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Change Detection of Vegetation Cover Using NDVI: A Case of Harispattuwa Divisional Secretariat Division in Kandy District

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Abstract

The study utilizes the Normalized Difference Vegetation Index (NDVI) to analyze changes in vegetation cover in the Harispattuwa Divisional Secretariat (DS) Division of Sri Lanka across three distinct periods 1997, 2009, and 2022. The NDVI data is complemented by in-depth spatial analysis and remote sensing techniques to provide a comprehensive understanding of the ecological changes in the area. The NDVI maps related to these years reveal significant shifts in vegetation distribution and health. In 1997, the division featured abundant vegetation covering 87% of its total land area, including forests, grasslands, and dense vegetation. By 2009, urbanization and infrastructure development had led to the expansion of built-up areas and reduced green spaces. By 2022, these trends had continued, with further expansion of built-up areas and an even larger extent of barren land, suggesting changes in land use and environmental conditions. These changes are reflected in the NDVI values, which indicate the health and coverage of vegetation. The study employs NDVI value ranges established by previous research to provide a detailed assessment of different land cover types. The results show the expansion of built-up areas and a decrease in dense vegetation over the years. The study highlights the dynamic nature of the landscape of Harispattuwa DS Division, underscoring the need for ongoing monitoring and sustainable land management practices to protect the region's unique ecosystem. It also emphasizes the importance of addressing the impact of urbanization on vegetation cover and the environment. In conclusion, this research provides valuable insights into the evolving vegetation cover in the Harispattuwa DS Division, calling for measures to balance development with environmental preservation and sustainable land management.

Keywords: NDVI, urbanization, vegetation cover change, remote sensing techniques, sustainable land management

1. Introduction

Vegetation cover plays an important role in maintaining ecological balance and biodiversity. Vegetation cover, as defined by Perez et al. (2022), includes the types of vegetation that provide green surface cover. Its importance deeply affects our environment: it boosts oxygen production, facilitates the transfer of nutrients and energy to living organisms, improves water quality, and purifies soil erosion and flooding and it even has a positive effect on climate development. Classified as forests, grasslands, tundra,

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deserts, and glaciers, the world's flora offers rich biodiversity. For example, forests are large areas inhabited by trees, both deciduous and evergreen, each of which contains a unique tropical, or boreal ecosystem and they cover considerable plots globally. Despite its rich herbal heritage, Sri Lanka has witnessed substantial flower loss over the years. Historical elements, which include British colonial endeavors in espresso and tea production, have brought about extensive deforestation, especially in highland regions. Iyyer (2009) noted that, every year there was a decrease of 26,800 hectares of woodland cover between 1990 and 2000, amounting to 1.14% of the island's total land location. Furthermore, Sri Lanka's flora has declined by 17.7% from 1990 to 2005, a trend underscored with the aid of estimations from the Food and Agriculture Organization, projecting a discount in woodland cover from 37.5% in 1990 to 34.2% in 2020 (Sellapperumage, 2020). The distinctive geological formation also significantly contributes to the diversity of plants. Another significant element that affects the distribution and types of vegetation in Sri Lanka is the climate. To name a few, there are tropical rain forests, wet and dry montane forests, tropical dry mixed evergreen forests, thorn forests, and scrubs and grassland in the desert regions (Abeysekara, 2022). Monitoring changes in vegetation over time is essential for the understanding of ecological dynamics and implementing effective conservation strategies (Zahir et al., 2024). Vegetation identification methods such as the Normalized Difference Vegetation Index (NDVI) provide a valuable tool for assessing vegetation health and detecting changes in land cover.

The use of NDVI to detect changes in vegetation cover has been investigated. Both Gandhi et al. (2015); Jung and Chang (2015) used NDVI to examine land cover changes, where Gandhi focused on the Vellore district and Jung focused on deciduous forests, as followed by Faramarzi et al. (2018) who applied NDVI over semi-arid ranches in western Iran. The relationship between vegetation and heritability was also examined, where Lee et al., (2020) found a high correlation using a multi-layered Perceptron Network on MODIS NDVI data to detect changes in vegetation cover over the Korean peninsula. Together, these studies demonstrate the effectiveness of NDVI in detecting changes in vegetation cover, which can be used in soil and environmental contexts. However, Scanlon et al. (2007) reported that forests cover more than 21% of the world's land area, with trees and grasslands covering about 19% each, while crops cover the same share of the remaining land In Sri Lanka. Differences in rainfall, elevation and soil texture create a wide variety of forests on the island, which are reorganized by specific geological factors.

Assessing land cover changes using MODIS NDVI data at different time intervals has been an important part of environmental assessment. Lunetta et al. (2022) emphasize the importance of processing NDVI temporal data for effective vegetation management. Gandhi et al., (2015) shows the effectiveness of NDVI in detecting vegetation change in the Vellore district. Bid (2016) uses NDVI to characterize changes in vegetation structure in the Panchet Hill Dam area, India. Jung and Chang (2015) proposed an NDVI-based method for spatial and temporal vegetation analysis. Similarly, Badamasi et al. (2010) and Agone and Bhamare (2012) use NDVI to assess vegetation change in Nigeria and the Tittur Basin, respectively. Nath and Acharjee (2013) focus on the role of NDVI in forest cover change detection, while Usman et al. (2015) used land use/land cover classification in Pakistan. Ibrahim and Al-Mashagbah (2016) confirm that NDVI is effective in assessing vegetation change in different regions. Together, these studies highlight the versatility and importance of NDVI in managing changes to land cover on a global scale.

Accordingly, Harispattuwa is one of the DS Divisions located in the Kandy district in Central province, with abundant vegetation cover. However, there have been several changes and a considerable loss of forest vegetation of the study area during the past few decades. The primary objective of this research is to examine the temporal changes in the vegetation cover from 1997-2022. By using NDVI data derived from satellite imagery, we aim to detect and quantify changes in vegetation distribution and density. Understanding these changes is critical to assessing the impact of human activities, climate variability, and land-use dynamics on the region's ecosystems. The current research will catalyze informed decision-making and a commitment to the responsible stewardship of this precious natural resource for generations to come as a sustainable perspective.

2. Materials and Methods

2.1 Study Area

Harispattuwa is an administrative DS Division within Kandy District, Sri Lanka, situated at approximately 7˚ 20' 2" North latitude and 80˚ 35' 25" East longitude. It shares borders with neighboring divisions, including Akurana, Poojapitiya, Thumpane, Gangawatakorale, and Yatinuwara. Therefore, the study area covers diverse landscapes characterized by verdant hills, lush forests, and fertile valleys. The region is renowned for its rich biodiversity, encompassing a variety of flora and fauna endemic to Sri Lanka's tropical climate. Harispattuwa is bordered by picturesque mountain ranges, including the iconic Knuckles Mountain Range, which adds to its scenic beauty and ecological significance. The study area involves different socio-economic activities including government and private sector employment, agriculture, foreign employment, self-employment, and temporary/part-time jobs. Agriculture is the most important sector, with major crops and livestock being raised.

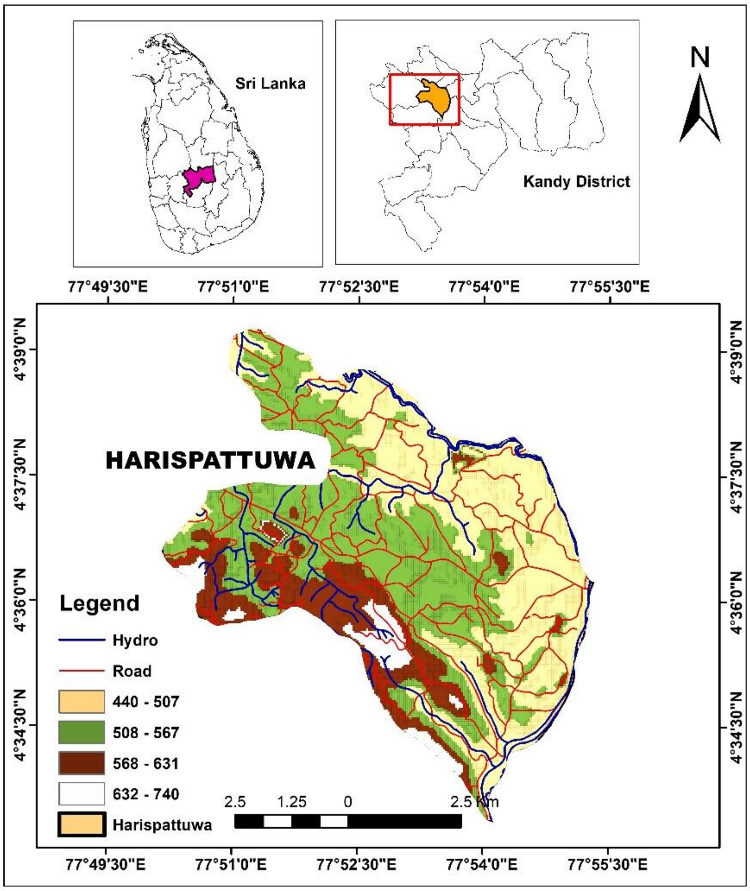


Figure 1: Study Area

2.2 Data Analysis Methods

2.2.1 Satellite Imagery

This study examined the temporal changes in vegetation cover within the Harispattuwa DS Division by analyzing land cover patterns in the years 1997, 2009, and 2022. To gather the necessary data, Landsat-5 and Landsat-9 images were acquired from the US Geological Survey (USGS) website, specifically on February 07, 1997, March 12, 2009, and January 19, 2022 (Table 1).

Table 1: Details of Landsat satellite image data

Year	Image type	Date	Cloud type
1997	Landsat-5	February 07, 1997	0
2009	Landsat-5	March 12, 2009	0
2022	Landsat-9	January 19, 2022	0

2.2.2 Cropping Image

One of the preprocessing processes carried out in this study is image clipping. Image cropping aims to limit and focus the image area according to the research area. By clipping the images, Map Processing eases the work and helps to filter and increase the clarity of the imagery.

2.2.3 NDVI (Normalized Difference Vegetation Index)

In this study, the analysis of vegetation cover changes in a specific area relied on satellite images captured in 1997, 2012, and 2022, and the primary method used for analysis was NDVI. Delarizka and Sasmito stated in a study that NDVI is a valuable tool for comprehending historical vegetation conditions, monitoring its present status, and making predictions about its future. NDVI serves as a vegetation index that provides insights into the density and existence of plant life on the Earth's surface (Delarizka and Sasmito, 2016).

A simple mathematical formula calculates the NDVI, and it transforms the raw satellite data into vegetation indices.

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{NIR} + \boldsymbol{RED})}{(\boldsymbol{NIR} - \boldsymbol{RED})} \longrightarrow \boxed{1}$$

NIR = Reflectance value of Infra-Red band

RED = Reflectance value of the Red band

Subtract the reflectance in the RED spectral band from that in the NIR.

Then it divides this by the sum of NIR and RED reflectance.

The bands used to calculate the NDVI for Landsat images are also different in this study, Landsat 5 and Landsat 9 images were used.

According to that, the following Formulas are used to calculate the NDVI.

For Landsat 5 satellite images,

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{Band\ 4} + \boldsymbol{Band\ 3})}{(\boldsymbol{Band\ 4} - \boldsymbol{Band\ 3})} \longrightarrow \boxed{2}$$

For Landsat 9 satellite images,

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{Band\ 5} + \boldsymbol{Band\ 4})}{(\boldsymbol{Band\ 5} - \boldsymbol{Band\ 4})} \longrightarrow \boxed{3}$$

Therefore, the Normalized Difference Built-up Index (NDBI) was used to validate the NDVI changes in the study area.

Normalized Difference Built-up Index (NDBI)

The NDBI is a remote sensing-derived index that assesses and quantifies the extent of built-up or urbanized areas within a given geographic region. It is calculated by using the normalized difference between the reflectance values in specific spectral bands associated with built-up surfaces, typically in the shortwave infrared (SWIR) and near-infrared (NIR) regions of the electromagnetic spectrum.

The formula for NDBI is generally expressed as:

$$\boldsymbol{NDBI} = \frac{(\boldsymbol{NIR} + \boldsymbol{SWIR})}{(\boldsymbol{NIR} - \boldsymbol{SWIR})} \longrightarrow \boxed{4}$$

Where:

NIR is the reflectance in the near-infrared band

SWIR is the reflectance in the shortwave infrared band

3. Results and Analysis

3.1 Analysis of Normalized Difference Vegetation Index (NDVI)

The NDVI method is crucial for assessing changes in vegetation density in Harispattuwa DS Division between 1997, 2009, and 2022. This analysis provides insights into shifts in vegetation health and cover over the specified timeframe, shedding light on the environmental changes occurring in the study area. NDVI, as described by Fusami et al. (2020), is a ratio that compares how much red light a surface absorbs to how much near-infrared light it reflects. In essence, it quantifies this relationship through a mathematical ratio.

Furthermore, Fusami et al. (2020) explained that negative values typically indicate water bodies, rocky terrain, or man-made structures, while bare land typically falls between 0.1 and 0.2. Healthy plants have positive values from 0.2 to 1, with dense vegetation above 0.5 and sparse vegetation from 0.2 to 0.5. In general, NDVI values of 0.2 to 0.4 indicate sparse vegetation, 0.4 to 0.6 suggest moderate coverage, and anything over 0.6 indicates the highest possible green density.

Table 2: Suitable NDVI value ranges identified for the land

Class	NDVI Ranges
Water	-0.28-0.015
Built-up	0.015-0.14
Barren Land	0.14-0.18
Shrubs and Grassland	0.18-0.27
Sparse Vegetation	0.27-0.36
Dense Vegetation	0.36-0.74

Source: Tahir Ali Akbar et al. (2019)

3.1.1 1997 NDVI of the Harispattuwa DS Division

The 1997 NDVI map offers a unique perspective on the extent and health of vegetation cover in Harispattuwa nearly three decades ago. The extracted NDVI data is visually represented in Figure 2. The NDVI map shows the state of the vegetation using a color scale. Dark green to different pink and red shades are in this color range. Areas displayed in dark green on the map correspond to high NDVI values, typically ranging from 0.36-0. 74. Light green sections of the map represent Sparse Vegetation values, typically between 0.27-0.36. These areas indicate moderate vegetation cover, which may consist of semi-arid landscapes, agricultural fields in varying conditions, or mixed vegetation. Lemongrass-colored areas typically have NDVI values between 0.18 and 0.27, suggesting Shrubs and Grassland. Red and pink areas exhibit NDVI values between 0.015 and 0.18, indicating non-vegetated or barren land and built-up areas. NDVI values below 0.015 indicate the water bodies.

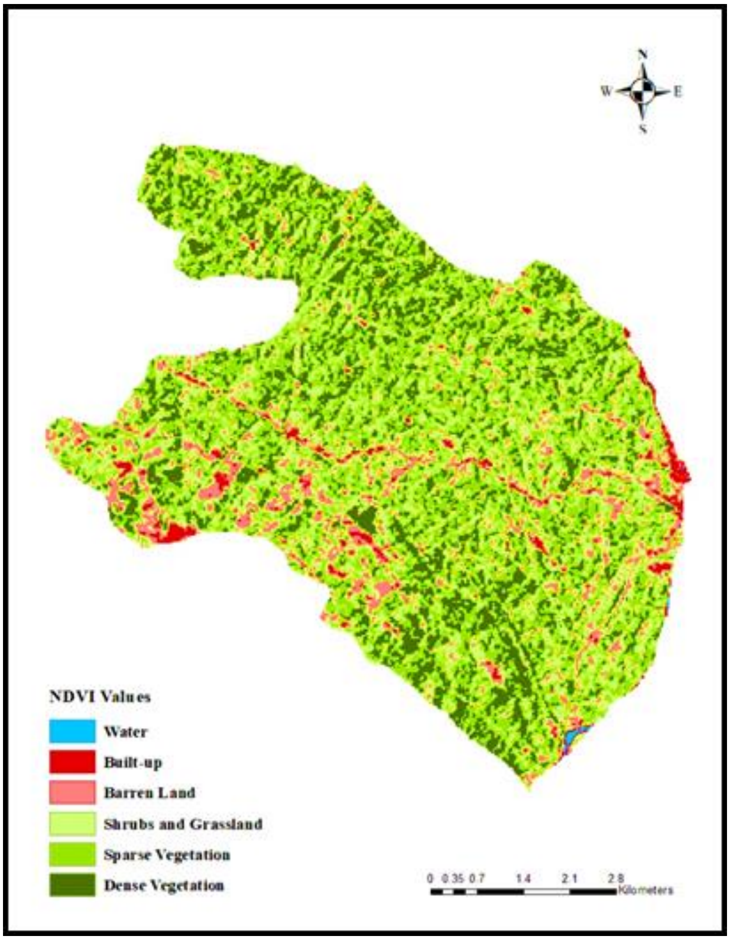


Figure 2: 1997 NDVI Map of Harispattuwa DS Division

The Northern part of the Harispattuwa DS Division was primarily bright green and light green on the 1997 NDVI map, indicating healthy and moderate vegetation. This area included forest areas, fields, and grasslands. Unvegetated or degraded parts are indicated by noticeable patches of red and pink in the division's center. These may be the areas that have been recently developed. When moving Southward, it indicates a variety of vegetation conditions. This could point to a mix of farming, natural vegetation, and perhaps localized stresses. This could be the result of elements like seasonal variations, soil qualities, or minor environmental stress. In the year 1997, the Harispattuwa DS Division covered less than 1% of water bodies, which is 0.486 km² of the total area, and the Built-up area covered 9.27 km², which is 2 % of the total area. Further, barren land covered 49.572 km², which is 10 % of the total area. Shrubs and Grasslands make up a substantial portion of the study area, covering around 126.153 km² (25% of the total area). A significant portion of the Study area, approximately 203.634 km² (40% of the total area), is dominated by sparse vegetation. Furthermore, dense vegetation covered 109.98 km², which is 22 % of the total area.

In 1997 substantial area of the Harispattuwa DS Division was covered by vegetation, accounting for 87% of its total land area. And 13% of land is covered by non-vegetation areas (Table 3). The 1997 NDVI map of Harispattuwa DS Division provides a clear description of the vegetation health and distribution within the areas during that specific year. It offers insights into the condition of the local environment, helping us understand the dynamics of vegetation cover. This map serves as a valuable reference point for tracking changes in land use, vegetation cover, and the impact of human activities over time.

3.1.2 The 2009 NDVI of the Harispattuwa DSD

A clear distinction can be observed between the 2009 NDVI map and the one from 1997, highlighting substantial changes in vegetation cover. The extracted NDVI data is visually represented in Figure 3. In the 2009 NDVI map of the Harispattuwa DS Division, the Northern areas predominantly exhibit shades of green, representing dense and sparse vegetation cover. These areas encompass lush forests, well-maintained agricultural fields, and thriving grasslands. When moving towards the central part of the division, patches of red and pink, indicative of areas with limited vegetation can be observed, and in the East part, a significant portion of the landscape is characterized by built-up areas and barren land.

These zones might correspond to urban developments or areas vulnerable to environmental degradation. Additionally, the Southern areas exhibited a combination of vegetation and built-up areas. There is a significant difference between the NDVI maps of 2009 and 1998, indicating notable changes in vegetation over the years (Table 3). Between 1997 and 2009, the land cover in the Harispattuwa DS Division underwent significant changes. In 1997, the division's landscape was characterized by a diverse composition. Towards 2009, the division's land cover distribution exhibited remarkable transformations. Water bodies remained below 1%, covering 0.441 km². However, the built-up area expanded significantly to 16.767 km², representing 3% of the division's total land area. Barren land extended further, now accounting for 16% of the area’s total area, covering 83.115 km². Shrubs and grasslands continued to occupy a substantial portion, comprising 23% of the total area or approximately 113.922 km². Sparse vegetation remained significant, covering 36% of the landscape with a total of 181.71 km². On the other hand, dense vegetation accounted for 21% of the land area, totaling up to 103.14 km².

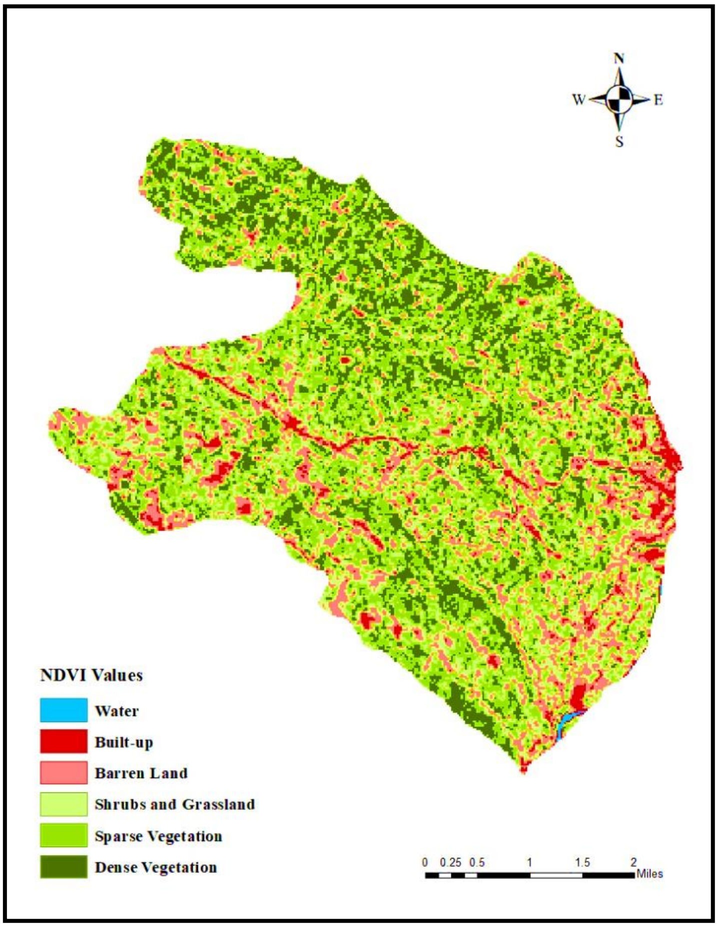


Figure 3: 2009 NDVI Map of Harispattuwa DSD

Finally, in 2009, the Harispattuwa DS Division featured an extensive coverage of vegetation, constituting a substantial 80% of its total land area, while the remaining 20% was comprised of non-vegetated areas. These changes which took place over the twelve years from 1997 to 2009 indicate shifts in land use and vegetation patterns within the Harispattuwa DS Division, with notable increases in built-up areas and barren land, while the extent of dense vegetation decreased.

3.1.3 The 2022 NDVI of the Harispattuwa DS Division

The 2022 NDVI map will provide critical information about the current distribution and condition of vegetation in the area, to better understand the ecological dynamics at play. NDVI data from 1997 revealed the extent and health of vegetation at that time, showcasing the division's natural and human-induced changes over the years. Moving forward to 2009, we observed notable changes in land cover distribution, including an expansion of built-up areas, increased barren land coverage, and shifts in vegetation patterns. By examining the 2022 NDVI map alongside the data from 1997 and 2009, we can gain a comprehensive understanding of how this area's vegetation has evolved and adapted over time. Transitioning to the year 2022, the Harispattuwa DS Division's land cover distribution underwent substantial transformations (Figure 4). Firstly, water bodies continued to occupy a minimal portion, constituting less than 1% of the division's total area, which equated to 0.702 km². The most noticeable change occurred in the expansion of built-up areas, which surged to encompass a significant 27.225 km², now constituting 5% of the division's total land area. Barren land saw a substantial increase in coverage, extending across a vast 116.451km², now accounting for a sizable 23% of the total area.

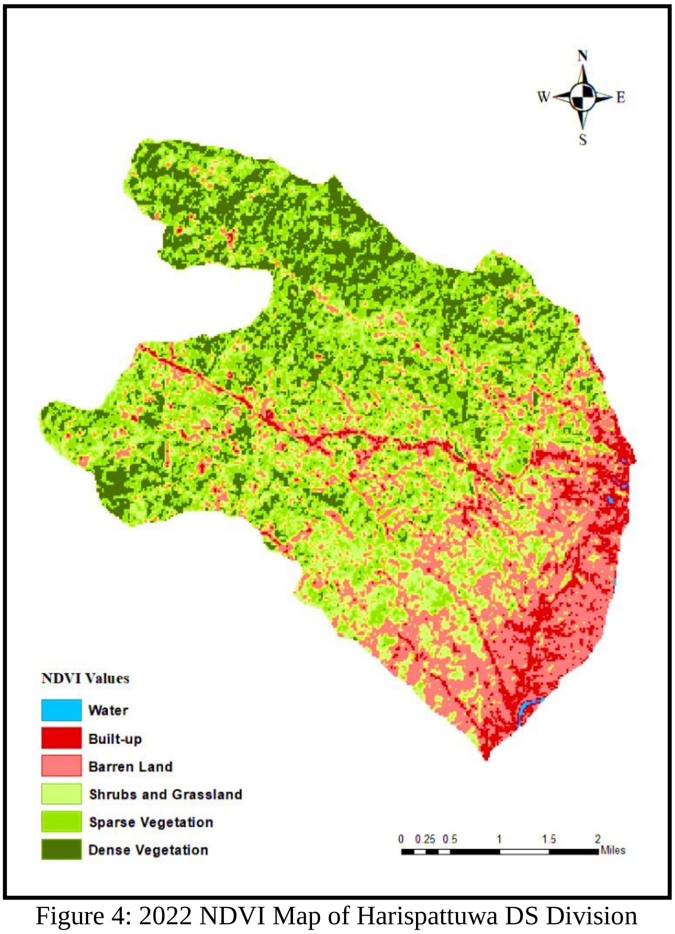


Figure 4: 2022 NDVI Map of Harispattuwa DS Division

Meanwhile, Shrubs and grasslands remained a substantial component of the landscape, covering approximately 115.938km², which represented 23% of the division's total area. Sparse vegetation, while still significant, comprised 30% of the division's landscape, totalling to 151.074km². The presence of this category indicated areas with less dense but still viable vegetation. In contrast, dense vegetation experienced a reduction in coverage, occupying 87.705km², or 18% of the total area. In summary, the vegetation cover in Harispattuwa DS Division has undergone significant changes when compared to the years 1997, 2009, and 2022. In 1997, the division exhibited a diverse landscape with substantial vegetation covering 87% of the total land area. By 2009, there were notable shifts, including an expansion of built-up areas, increased barren land, and changes in vegetation patterns.

In 2022, these trends had evolved further, with potential implications for land use, urbanization, and the environment. These changes underscore the dynamic nature of the area and emphasize the importance of ongoing monitoring and sustainable land management practices to preserve and protect the unique ecosystem of Harispattuwa Division.

Table 3: Distribution of NDVI values in Harispattuwa DSD in 2022

Class	**NDVI Value Ranges**	**Area (sq Km) 1997**	**Area (sq Km) 2009**	**Area (sq Km) 2022**
Water	-0.28-0.015	0.486	0.441	0.702
Built-up	0.015-0.14	9.27	16.767	27.225
Barren Land	0.14-0.18	49.572	83.115	116.451
Shrubs / Grassland	0.18-0.27	126.153	113.922	115.938
Sparse Vegetation	0.27-0.36	203.634	181.71	151.074
Dense Vegetation	0.36-0.74	109.98	103.14	87.705

Over the years, the Harispattuwa DS Division has undergone significant transformations in its vegetation cover, as evidenced by the data from 1997, 2009, and 2022. In 1997, the division displayed a relatively balanced landscape with substantial coverage of natural elements. Water bodies covered 0.486 km², signifying the presence of natural water sources. Built-up areas accounted for 9.27 km², indicating the initiation of urban development. However, it was the expansive coverage of barren land at 49.572 km², along with the vast expanse of shrubs and grasslands totalling 126.153 km², which defined the division's character. Sparse vegetation dominated a significant portion, encompassing approximately 203.634 km², while dense vegetation added to the lushness, covering 109.98 km². This composition changed notably by 2009, with urbanization and infrastructure expansion driving the growth of built-up areas to 16.767 km² and barren land to 83.115 km². Shrubs and grasslands remained a significant portion at 113.922 km², but the extent of dense vegetation decreased to 103.14 km², indicating shifts in the ecological balance.

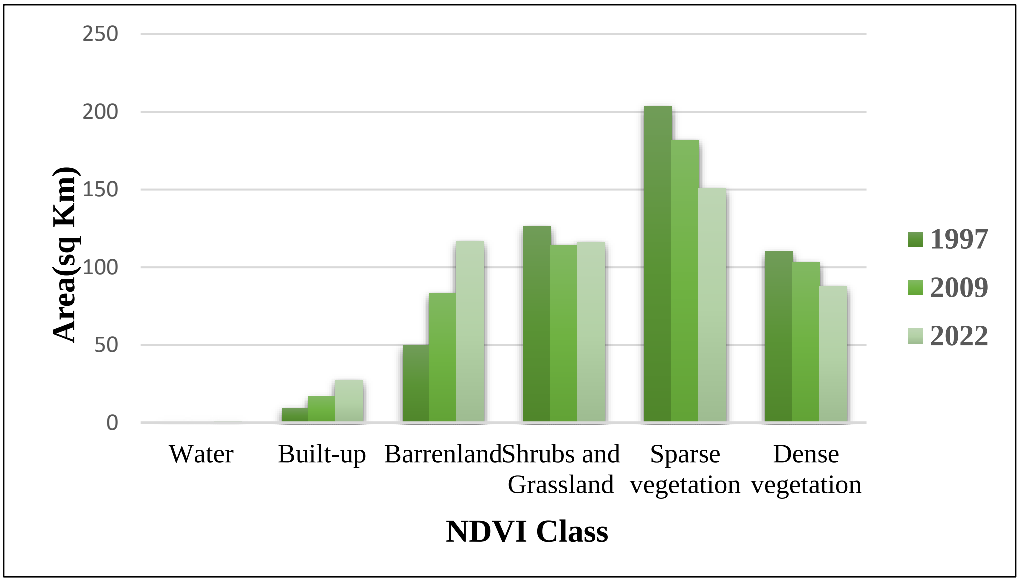
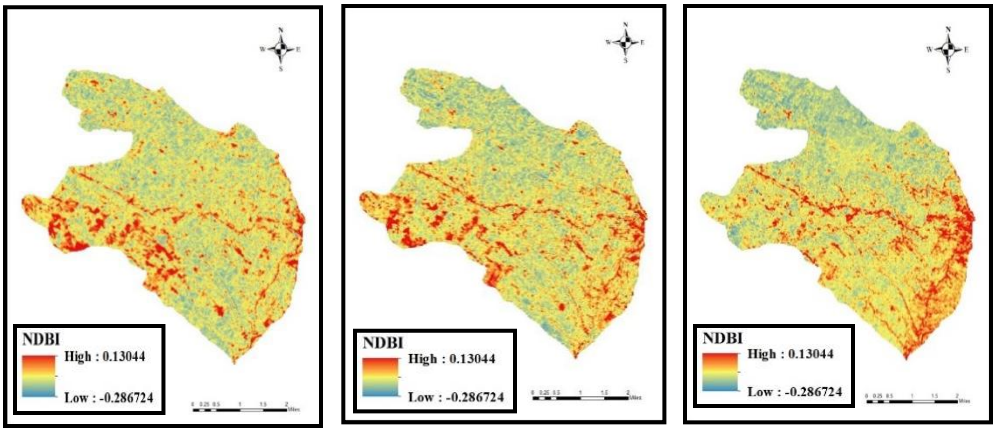


Figure 5: Distribution of NDVI Class ranges in 1997, 2009 and 2022

Moving forward to 2022, the division continued to experience urban growth, with built-up areas expanding to 27.225 km². The trend of barren land expansion continued, reaching 116.451 km², potentially driven by changes in land use or natural processes. Shrubs and grasslands remained relatively stable at 115.938 km², but sparse vegetation decreased to 151.074 km², and dense vegetation further diminished to 87.705 km² (Figure 5). These changes collectively reflect the dynamic interplay of urbanization, land use practices, and natural factors shaping the Harispattuwa DS Division's evolving vegetation cover over the years. Understanding these dynamics is crucial for informed land management and conservation efforts in the area.

NDBI is valuable in monitoring urban expansion, land-use changes, and the impact of human activities on the landscape. It is often employed alongside other indices like NDVI (Normalized Difference Vegetation Index) to provide a more comprehensive analysis of land cover dynamics in a study area (Figure 6).



(a) **(b)** **(c)**

Figure 6: 1997, 2009 and 2022 NDBI map of study area

The resulting NDBI values range from -1 to 1, with higher values indicating a higher proportion of built-up or impervious surfaces. A positive NDBI value suggests the presence of urbanized areas, while a negative value indicates the dominance of natural features or non-built-up land cover.

4. Conclusion

The Harispattuwa DS Division in Sri Lanka was thoroughly analyzed, focusing on its geographic and climatic characteristics, as well as vegetation cover changes over the years. The study area is characterized by diverse topographical features, hilly terrain, and significant vegetation cover, with 87% of its land area covered by vegetation in 1997. The analysis of the NDVI revealed notable changes in vegetation patterns over time. In 2009, there was a significant expansion of built-up areas and increased barren land coverage. By 2022, urbanization and land use changes had intensified, with a further expansion of built-up areas and barren land. These changes reflected the dynamic nature of the region and underscored the importance of ongoing monitoring and sustainable land management practices to preserve and protect the unique ecosystem of the Harispattuwa DS Division.

The use of satellite imagery, image cropping, and NDVI calculations allowed for a comprehensive assessment of the vegetation cover changes over 25 years. Band composite images provided visual and analytical evidence of these changes, with a particular focus on the impact of urbanization. This comprehensive analysis contributes to our understanding of how natural and human-induced factors influence land cover dynamics in Harispattuwa and highlights the need for informed land management and conservation efforts in the area. In conclusion, the study provides valuable insights into the evolving landscape of the Harispattuwa DS Division, emphasizing the importance of sustainable development and conservation practices to maintain the ecological balance of this unique region.

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