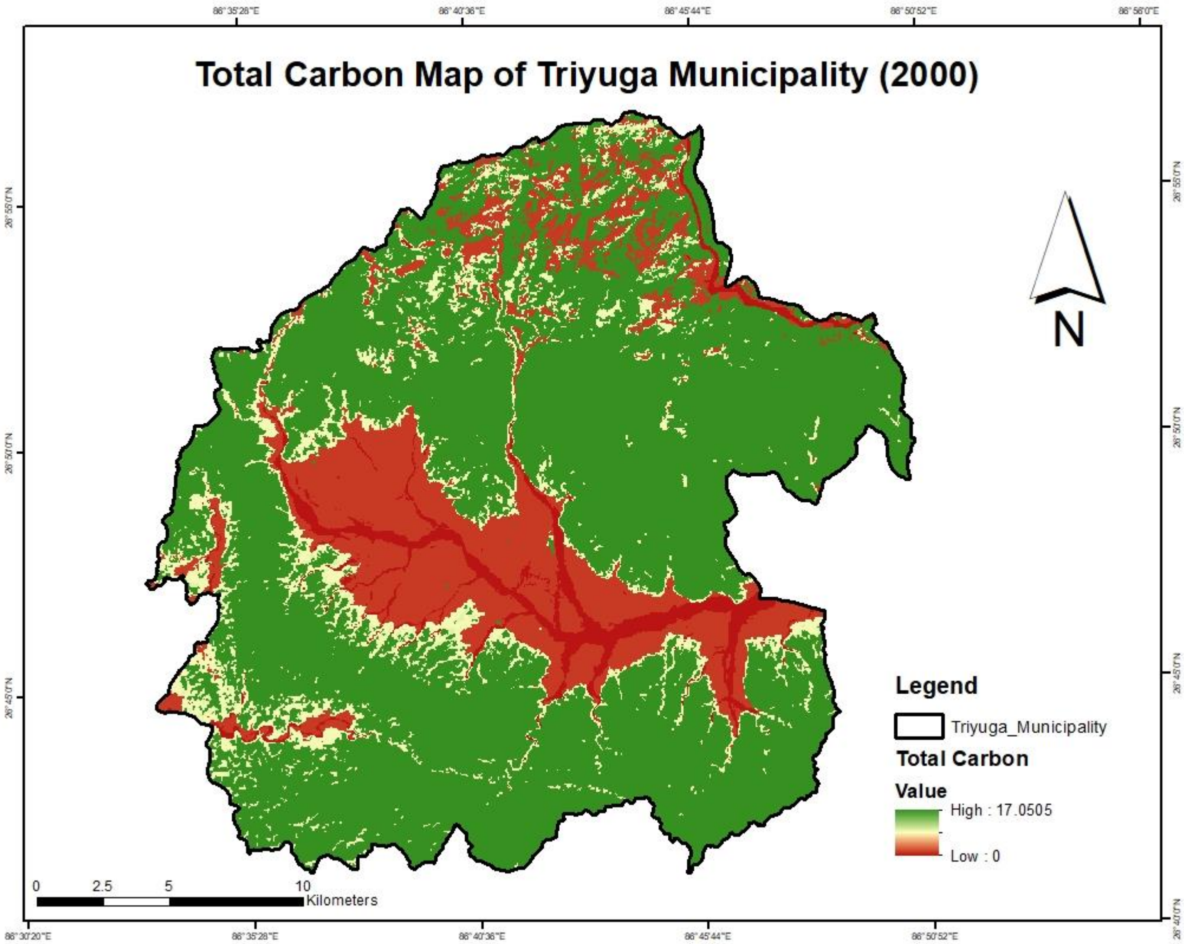

Figure 19: Total carbon value map of Triyuga Municipality

Table 11: Carbon stock value of 6 land cover class

LULC	Total Pixel count for c (T)	Carbon in each lulc area class % (T)
Water bodies	0.00	0.00
Forest	189.45	7311356.70
Bare soil	0.00	0.00
Built-up area	0.00	0.00
Cropland	14.00	130096.26
Grassland	98.90	358826.01
Other wooded land	105.24	87081.89

3.5.3. Carbon storages in different carbon pools (2000)

The spatial distribution of carbon storage in various carbon pools in the research region was compiled by the InVEST carbon storage and sequestration model into a raster output. As intermediate output of the InVEST carbon storage model, the amount of carbon storage in the above ground ranges from 0 to 8.7921ton per pixel, in below ground ranges from 0 to 5.4 ton pixel, in organic soil matters ranges from 0 to 8.9082 ton per pixel and in organic dead matters from 0 to 0.18 ton per pixel as shown in figure 21.

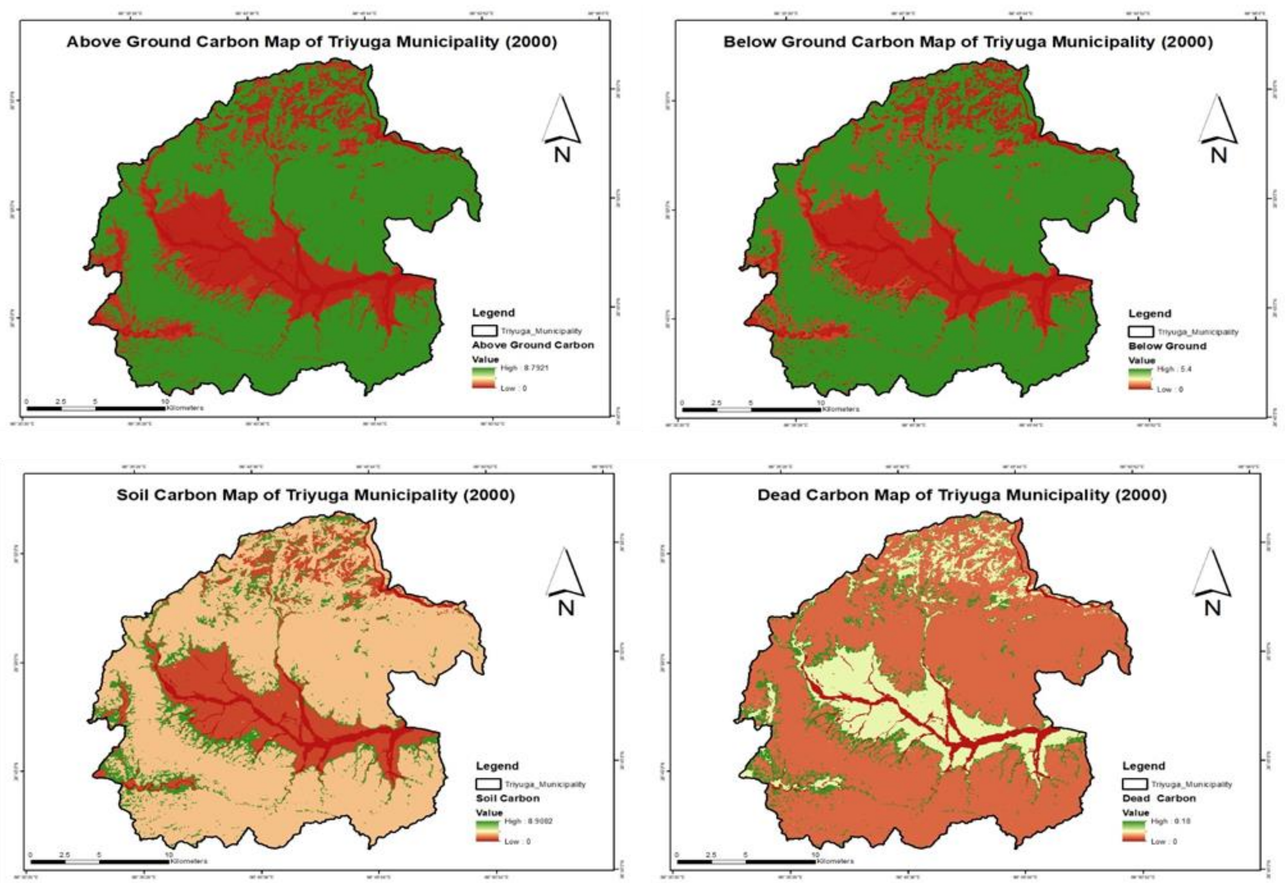

Figure 20: Four carbon pool value map of Triyuga Municipality (2000)

3.6. Effects of LUCC on carbon stocks in the period 2000–2023

This change in the land cover in Triyuga Municipality may have a significant impact on the study's overall goal of reducing carbon stocks by 2654049 Ton. From 2000 to 2010, carbon stocks fell by 9201.436 Ton each year. However, the carbon loss rate from 2010 to 2023 was 197079.615 tons per year, which is significantly greater than the rate from 2000 to 2010 and 2015. This is a result of the conversion of forested land into developed land, primarily agricultural land. Because it accounted for a very minor portion of the total area, the loss of grassland could be disregarded when considering carbon reserves. Rapid conversion of farmed land to built-up space is another cause of carbon loss.

3.7. Estimated biomass and soil carbon stocks in different land cover types

For the year 2000 and 2010 Landsat TM/ETM land cover type dataset with the spatial resolution of 30 m × 30 m and for the year 2023 Sentinel-2A image with 10 m × 10 m were used. Calculation of areas and area percent of the data was done according to the input data type. The data set covers the changes from year 2000 to 2023, about 23 years period within the 6 major land cover types: Water Bodies, Bare lands, Forest lands, Other Wooded lands, Crop Lands, Built-up Areas. From the year 2000 to 2023 built-up areas has increased from 0.07 % to 2.16 i.e. the percentage of land cover change is huge for this land cover. Similarly, Crop land also has increased from 17 % to 30.02 %, OWL from 1.51 % to 3.88 % which seems to have less change percentage than built-up and crop lands. Furthermore, Bare lands areas also seems in decreasing trends: from 3.85%, 3.58% to 1.22% in the year 2000, 2010 and 2023, respectively. Similarly, two land cover forest and water showed decreasing trend from 77.42 % to 62.53% and 0.33 % to 0.19% as shown in table 12 and figure 22.

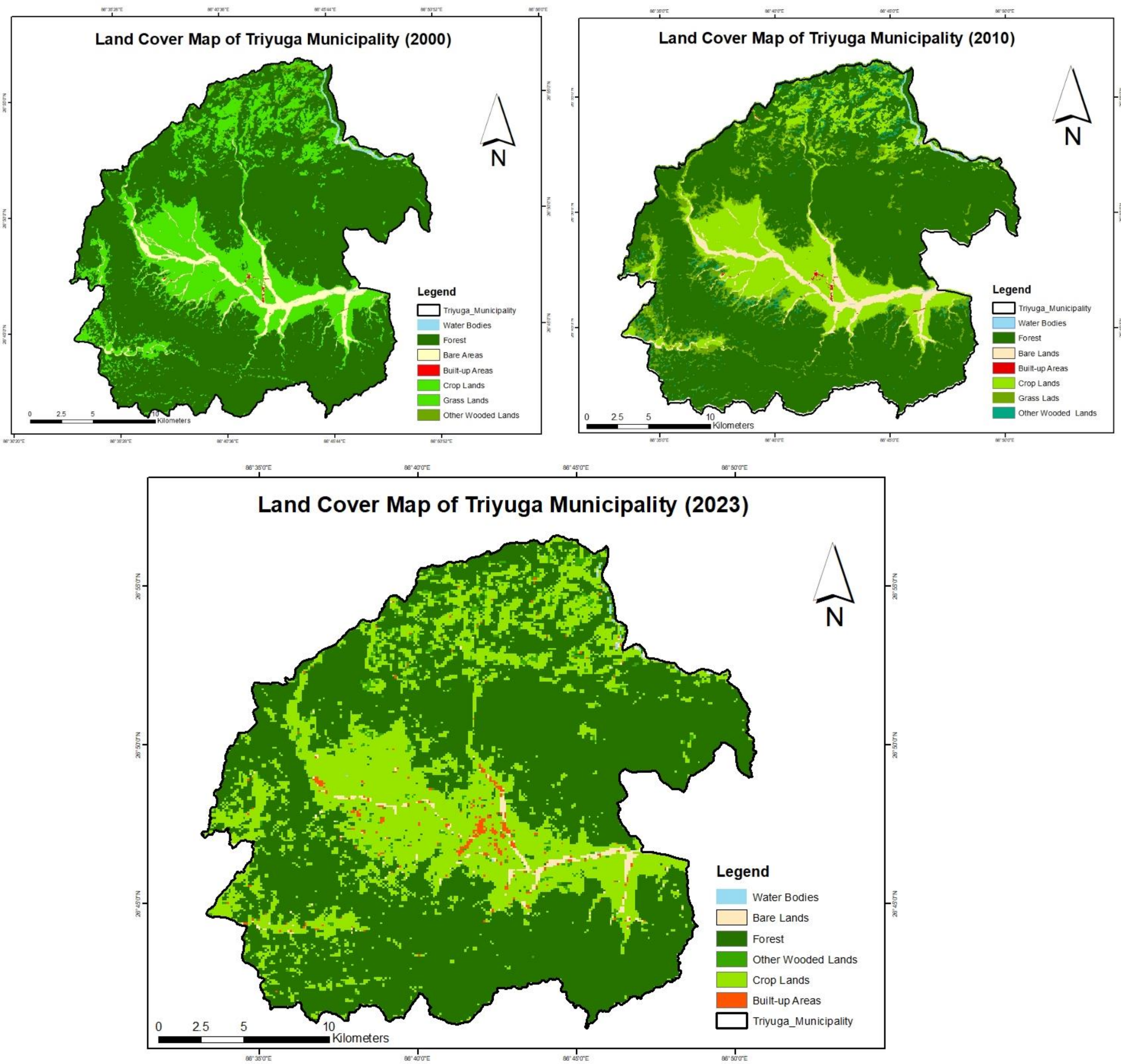

Figure 21: Showing land cover map of 200, 2010 and 2023

Table 12: Land cover area change statistics from 2000 to 2023

LULC	2000		2010		2023	
	Area (ha)	Area %	Area (ha)	Area %	Area (ha)	Area %
Water Bodies	181.71	0.33	164.07	0.30	103.69	0.19
Bare lands	2105.19	3.85	1958.13	3.58	666.38	1.22
Forest lands	42220.71	77.24	42028.74	71.16	34157.48	62.53
Other Wooded lands	827.46	1.51	928.71	1.70	2121.58	3.88
Crop Lands	8292.59	17.00	9533.79	17.44	16399.66	30.02
Built-up Areas	36	0.07	50.76	0.09	1179.75	2.16

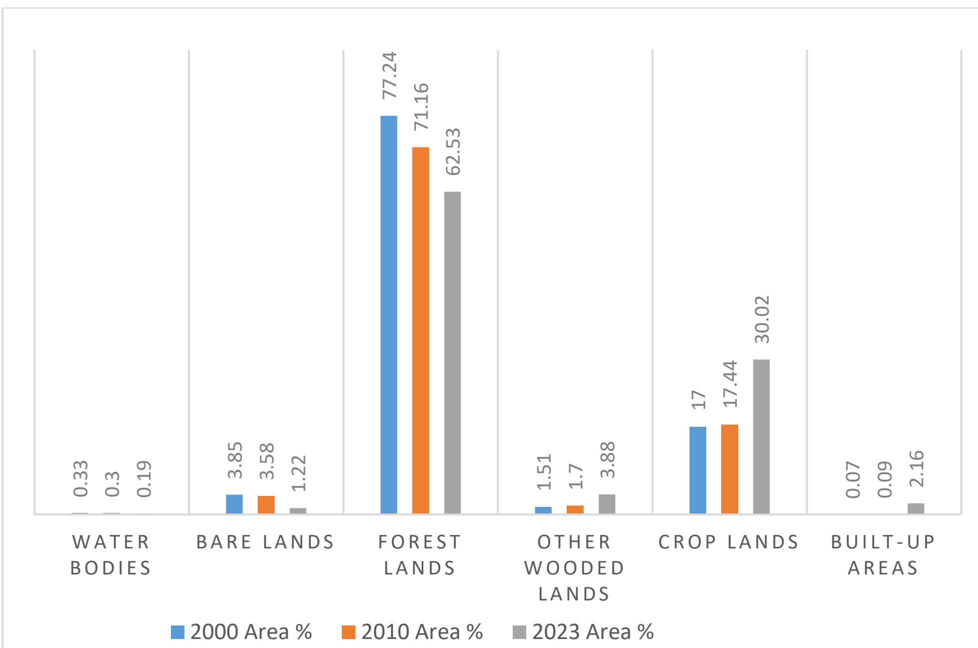

Figure 22: Land cover class area percentage of 2000, 2010 and 2023

[Note: for the year 2000 and 2010 forest cover is the addition of grass land and forest areas]

3.8. Discussion

3.8.1. Result Implication to Triyuga Municipality and Nepal

Our analyses of Nepalese forest biomass, carbon, and LUCC, as well as their linkages, provide information for researchers, policymakers, and practitioners at the international, national, and local levels in the context of growing worries about sustainable environmental health. It is clear that Nepalese forest commons have the potential to increase carbon storage and conserve biodiversity, and as a result, they support emerging international policy initiatives like the Convention on Biological Diversity (CBD), sustainable management of forests, conservation of forests, and enhancement of forest carbon. They must be taken into account when planning and implementing forestry initiatives at both the national and local levels since they are AGB, carbon, and LCC. The management of forest resources is emphasized in Nepal's forest policy as being mostly community-based. According to Ghimire and Lamichhane (2020), 80% of Nepal's total forest area has been managed under the general framework of community-based forest management. Local participation in the management of forest resources has led to improvements in the state of the forests in Nepal. There has been an increase in Nepal's forest cover as indicated by various evaluations, including 29% (DFRS, 1999), 40.36% (DFRS, 2015c), and 41.69% (FRTC, 2022).

Despite these facts, the amount of ABG in Triyuga Municipality is decreasing from 2000 to 2023 according to calculations made using the InVEST model for the years 2000 and 2010 and manual calculation for 2023 using allometric equations. The outcome emphasizes the necessity for management intervention to lessen deforestation and forest degradation through sustainable forest management in all the woods of Triyuga Municipality to deal with the effects of climate change in order to boost AGB in the future. Dedicated institutional and policy frameworks, thorough site-specific planning of silvicultural operations, appropriate implementation, and regular monitoring of forestry projects are also necessary for the effectiveness of these safeguards.

3.8.2. Implication of InVEST model and results

In this research, the result showed the application of InVEST Model for the Carbon measurement using the carbon pool values of land cover classes. Similar research has been conducted in Pakistan using InVEST Model to explore the relationship between the dynamics of terrestrial carbon stocks and LUCC from 1990 to 2015 (Mannan et al., 2018). Similar research using Landsat satellite images and InVEST has done in in the Koshi River Basin, Nepal during 1996–2016 in which this study analyses the spatiotemporal variations of land use and land cover and quantifies the change in three important ecosystem services (food production, carbon storage,and habitat quality) (Rimal et al., 2019) .This results of the current study can be compared with the study conducted by Kumarasiri et al. (2021). According to that study, the Samanalawewa watershed in Sri Lanka's carbon storage has been evaluated using the InVEST carbon storage and sequestration model (version 3.7). Similar to the current work, they have estimated the total carbon storage of the study region by using the carbon data from four carbon pools: above ground biomass, below ground biomass, soil organic matter, and dead organic matter. The spatial distribution of carbon storage has been estimated and the total amount of carbon storage in a given study area has been predicted using the same modeling approach by numerous researchers around the world (Babbar et al. 2021; Chacko et al. 2019; He et al. 2016; Jiang et al. 2017; Kumarasiri et al. 2021; Lyu et al. 2019; Zhao et al. 2019). As explained by Kumarasiri et al. (2021), the InVEST carbon storage and sequestration modeling approach can be effectively used inthe investigation of forest quality and the significance of forests in terms of carbon sequestration and storage. Moreover, (Chacko et al. 2019) revealed approach can be applied in various scenarios to map the spatial distribution of carbon storage coupling with GIS techniques. In agreement with other researchers, sharp et al. (2018) highlighted that the InVEST carbon storage and sequestration model can be used to evaluate the carbon sequestration or carbon loss over time if the current LULC data and future forecasted LULC data are provided. This explanation is successfully demonstrated by some researchers by coupling the InVEST model with other modeling approaches in various studies (Babbar et al. 2021; He et al. 2016; Jiang et al. 2017; Lyu et al. 2019; Zhao et al. 2019). In scenario analysis, the formulation of future LULC data and the obtaining of carbon pool values in each LULC type are critical since the whole model is run based on these two major data inputs (Sharp et al. 2018). Moreover, in order to model the future LULC maps, urban expansion and land-use change simulation and prediction model (SLEUTH-3r model) (Lyu et al. 2019) and Marcov chain model (Babbar et al. 2021; Zhao et al. 2019) have been used in previous cases. To assure the accuracy of the InVEST carbon storage and sequestration model's results, a precise carbon pool table must be created. Thus, as the IPCC 2006 report is one of the most trustworthy sources of carbon data worldwide, it has been used to collect the carbon data in the majority of situations (Hiraishi et al. 2014; Sharp et al. 2018).

The findings showed that there are six LULC classes, and that out of the six LULC classes, forest areas have significantly greater carbon storage values, while grassland and farmland exhibit moderate carbon storage values. Additionally, built-up area and barren area LULC types with very low carbon densities were observed. Similar studies have looked into the difference between urban areas with barren ground bearing little carbon storage and woods with evergreen trees holding the highest amounts of carbon stock (Chacko et al. 2019, Sedjo 2001). Similar to how it was reported in other regions of Nepal, Poudel and Rimal detailed how urban expansion was taking place at the expense of agricultural land (Paudel et al., 2016; Rimal et al., 2018c).

It is useful to estimate the changes in ecosystem services in response to LUCC (Grafius et al., 2015; Liu et al., 2020). For instance, using Costanza's unit ecosystem services value (ESV) and the example of China (Costanza et al., 2014), Lawler et al. (2014) evaluated the fluctuation in ecosystem services produced by LUCC in the United States from 2011 to 2051. They exposed significant variations in land-use patterns that result in modifications to carbon storage, timber production, and food production. Furthermore, LUCC affects not just terrestrial ecosystems but also other ecosystems. In order to understand the impact of land use cover change (LUCC) on wetland ecosystems, Ma et al. (2020) undertook a statistical analysis of the conversion process of land use types over the years 2000–2015 in the inland lake wetlands of Central Asia. Others have explored the relationship between land use structure and emission intensity of carbon at different scales (Mi et al., 2016; Chen et al., 2018; Yang et al., 2020).

Understanding how human activities affect the quality and quantity of ES requires estimation of changes in ES linked with LULC change. Since both natural processes and community livelihoods can be adversely impacted by unfavorable LULC change, such estimation at local and regional levels is crucial in influencing relevant policies to enhance sustainable development (Tolessa et al., 2017).

4. Conclusion and Recommendations

4.1. Conclusion

In this study, we used the Carbon Storage and Sequestration model, a component of the InVEST model, to analyze the effects of LUCC on the spatiotemporal variation of biomass and LULC change from 2000 to 2023. We mainly concentrated on the use of precise spatial datasets and trustworthy carbon stock estimates, assisting to achieve SGDs. The findings show that urban LUCC hotspots were brought on by decreases in carbon sequestration. In the years 2000, 2010, and 2023, the above-ground carbon value was 7887360.87 T of carbon, 7795346.07 T of carbon, and 5233311.076 T of carbon, respectively. Carbon was estimated to be 146.06 T, 144.35 T, and 96.91 T in the years 2000, 2010, and 2023, respectively. From 2000 to 2010, the total AGB stocks in Triyuga Municipality declined by 9201.436 Tons per year (1.16%), and from 2010 to 2023, the carbon loss rate increased to 197079.615 Tons per year (30%), which is significantly greater than the rate from 2000 to 2010. The entire amount of carbon in the Triyuga Municipality dropped from 2000 to 2023, totaling 2654049.35 T of C. From 1990 to 2015, built-up area carbon stocks increased year by 5.8%, whereas all other types of land cover types experienced a steep decline. The total amount of carbon dropped from 2000 to 2023 was 2078045.63 ton since forests are the main land cover class for carbon stock. The reason for this much huge change in forest carbon is because of huge increase in cropland area 7107.07 ha which 76.48 % from 2000 to 2023.

In regards with LULC change, built-up areas has increased from 0.07 % to 2.16 %, i.e. that percentage of land cover change is huge for this land cover. Similarly, Crop land also has increased from 17 % to 30.02 %, OWL from 1.51 % to 3.88 % which seems to have less change percentage than built-up and crop lands. Furthermore, Bare lands areas showed in decreasing trends: from 3.85%, 3.58% to 1.22% in the year 2000, 2010 and 2023, respectively. Similarly, two land cover forest and water showed decreasing trend from 77.42 % to 62.53% and 0.33 % to 0.19% from 2000 to 2023.

Nevertheless, our research has shed light on the region's shifting LULC pattern and rate of carbon stock change over the past 23 years. The findings will be helpful for decision- and policy-makers in the Triyuga Municipality in preserving natural ecosystems to support mitigation goals for climate change as well as preserving habitat quality for biodiversity preservation. Regulating the link between the extent of built-up regions and the area of green space is a crucial step to increase carbon sequestration from the standpoint of land use in the process of rapid urbanization. A new carbon balance is anticipated as a result of improving the design of urban green space and enacting more sensible land use laws, which will partially offset past periods' carbon loss. The foundation of developing policy should be the environmental benefits of forests and grasslands.

4.2. Limitation

We are aware of the study's shortcomings. The impact of management decisions on the advancement of AGB, carbon storage, LUCC, and their interactions was not examined in this study. As a result of solely using trees and pole DBH for AGB assessment (and ignoring below-ground and soil carbon), the AGB and carbon estimations are conservative. Uncertainties resulting from plot variation are included in estimates of both carbon and AGB, of course. Estimates may have been impacted by within-plot variance, allometric equation errors, inaccuracies relating to wood density and carbon factors, sample design uncertainties, and assumptions made on vast landscapes.

For the year 2023, we merely grouped LULC into six broad categories, whereas we used the seven classes that had already been established for the years 2000 and 2010. For example, various forest types have variable carbon storage capacities, and this was not taken into account in this study.

Even though we had excellent classification accuracy, the lack of current, updated reference data and complicated topography only allowed for 85%, 88%, and 80% accuracy overall for the various years. Like the LULC change process, our study only measured LUCC, AGB, and carbon from

2000 to 2023 and the application of current methodologies. These ES include water regulation, sediment retention, and flood management, all of which are significant for our study region.

4.3. Recommendations

Carbon sequestration by forests is important for climate change mitigation. Consequently, regular monitoring of forest carbon dynamics should occur on a regional or national basis to provide feedback important for assessing the effectiveness of forest management policies and activities at maintaining or enhancing forest carbon stocks. Future research in this field should prioritize the following areas.

Research and implementation of research findings should go hand in hand. The research findings of project work provide insights into the InVEST model to calculate the carbon value and I have presented the Carbon value (ton) of Churia region.

Since InVEST model works in different carbon pool value of different LULC and the proper data in the form of Raster is still not available for below ground, Soil organic carbon and Dead organic value and we are using the different values provided by the different literature. That could lead us slight variation in the carbon value. Therefore, concerned authorities should take action in those fields.

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Annex

1. Stem-wood density of Churia Trees

SN	Species	Local name	Air-dried density (kg/m³)
1	Acacia catechu	Khair	960
2	Adina cordifolia	Haldu/Karma	670
3	Albizia spp.	Siris	673
4	Alnus nepalensis	Utis	390
5	Anogeissus latifolia	Banjhi	880
6	Bombax ceiba	Simal	368
7	Dalbergia sissoo	Sissoo	780
8	Eugenia jambolana	Jamun	770
9	Lagerstroemia parviflora	Bot Dhaiyero	850
10	Michelia champaca	Chanp	497
11	Pinus roxburghii	Khote Shorea robustala	650
12	Quercus spp	Khasru	860
13	Schima wallichii	Chilaune	689
14	Shorea robusta	Shorea robusta	880
15	Terminalia tomentosa	Asana	950
16	Trewia nudiflora	Gutel	352
17	Miscellaneous in Terai		674
18	Miscellaneous in Hills		674

Source: Sharma and Pukkala, 1990

2. Species-specific coefficients used for calculating the volumes of individual Trees

SN	Species	Local name	a	b	c
1	Acacia catechu	Khair	-2.3256	1.6476	1.0552
2	Adina cordifolia	Haldu/Karma	-2.5626	1.8598	0.8783
3	Albizia spp.	Siris	-2.4284	1.7609	0.9662
4	Alnus nepalensis	Uttis	-2.7761	1.9006	0.9428
5	Anogeissus latifolia	Banjhi	-2.272	1.7499	0.9174
6	Bombax ceiba	Simal	-2.3865	1.7414	1.0063
7	Dalbergia sissoo	Sissoo	-2.1959	1.6567	0.9899
8	Eugenia jambolana	Jamun	-2.5693	1.8816	0.8498
9	Lagerstroemia parviflora	Bot Dhaiyero	-2.3411	1.7246	0.9702

10	Michelia champaca	Chanp	-2.0152	1.8555	0.763
11	Pinus roxburghii	Khote Shorea robustala	-2.977	1.9235	1.0019
12	Quercus spp	Khasru	-2.36	1.968	0.7469
13	Schima wallichii	Chilaune	-2.7385	1.8155	1.0072
14	Shorea robusta	Shorea robusta	-2.4554	1.9026	0.8352
15	Asana	Terminalia tomentosa	-2.4616	1.8497	0.88
16	Trewia nudiflora	Gutel	-2.4585	1.8043	0.922
17	Miscellaneous in Terai		-2.3993	1.7836	0.9546
18	Miscellaneous in Hills		-2.3204	1.8507	0.8223

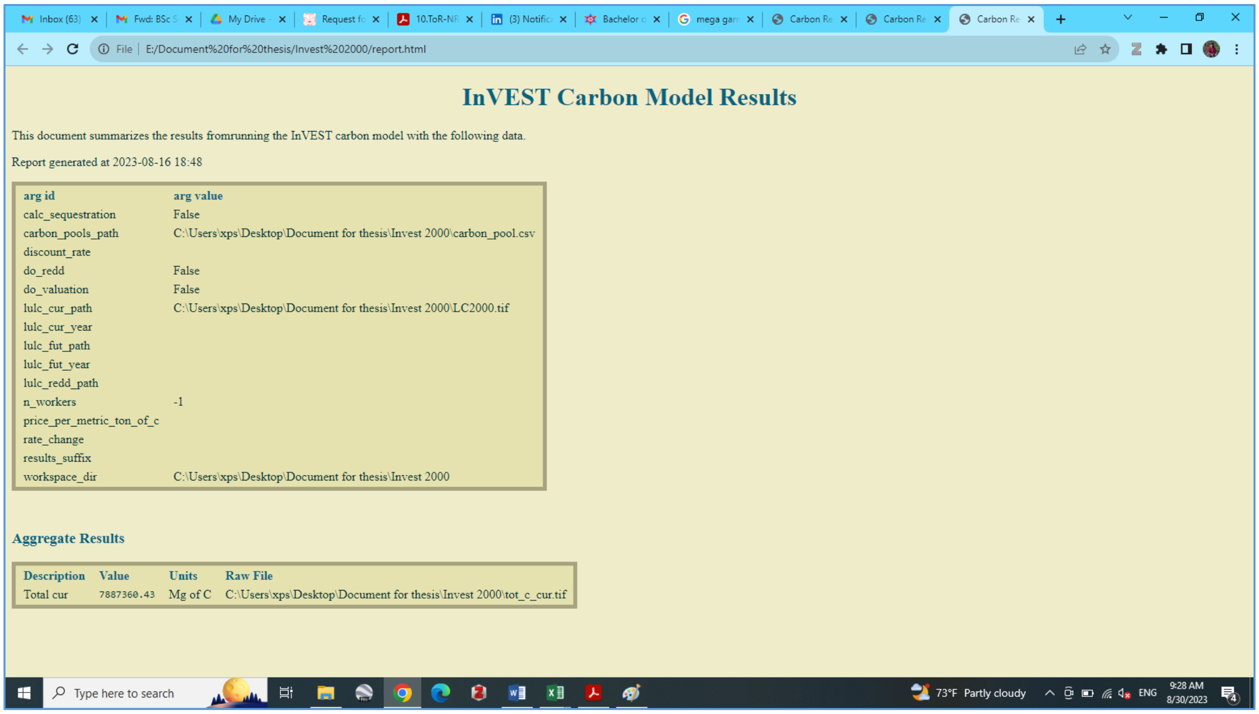
Source: Sharma and Pukkala, 1990

3. Carbon storage value

LULC Name	C_above	C_below	C_soil	C_dead	C_total
Waterbody	0.1 (Amthor et al., 1998)	-	-	-	0.1
Forest	97.69 (DFRS, 2015)	-	31.44 (DFRS, 2015)	0.32 (DFRS, 2015)	129.45
Riverbed	3.6 (Syahrinudin, 2005)	4 (Syahrinudin, 2005)	-	-	7.6
Built-up Areas	5 (Amthor et al., 1998)	-	-	-	5
Croplands	3.95 (Wani et al., 2010)	-	6.6 (Shrestha et al., 2004)	-	10.55
Grass lands	-	-	84.90 (Shrestha, 2016)	-	84.9
Other wooded lands	5.81 (IPCC 2006)	-	98.98 (IPCC 2006)	0.45 (IPCC 2006)	105.24

Source: Rimal et al., 2019

4. InVEST Carbon Sequestration model Result (2000)



InVEST Carbon Model Results

This document summarizes the results fromrunning the InVEST carbon model with the following data.

Report generated at 2023-08-16 18:48

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do_valuation	False
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lulc_fut_path	
lulc_fut_year	
lulc_redd_path	
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Aggregate Results

Description	Value	Units	Raw File
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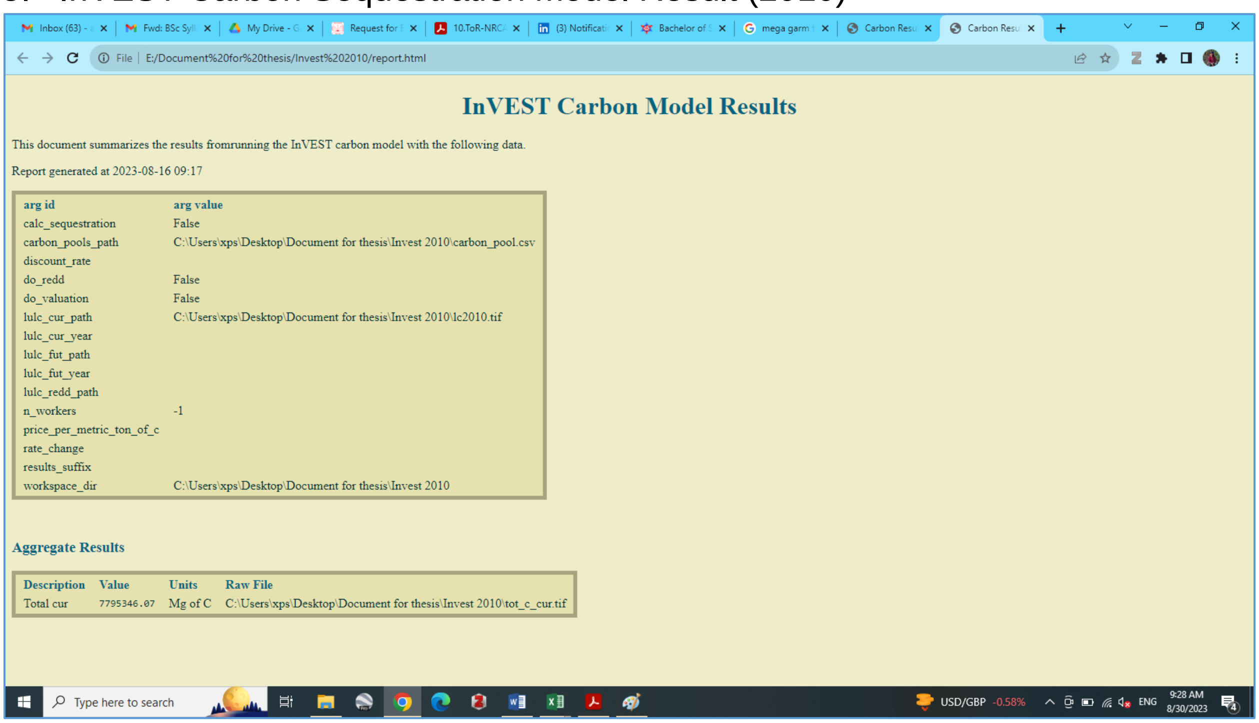
5. InVEST Carbon Sequestration model Result (2010)



InVEST Carbon Model Results

This document summarizes the results fromrunning the InVEST carbon model with the following data.

Report generated at 2023-08-16 09:17

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lulc_redd_path	
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Aggregate Results

Description	Value	Units	Raw File
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6. Above Gound Biomass Calculation

Sample plot number	Subdivision name	Average diamete per plot (cm)	Average height per plot (m)	Average biomass per plot (Ton/Ha)	Average carbon (Ton/Ha)
1	Gaighat	37.50	13.83	175.86	82.66
2	Gaighat	27.94	12.83	96.83	45.51
3	Gaighat	28.49	13.75	87.17	40.97
4	Gaighat	16.39	9.75	27.59	12.97
5	Gaighat	27.24	12.75	80.97	38.05
6	Gaighat	31.60	13.17	156.60	73.60
7	Gaighat	34.94	36.63	356.45	167.53
8	Gaighat	35.71	17.38	175.98	82.71
9	Gaighat	27.11	13.50	95.45	44.86
10	Gaighat	31.92	15.43	172.00	80.84
11	Gaighat	29.30	15.00	128.84	60.56
12	Gaighat	33.92	15.50	137.09	64.43
13	Gaighat	36.55	14.71	180.76	84.96
14	Gaighat	36.58	15.33	178.20	83.75
15	Gaighat	35.07	15.33	193.49	90.94
16	Gaighat	43.98	16.75	2072.47	974.06
17	Gaighat	32.28	9.89	92.69	43.56
18	Gaighat	38.83	16.20	197.34	92.75
19	Gaighat	38.68	16.33	234.36	110.15
20	Deuri	42.52	17.30	408.91	192.19
21	Deuri	60.69	22.14	545.25	256.27
22	Deuri	39.84	14.27	165.62	77.84
23	Deuri	34.33	14.90	173.42	81.51
24	Deuri	52.74	15.78	458.09	215.30
25	Deuri	52.13	17.75	408.52	192.00
26	Deuri	32.77	12.15	171.38	80.55
27	Deuri	34.75	14.00	182.96	85.99
28	Deuri	27.40	10.10	78.86	37.06
29	Deuri	45.11	14.00	198.11	93.11
30	Deuri	35.07	12.57	153.88	72.32
31	Deuri	35.60	13.50	120.75	56.75
32	Deuri	34.47	13.65	131.63	61.87
33	Deuri	36.00	13.80	215.37	101.22

34	Deuri	26.20	12.60	63.83	30.00
35	Deuri	30.82	10.73	93.58	43.98
36	Deuri	27.92	9.58	70.64	33.20
37	Deuri	31.30	12.10	93.45	43.92
38	Deuri	36.83	12.33	191.54	90.02
39	Deuri	31.80	12.33	104.67	49.20
40	Deuri	19.25	12.92	41.33	19.42
41	Khabu	27.58	16.84	105.07	49.38
42	Khabu	34.36	15.09	185.16	87.03
43	Khabu	32.85	13.45	184.82	86.87
44	Khabu	36.44	12.06	158.51	74.50
45	Khabu	30.79	15.64	128.77	60.52
46	Khabu	31.88	12.75	118.18	55.54
47	Khabu	39.76	18.00	216.76	101.88
48	Khabu	47.39	15.50	328.40	154.35
50	Khabu	42.85	16.92	225.71	106.08
51	Khabu	44.79	17.36	237.20	111.48
52	Khabu	44.85	17.08	228.66	107.47
53	Khabu	53.00	17.30	313.96	147.56
54	Khabu	56.08	18.46	374.19	175.87
55	Khabu	47.23	17.23	271.94	127.81
56	Khabu	48.79	17.53	264.70	124.41
57	Khabu	68.20	19.00	553.12	259.97
58	Khabu	47.08	17.75	429.25	201.75
59	Khabu	21.21	11.00	44.27	20.81
60	Khabu	25.24	13.23	76.67	36.03
61	Khabu	49.14	15.86	267.19	125.58
62	Khabu	23.61	10.33	59.65	28.04
63	Khabu	30.79	11.50	112.81	53.02
64	Khabu	33.18	12.00	125.41	58.94
64	Khabu	34.73	13.58	150.12	70.56
66	Khabu	32.57	12.77	116.93	54.96
67	Khabu	34.07	15.48	141.23	66.38
68	Khabu	33.59	14.14	139.35	65.50
69	Khabu	39.15	15.00	182.55	85.80
70	Khabu	40.37	21.73	266.91	125.45

7. Photo Plates