Assessing Vegetation Dynamics in Lingzhi Using Normalized Difference Vegetation Index (NDVI)

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Abstract: The assessment of vegetation dynamics using the Normalized Difference Vegetation Index (NDVI) is crucial for the development of effective strategies for biodiversity conservation and management. Using Landsat images, this article investigates the vegetation dynamics in the Bhutan highlands of Lingzhi between 2010 and 2021. The NDVI measurements were classified into five categories, and NDVI differencing was used to determine vegetation changes over time. The main objective of the study was to assess vegetation fluctuation, which assists in the investigation of anthropogenic pressure, deforestation, urban development, natural disasters, and regular landscape changes over time. The article discovered a decline in the moderate vegetation class, which was ascribed to grassland nationalization, the legality and regularization of cordyceps collection, and a decrease in illicit cordyceps harvesting. The results highlight the need to adopt image recognition methods and the NDVI index to understand forest changes. These findings can help planners and decision-makers steer sustainable land development in similar places.

Keywords: Normalized Difference Vegetation Index, anthropogenic pressures, cordysceps, Bhutan highlands, sustainability.

Introduction

Thimphu Dzongkhag comprises eight administrative districts (*Gewog*), namely Chang, Kawang, Dagala, Genekha, Mewang, Lingzhi, Soe, and Naro (National Statistics Bureau, 2020). The focus of this study is Lingzhi *Gewog*, located in the northern part of Bhutan and recognized for its spectacular snow-capped mountains, grasslands (*tsamdro*), stunning lakes, and an environment that is often considered pristine. Lingzhips, as inhabitants of Lingzhi are referred to, are dominantly

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associated with the yak-herding tradition in Bhutan's northern belt (Wouters, 2021). Many of them still herd yaks, even as in recent years the highlands witnessed the emergence of secondary employment sectors, including that of medicinal plants (Choki, 2021).

Ethnographic research is a part of this study, which incorporates three months of fieldwork in the highlands. Data collection involved face-to-face and telephone interviews, field observations, the review of extant literature, and a snowball sampling approach. The sample comprised 39 individuals, ranging in age from 20 to 102, with 18 females and 21 males. The study employed purposive field sampling to collect data, with 35 face-to-face interviews and 4 telephone interviews conducted (Table 1).

The study area, Lingzhi, encompasses a substantial geographical area but exhibits significant variation in altitude, complex topography, and diverse land cover. Since 1995, the entire Lingzhi administrative district has been within the Jigme Dorji National Park. The altitude ranges from 6400 to 3280 meters above sea level (masl), covering a total area of 38678.9 hectares, with a forest cover of 9.47% and a total forest area of 7116.48 acres (National Statistics Bureau [NSB], 2020; Ministry of Agriculture & Forest [MoAF], 2009). Lingzhi Gewog is situated 92 km away from Thimphu district, housing 94 houses and a population of 490 people. The Gewog comprises five Chiwogs and 12 villages.

Table 1: Socioeconomic background of the participants

Sl. No.	**Category**	**Specific**	**Total**
1	Gender	Male	21
		Female	18
		Total	39
2	Age group	Below 40	13
		40-60	8

		Above 60	18
3	Education	Literate	6
		Illiterate	33
4	Location	Chakphu	6
		Gangyuel	11
		Shayuel	9
		Chuzakhar	8
		Khangkidyuel	5
5	Altitude	4100 masl	6
		3900 masl	33

The vegetation in the study area lacks detailed ecological or meteorological data. However, it consists of scattered shrubs of alpine scrub, including Juniper scrub at lower elevations, as well as Rhododendron shrubs with various species mixed with Primula and *Bryocarpum himalacum*. Coniferous forests and cool temperate mixed broadleaf forests are abundant on north-facing slopes, while grasslands dominate south-facing slopes (Lakey & Dorji, 2016; Ohsawa, 1987). Conifer trees like *Larix griffithiana*, *Cupressus cornetana*, and *Picea spinulosa* can be found in the cool temperate mixed broadleaf between 2480 and 3355 masl (Yeshi et al., 2021; Wangchuk et al., 2020). The forest boundary overlaps with the lower limit of extensive Rhododendron scrub, indicating the expansion of Abies forest understory trees. In addition to yak-herding, the local communities rely on the sale of cordyceps, which is an insect fungus that fetches higher prices in the international market for its medicinal properties (Choki, 2021). The local economy is mostly based on yak herding and cordyceps collection, with most community members spending the winter in their villages and the summer on high-altitude grazing pastures, where they reside in temporary camps (Lakey & Dorji, 2016).

Since the mid-2000s, the geographical region under consideration has undergone a persistent wave of developmental activities as documented by the Ministry of Agriculture and Forestry (MoAF, 2009). These pronounced fluctuations and developmental trends have exerted consequential effects on the dynamics of vegetation and the accessibility of resources for the community in this region. The peak of the cumulatively increasing developmental trend resulted in a large-scale vegetation change (Lahkar, 2008). By the same effect, it was noticed that during the subsequent 2010-2021 period, a drastic change in vegetation continued. Throughout history, fluctuations in forest cover have largely been affected by development of the region.

In recent years, there has been an observable decline in vegetation cover within this region, as indicated by the National Statistics Bureau (NSB, 2020). The methodology employed in data collection for this study includes the utilization of Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+) Operational Land Imager (OLI) satellite imagery, acquired from the United States Geological Survey (USGS) website, to examine the variability and trends in land surface conditions within the Lingzhi area, with a specific focus on vegetation index data (see Table 2). The selected Landsat imagery possesses a temporal resolution of one image per year, with acquisitions dated November 4, 2010, and November 4, 2021, chosen due to their minimal cloud cover and snow interference, rendering them suitable for Normalized Difference Vegetation Index (NDVI) computation.

Nevertheless, it is essential to acknowledge that more frequent data acquisitions at intermediate intervals could provide a more holistic comprehension of vegetation dynamics and alterations in land cover. The restricted temporal scope of the current dataset may fail to capture short-term vegetative transformations or phenological variances occurring within the growth season. For the accurate assessment of vegetation dynamics, higher-resolution imagery (Gilani et al., 2015) or Land Use/Land Cover (LULC) data would be the preferred choice however, such data resources were not available for the study area, hence requiring the utilization of medium-resolution Landsat images characterized by minimal snow coverage, negligible cloud presence, and limited atmospheric contaminants such as haze, aerosols, and water vapor. Despite the application of atmospheric correction techniques, residual atmospheric interference remains a potential source of uncertainty in the NDVI calculations.

Table 2: Satellite imagery used.

Satellite/sensor	Date	Path	Row
Landsat TM 5	November 04, 2010	138	041
Landsat 8	November 04, 2021	138	041

Normalized Difference Vegetation Index

The assessment of vegetation dynamics using the Normalized Difference Vegetation Index (NDVI) and analysis of land cover changes are critical for understanding environmental changes, biodiversity conservation, and sustainable land use. This article investigates the vegetation dynamics in Lingzhi, Bhutan, between 2010 and 2021, focusing on the application of NDVI analysis to study land cover changes and the associated environmental factors. Numerous studies have demonstrated the significance of NDVI as a reliable indicator of vegetation dynamics and ecosystem health (Pettorelli et al., 2011). NDVI, calculated from satellite imagery using the near-infrared (NIR) and visible red (RED) reflectance bands, provides a quantitative measure of vegetation greenness and density. It has been widely used to monitor changes in vegetation cover, assess land degradation, and identify trends in ecosystem productivity. NDVI analysis has proven valuable in conservation planning and land management efforts. Studies by Pettorelli et al. (2011) and Taddeo et al. (2019) demonstrated the utility of NDVI in monitoring habitat fragmentation, detecting ecosystem disturbances, and guiding conservation interventions. Additionally, the application of NDVI in assessing the impact of policy changes on vegetation, such as grassland nationalization in Bhutan, has been demonstrated by Singh et al. (2005).

Over the years, advancements in remote sensing technology and image processing techniques have improved the accuracy and precision of NDVI analysis. Researchers have explored the use of high-resolution satellite data, such as Sentinel-2 and Planet Scope imagery, to capture fine-scale changes in vegetation (Gislason et al., 2006). Furthermore, machine learning algorithms and deep learning techniques have been applied to enhance image recognition and classification (Rai et al., 2018), providing opportunities for more sophisticated vegetation dynamics assessments.

A similar study was carried out in Haa and Phobjikha valley to investigate vegetation dynamics utilizing Landsat NDVI data and identified the drivers of vegetation changes, including agricultural expansion and urban development (Chaudhary et al. 2017). Kafle (2015) examined vegetation dynamics in the Himalayan region of Nepal, which shares similarities with Lingzhi in terms of mountainous terrain and vegetation types. The research employed time-series NDVI data to understand the impact of land use changes on forest cover and biodiversity and found that urban development was the main drivers of vegetation changes. Choudhury et al. (2021) conducted a land cover change analysis in the Sikkim region of India, which has similar ecological characteristics to Lingzhi. The study used Landsat imagery and classification techniques to identify changes in forest cover, agriculture, and urbanization. The research used NDVI and supervised classification methods to detect urbanization, anthropogenic activity, and land cover changes and their drivers.

The literature review provides a theoretical background for the research on vegetation dynamics, NDVI analysis, and land cover changes in Lingzhi, Bhutan. It establishes the context of the study by drawing on relevant research conducted in similar regions with comparable ecological characteristics. By incorporating insights from these studies, the research can better contextualize its findings and contribute to broader knowledge on environmental change and sustainable land management in high-altitude regions. The NDVI approach is used to extract the various features present in the Lingzhi administrative district's 3-band satellite image. One of the most significant biophysical markers for determining the distribution and patterns of green vegetation is vegetation cover. From the equation, NDVI is calculated as:

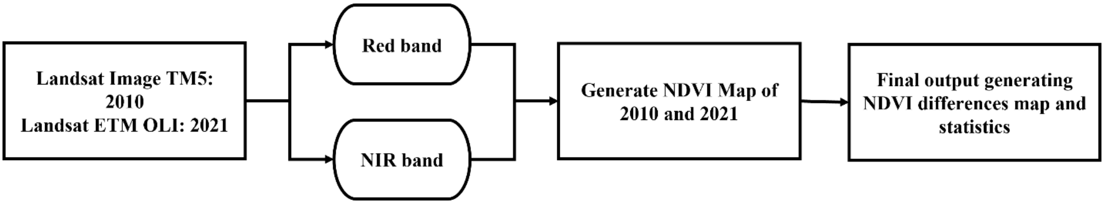
Figure 1: Equation

NDVI calculation

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

In this calculation, RED is visible red reflectance (600-700 nm) and NIR is near-infrared reflectance (750-1300 nm). The NDVI image was used to check the spectral signature of the vegetation, the changes in vegetation, and the dynamics of the land use/ land cover (LULC).

Figure 2: Operational processes to generate NDVI maps and NDVI differentiating.



In this study, the NDVI threshold for change detection was established to classify the vegetation into different categories and identify significant changes over time. The threshold selection process involved two main steps: (1) ignoring values between -1 and 0, and (2) using statistics from the mean and standard deviation of NDVI images for each year to determine the threshold values. NDVI values range from -1 to 1, where negative values represent non-vegetated areas, zero represents areas with no green vegetation, and positive values indicate the presence of vegetation. Since NDVI values between -1 and 0 do not correspond to any meaningful vegetation, they were ignored during the change detection process. To set the threshold for change detection, the mean and standard deviation of NDVI values for each year were calculated. The threshold was then determined based on a certain number of standard deviations from the mean. The rationale behind this approach is to identify significant changes in vegetation that deviate from the normal variation.

The choice of threshold was based on the need to strike a balance between sensitivity to change and reducing false positives or negatives. A threshold that is too low may result in excessive detection of changes, including minor fluctuations or noise in the data, leading to false positives. On the other hand, a threshold that is too high may miss genuine changes, leading to false negatives. By using the mean and standard deviation, the threshold was selected to encompass a range of NDVI values that are likely to represent meaningful changes in vegetation cover (Anyamba, et al., 2005). This approach ensures that only significant changes in vegetation, beyond the typical year-to-year variation, are identified as a result of the analysis.

To assess the sensitivity of the results to the chosen threshold, a sensitivity analysis could be performed by varying the threshold value and observing its impact on the detected changes. This analysis would help to understand how different threshold values influence the extent and magnitude of detected changes. Furthermore, comparing the results of the change detection analysis with ground truth data or other independent sources of information can provide additional validation of the chosen threshold. If possible, validation through ground truth data would help determine the accuracy and reliability of the change detection process.

Analysis and NDVI Map classes for 2010-2021

NDVI differencing and post-classification comparison were used to analyze the vegetation changes over time in Lingzhi. These methods are commonly used in remote sensing studies to detect and quantify changes in land cover and vegetation over time (Singh et al., 2005). In this study, the aim was to assess the changes in vegetation cover between the years 2010 and 2021. Post-classification comparison involves comparing the classified land cover maps of different periods to identify changes in vegetation classes. For this study, land cover maps were generated based on the NDVI classification results for the years 2010 and 2021 (Figures 3 and 4). The land cover classes were categorized as dense vegetation, high vegetation, moderate vegetation, sparse vegetation, and non-vegetation.

Figure 3: NDVI map of Lingzhi 2010

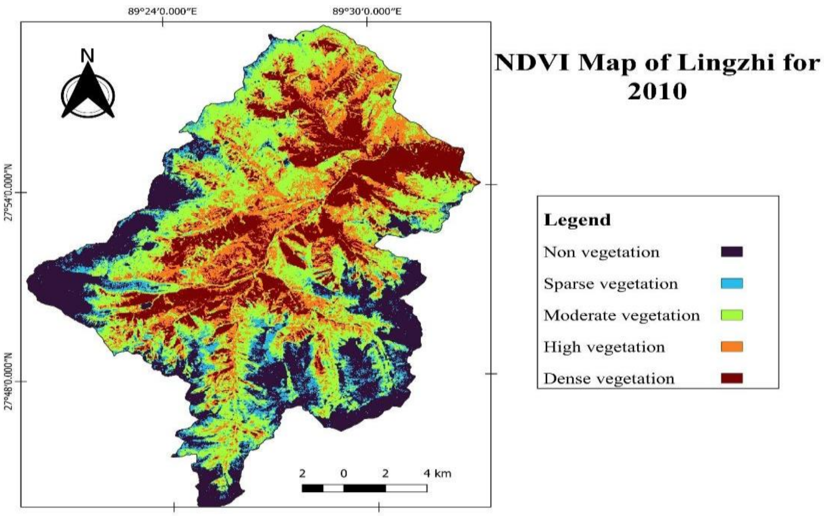
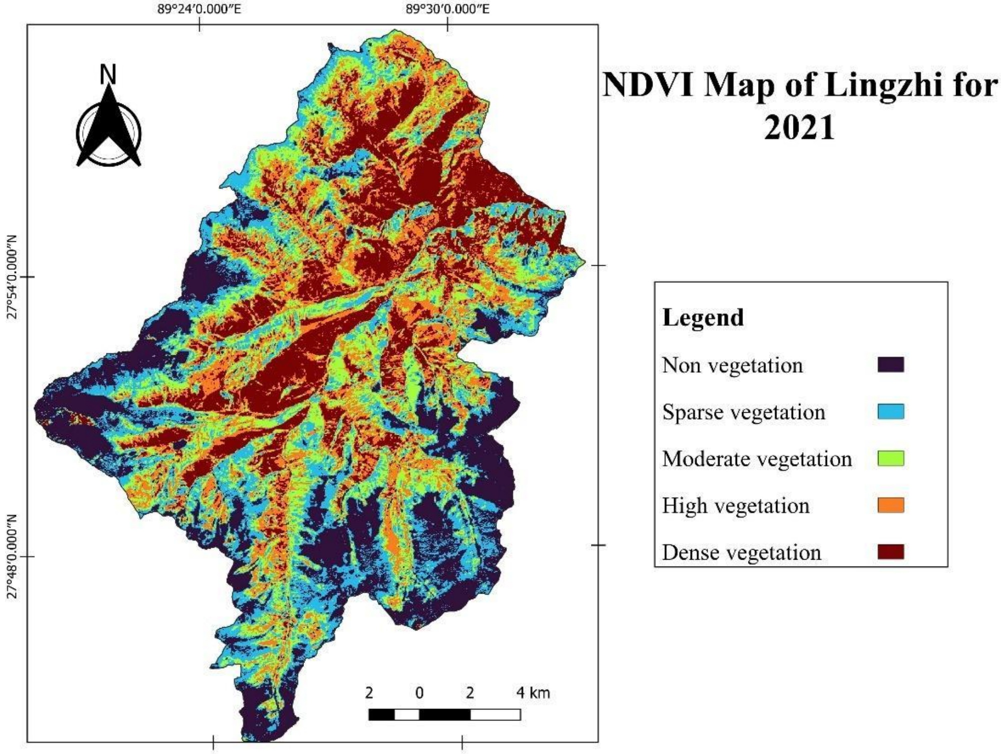


Figure 4: NDVI map of Lingzhi 2021



The comparison of the land cover maps revealed notable changes in vegetation patterns within the study area (see Table 3 and Figure 5 below). The moderate vegetation class showed a decline from 2010 (96,759 ha) to 2021 (60,892.2 ha). This decrease can be attributed to various factors, including the nationalization of grasslands, climate change, the legalization and regulation of cordyceps collection, and a reduction in illegal cordyceps harvesting. These findings suggest that the implementation of policies and regulations (Hazell & Wood, 2008) has influenced the vegetation dynamics in Lingzhi. The Land Act of Bhutan 2007 nationalized the highlander's grassland which were previously owned by private individuals or communities through acquisition of the land. The government now controls the grassland, leading to a significant change in grassland use (Royal Government of Bhutan [RGoB], 2007; Dhakal, 2018). Later, the government exclusively leased the grasslands to the residents which has resulted in significant increase in land use. It should be noted that at this time, the full impact of nationalization of grasslands cannot be assessed and will require more time.

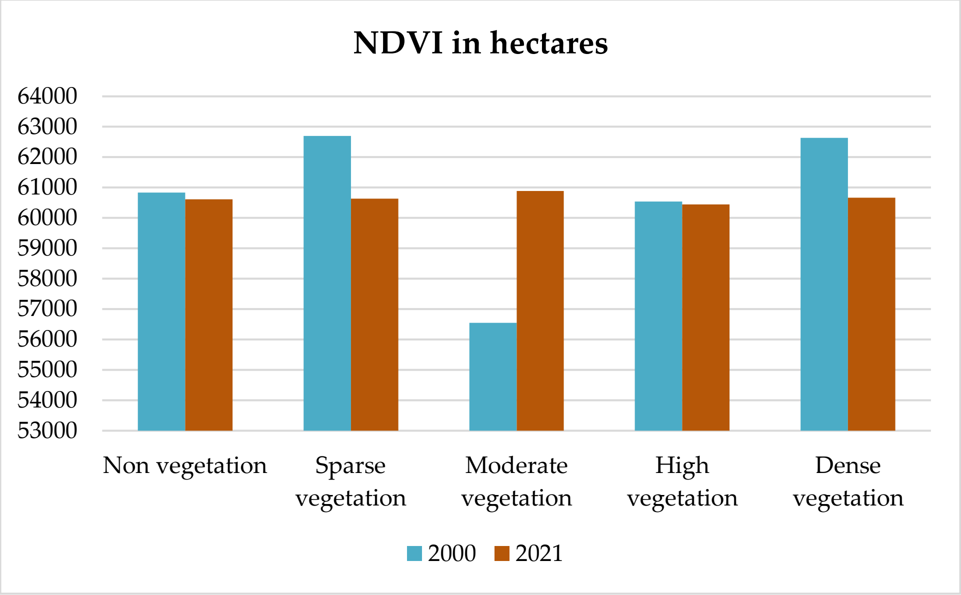
However, unsustainable practices such as exploitation of natural resources (non-wood products and wood products), seasonal migration, unsustainable tourism, and leaving the dunged areas open by the locals have resulted in a decline in vegetation, worsened by climate change and uncontrolled burning. The reduction in grassland has shifted the ecosystem towards less productive plant species. Clearly, the change in land ownership and practices has led to a decrease in vegetation growth in the area. The nationalization of the grasslands owned by highlanders has resulted in a decrease in vegetation growth due to unsustainable practices and climate change. Additionally, the legalization of cordyceps collection and construction activities has also contributed to the decline in vegetation. Overall, these factors have led to a noticeable reduction in vegetation in the area, requiring attention for ecological restoration.

Furthermore, the analysis indicated an increase in the sparse vegetation class from 2010 (24,849.9 ha) to 2021 (60,638.4 ha). This expansion of sparse vegetation may be associated with factors such as settlement expansion, the renovation of the Lingzhi fortress, and the introduction of prisoners for construction activities. These findings highlight the impact of human activities and infrastructure development on the vegetation dynamics in the region. The non-vegetation class exhibited relatively stable trends over the years, with minor changes observed from 1991 to 2021. This indicates that non-vegetated areas, such as barren lands and built-up areas, have remained relatively constant in Lingzhi.

Table 33: NDVI in hectares

Class	**2010**	**2021**
Non-vegetation	60678.9	60618.6
Sparse vegetation	24849.9	60638.4
Moderate vegetation	96759	60892.2
High vegetation	62199.9	60441.3
Dense vegetation	58768.2	60665.4

Figure 5: NDVI pattern in hectares



NDVI differencing

Changes in LULC have a significant impact on global climate change. Developmental activities such as urbanization, infrastructure, and industries can lead to deforestation, encroachment, fire, plantations, mega-dams, reclamation, water logging, agriculture, shifting cultivation, and other developmental variables to detect NDVI changes. NDVI shows the vegetation index and displays the increase and decrease in vegetation (Singh et al., 2005). NDVI distinguishes vegetation from other land cover and determines its overall status. It enables the mapping of vegetated regions as well as the detection of anomalous alterations in the growth process (Hazell & Wood, 2008). It assesses the status and health of the plants by measuring biomass. It is also fast and accurate in estimating vegetation losses induced by extreme weather, drought, exploitation, and anthropogenic activities. The disadvantage of NDVI is that its high vegetation content makes differentiating between moderately high and high vegetation difficult; hence, during categorization in 2010, the vegetation change was particularly high in comparison to prior years.

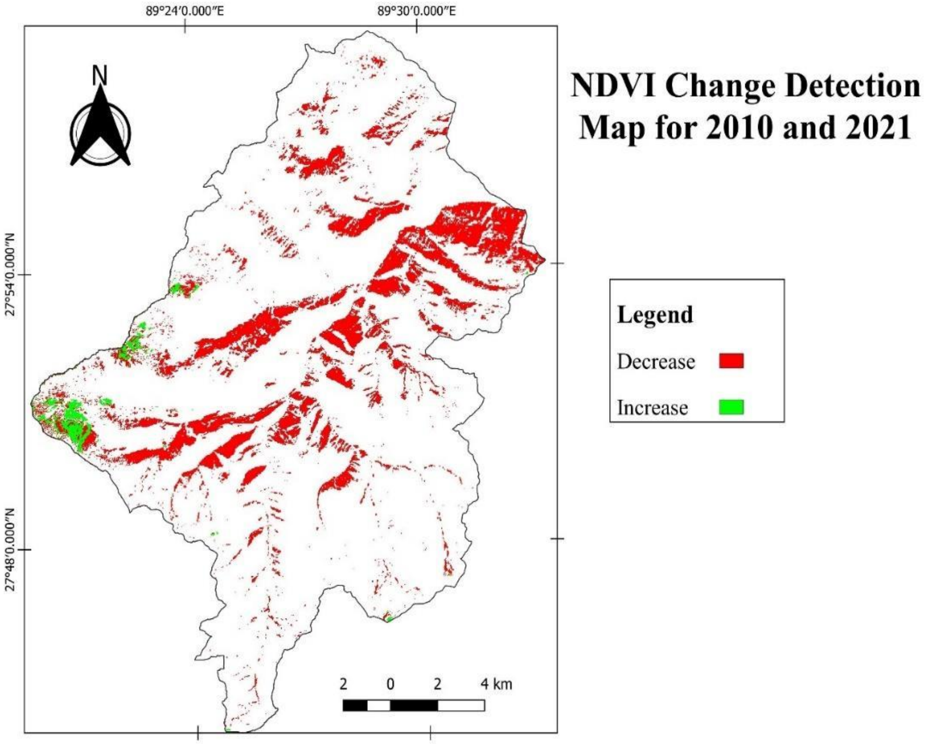
The georeferencing process is a crucial step in remote sensing studies as it ensures that satellite imagery is accurately aligned with real-world geographic coordinates.

In this study, the Landsat TM and Landsat ETM OLI satellite images were georeferenced using Ground Control Points (GCPs) collected from known locations on the Earth's surface. The georeferencing was performed using robust transformation methods to minimize spatial distortions. Despite the careful georeferencing process, certain errors and uncertainties can still affect the spatial accuracy of the remote sensing data used in the analysis. Some of these potential issues include the accuracy of georeferencing heavily relies on the selection of appropriate GCPs. Errors in GCP selection, such as misidentifying locations or using inaccurate coordinates, introduced inaccuracies into the geospatial information. However, ground truth validation was conducted to verify the accuracy of the georeferenced data and to assess the spatial agreement between satellite imagery and on-ground measurements. Lingzhi's mountainous terrain poses challenges for accurate georeferencing due to variations in topography. Steep slopes and rugged terrain may result in distortions, especially in regions with limited GCP coverage. Geolocation errors in the satellite imagery, caused by sensor inaccuracies or orbital variations, can lead to misalignments between image pixels and geographic coordinates, affecting the overall spatial accuracy. Atmospheric conditions, such as aerosol scattering and water vapor content, can introduce uncertainties in the radiometric calibration of satellite images, potentially impacting the derived NDVI values and vegetation classifications.

NDVI differencing for 2010-2021

The NDVI map was analyzed to quantify vegetation change in the Lingzhi administrative district’s landscape. One NDVI change detection map, as shown in Figure 6, was created to understand the landscape and vegetation dynamics of the study area. The main objective of using NDVI was to highlight changes in vegetation in time series data because NDVI data has minimal air disturbance and bias and is free from classification subjectivities. Only vegetation increase and decrease were evaluated since they would aid in analyzing anthropogenic pressure, deforestation, urban expansion, the influence of natural catastrophes, and normal landscape change through time. The NDVI changes due to changes in the spectral signature of the vegetation. NDVI differencing, is sensitive to temporal variations in vegetation, making it susceptible to seasonal changes and intra-annual fluctuations. Moreover, NDVI differencing may not effectively discriminate between different vegetation classes, particularly in areas with high vegetation content, leading to challenges in accurately identifying changes.

Figure 61: NDVI change detection map for 2010-2021



The Lingzhi NDVI map change detection study demonstrates a change in landscape. According to Table 4, the highest negative change is noted from 2010 to 2021 (40688.1 ha), which may be attributed to an increase in settlements, electricity, fortress restoration, the import of prisoners as laborers in the study area, changes in snow cover, changes in spectral signature, and vegetation loss.

Table 44: NDVI change detection representing the decrease and increase of six maps.

Class	**2010-2021**
Decrease	40688.1
Increase	2444.4

There is a drastic change in vegetation, which may be attributed to the rebuilding of the *Yügyal Dzong* (fortress) in Lingzhi in 2005 (image of the *Yügyal Dzong* in image 7). About 300 prisoners were relocated there in 2010 or 2015 for construction, which may have degraded the natural environment. Construction alone has an impact on the environment, as does transporting raw materials. The prisoners were housed in a neighboring grassland region, and they may have utilized fodder, putting more pressure on the natural resources.

Image 1: Picture of Yügyal Dzong in Lingzhi during November (Photo: Thinley Dema)

The development of the area required considerable tree-cutting for construction purposes, which is a source of debate in the village. According to oral history, these trees in Lingzhi are the physical manifestations of the Great Tibetan Lama Zhabdrung Ngawang Namgyel's guardians, so cutting down these trees is frowned upon in *Cheybeysa* (village). This idea depicts a conflict between materialists and religious people (Dema, 2021). The homes were likewise well-furnished, and even the furniture is adorned with traditional sculptures, making it impossible to distinguish the altars from regular shelves. Highlanders would cut a growing number of trees to build these houses. However, there is a tension between the spiritual and historical value of these trees and the legislation prohibiting their removal. Bhutan's strong environmental consciousness is demonstrated by the view that portions of the environment, such as sacred sites, cliffs, and lakes, are not available as resources to be exploited (Ura, 2001; Wouters and Dema, forthcoming). In contrast, as the number of houses being built increases, it has become unavoidable for highlanders to cut down trees. People have also begun to dig additional ground to drill foundations, destroying many rocks in the process. All these behaviors are supposed to provoke the local deities (Wouters, 2023).

Linking Research Findings to Policy Recommendations

The research findings on vegetation dynamics in Lingzhi, Bhutan, provide valuable insights into the state of the region's natural resources and the impact of various drivers of change. These insights have significant implications for policy development and decision-making aimed at biodiversity conservation, sustainable land use, and community livelihood improvement. Based on the research findings, the following policy recommendations are suggested.

The first recommendation underscores the need to intensify conservation efforts in Lingzhi, particularly in response to the diminishing moderate vegetation class. This involves measures to safeguard and restore deteriorated grasslands, forests, and alpine scrub habitats. It also advocates for enhanced monitoring and enforcement of Jigme Dorji National Park's regulations to safeguard vital habitats and curb illicit activities that further threaten vegetation. Additionally, biodiversity assessments are recommended to pinpoint ecologically sensitive zones and prioritize conservation strategies for safeguarding the region's distinctive flora and fauna.

The second recommendation centers on promoting sustainable land use practices in grasslands, striking a balance between the livelihood requirements of highlanders and ecological preservation. It encourages strategies like rotational grazing and sustainable resource harvesting to prevent overexploitation and degradation. Moreover, it calls for the development of land use plans that consider ecological carrying capacities and the promotion of agroforestry practices to bolster vegetation cover while supporting local livelihoods.

The third recommendation seeks to improve community livelihoods and socio-economic development. This involves launching capacity-building programs to enhance highlanders' expertise in sustainable land management practices and diversifying income sources beyond cordyceps collection and yak herding. Initiatives such as eco-tourism and sustainable use of non-timber forest products are explored as means to reduce dependence on cordyceps harvesting. The promotion of community-based conservation efforts that empower local communities in decision-making processes and ensure equitable benefits from conservation endeavors is also emphasized.

The fourth recommendation urges the conduct of vulnerability assessments to understand climate change's potential impact on vegetation dynamics and identify adaptation strategies for the region. Climate-resilient practices, including afforestation, reforestation, and soil conservation, are proposed to bolster ecosystem resilience against climate-induced disturbances.

These recommendations aim to strike a harmonious balance between environmental preservation, sustainable land use, and the enhancement of community livelihoods in Lingzhi. By integrating these policy recommendations, stakeholders can work collaboratively to safeguard the region's exceptional biodiversity, boost resilience against environmental shifts, and promote sustainable development for both current and future generations.

Limitations of the Study

The data collection process in remote sensing studies can introduce several limitations that may impact the accuracy and reliability of the results. Cloud Cover and Snow Interference was prevalent in Lingzhi, as it is a mountainous region, prone to cloud cover and snow during certain periods, which can hinder the acquisition of cloud-free and snow-free satellite images. This limitation led to data gaps and inconsistencies in the analysis. The availability of satellite imagery with suitable temporal resolution was one of the limitations, especially in areas with frequent cloud cover. The availability of satellite imagery with suitable temporal resolution was one of the limitations, especially in areas with frequent cloud cover.

In this study, I utilized Landsat TM and Landsat ETM OLI images with a temporal gap of 11 years. A longer temporal gap may overlook short-term vegetation fluctuations. 11-year temporal gap might not capture short-term fluctuations in vegetation dynamics. Future studies could benefit from employing satellite data with higher temporal resolution to monitor more frequent changes in vegetation cover over time. The spatial resolution of Landsat data (30 meters) used in this study may not fully capture fine-scale changes in land cover. Utilizing imagery with higher spatial resolution, such as Sentinel-2 or commercial high-resolution satellites, would provide more detailed insights into vegetation dynamics at a local scale. Due to the challenging terrain and remoteness of the study area, ground truth validation of vegetation changes was not conducted. Including ground-based data collection and validation techniques, such as field surveys or drone imagery, in future research would improve the accuracy and reliability of the analysis. The choice of the NDVI threshold for change detection introduces subjectivity. Future studies should explore alternative methods, such as data-driven approaches or machine learning algorithms, to objectively determine optimal threshold values. The study lacks detailed ecological or meteorological data, which could have provided additional context for understanding vegetation dynamics. Integrating ancillary data, such as climate variables and topographic characteristics, would enhance the comprehensiveness of the analysis.

Future Research Directions

Conducting long-term monitoring of vegetation dynamics in Lingzhi and other similar regions would facilitate a deeper understanding of vegetation trends, including the impact of climate change, anthropogenic activities, and conservation efforts. Investigate the specific drivers of vegetation change in the study area by incorporating socio-economic data, land use policies, and human activities. This could provide valuable insights into the causal factors behind observed vegetation fluctuations. Analyze the impact of land use changes on landscape fragmentation and connectivity to understand how human activities affect ecological corridors and biodiversity conservation. Combine data from multiple sensors, including optical and radar imagery, to complement the analysis and overcome limitations related to cloud cover and snow interference. Engage local communities and stakeholders in participatory research to gain insights into their perceptions of vegetation changes, the effectiveness of conservation policies, and their adaptation strategies in response to environmental shifts. Conduct an ecosystem services assessment to understand the benefits provided by the various land covers and how changes in vegetation affect ecosystem functions, such as carbon sequestration, water regulation, and habitat provision. Assess the effectiveness of ecological restoration efforts, such as afforestation and reforestation programs, to mitigate the impacts of land use changes and promote sustainable land management. By addressing these limitations and pursuing these future research directions, we can advance our understanding of vegetation dynamics in Lingzhi and other ecologically sensitive regions. Such research outcomes will have significant implications for biodiversity conservation, sustainable land development, and informed decision-making in the face of environmental change.

Conclusion

The article contributes to a broader understanding of environmental changes and sustainable land management in high-altitude regions, with implications for policy development and decision-making. The findings underline the importance of proactive conservation strategies and sustainable land use practices in maintaining the ecological integrity of Lingzhi and similar regions, as well as the importance of engaging local communities in these efforts. The objective of this study was to perform NDVI to assess the vegetation dynamics in Lingzhi over 11 years, from 2010 to 2021, in order to comprehend environmental changes. NDVI differencing was also performed on all two-time series to get an unbiased and minimal atmospheric distortion while analysing vegetation in the study area. Vegetation changes were assessed in the study since they would aid in analyzing anthropogenic pressure, deforestation, urban expansion, the influence of natural catastrophes, and normal landscape change through time. The results for NDVI also show changes in vegetation cover, which are caused by anthropogenic pressure, socio-economic development, and policies. The increased transportation of raw materials, the introduction of labourers for the construction of the fortress, and the construction of schools have all had a severe influence on grassland regions. Other reasons, such as the placement of communications towers near villages and the use of its branches as fuel by highlanders, have had an influence on the vegetation cover. In some areas, vegetation has grown due to the national park declaration and nationalization of grassland. Grassland degradation is due to digging of the soil for collection and trampling when they crawl to search for cordyceps. This study serves as a foundation for informed actions that will not only benefit the environment but also the well-being of the people who call this region home.

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