Analysis of Agricultural and Plantation Land Use Changes Using Spatial and Temporal Data in Deraniyagala and Dehiowita DS Divisions in Sri Lanka

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ABSTRACT

Comprehending the dynamics of land use, particularly in agricultural and plantation sectors, has become increasingly vital for ecological sustainability. This research provides an overview of changes in farming and plantation land use in the Deraniyagala and Dehiowita DS divisions of Sri Lanka over the past decade, analyzing remote sensing data from different time periods. This study evaluates urban growth and vegetation, water, and hydric resources within the area using the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Built-up Index (NDBI). The results reveal contrasting trends: Deraniyagala showed greater urban and environmental strain, coupled with declining vegetation and surface moisture levels, whereas Dehiowita demonstrated comparatively more stable ecological conditions, indicating more sustainable land use. Shifts in crop cultivation patterns demonstrated a pivot of traditional plantation crops, including tea and rubber, towards alternative crops such as coffee and pepper, reflecting demographic pressures and evolving land management practices. This study highlights the potential of remote sensing to capture fine-scale environmental dynamics and facilitate spatial analysis, underscoring the urgent need for integrated strategies in land and water resource management, along with evidence-based spatial planning approaches, to foster sustainable ecological and rural development in environmentally sensitive areas.

Keywords— Land use changes; Satellite imagery; Commercial crop cultivation; NDVI; NDWI; NDBI

INTRODUCTION

Land use changes provide a specific component for determining the environmental dynamic influence on ecological sustainability, economic development, and social well-being [1]. Due to population density, economic activities, and intensive natural and landscape changes, transformational environmental impacts are occurring. Globally, the land use changes in agricultural expansion and infrastructure development affect almost 62% of the global land area [2]. In the long-term assessment, the impact is greater due to changes in land use. Geographical divergence, land-use changes, afforestation, and global north cropland abandonment are evident. However, the southern regions are increasing their agricultural land use. Urban sprawl has also accelerated, with the United Nations projecting that more than 68% of the world's population will be in urban areas by 2050, leading to agricultural pressure for loss of biodiversity and climate change due to increased greenhouse gas emissions, altered hydrological cycles, and ecosystem services [3].

The historical Sri Lankan economy depended heavily on agriculture, especially on plantation crops like tea and rubber [4]. Coconut and spice cultivation are mainly found in the central and southwestern regions. The plantation sector significantly changed land cover, leading to the conversion of forests into cultivated farmland over many years [5]. Kegalle district, Dehiowita, and Deraniyagala DS divisions are chosen based on population density and crop type distribution in the area. The Deraniyagala and Dehiowita regions are characterized by lush forests and hilly terrain, and they have experienced fluctuations in forest cover due to land conversion to agriculture and settlement growth. Likewise, Dehiowita has faced pressures from suburban development and the depletion of its water resources.

Satellite-based remote sensing technologies have transformed the ability to monitor land use changes over

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large areas and over time [6]. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI) have become essential tools for detecting shifts in vegetation cover and water bodies, respectively [1]. These indices allow researchers to quantify and visualize vegetation pattern changes over time and space, offering important insights into how land use changes under various human influences [7]. The current study aimed to identify land use changes by examining spatial and temporal variations in satellite-derived data, specifically in planting areas [4]. Data from the Sri Lanka Census Department was used to identify specific plantations and land use types across the Dehiowita and Deraniyagala Divisional Secretariats in the Kegalle District. This research addresses gaps in understanding the spatial and temporal dynamics of land use in the Dehiowita and Deraniyagala Divisional Secretariats in Sri Lanka. It aims to support local planning and management efforts by developing a methodological framework that uses remote sensing indices for detailed land cover analysis, tailored for GIS technologies [8]. Finally, by comparing local findings with global trends, this research highlights both universal patterns and local factors that shape land-use change.

METHODOLOGY

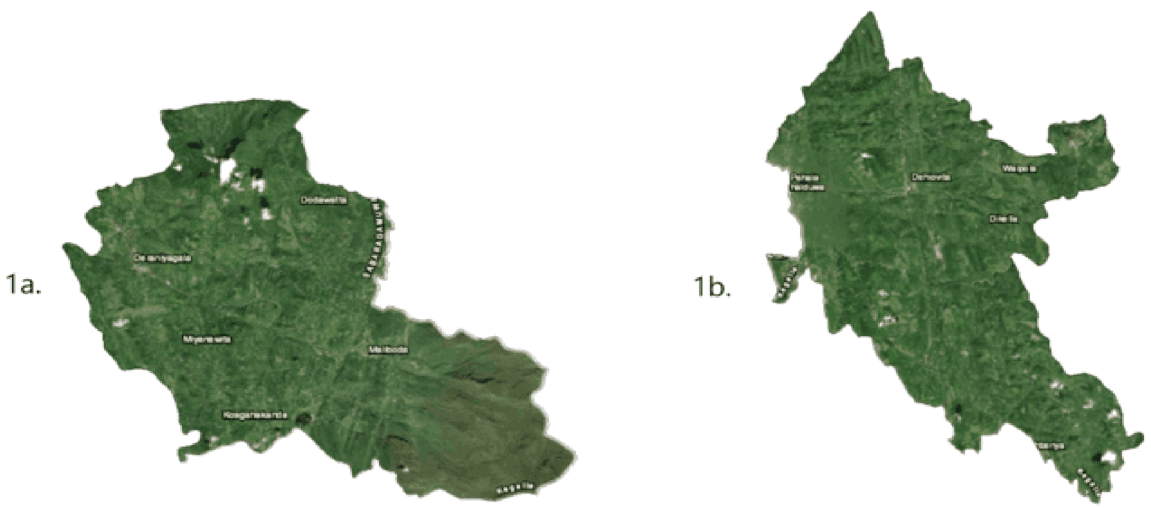
Study Site

The experimental site, Deraniyagala and Dehiowita, was selected under the population density distribution in the Deraniyagala and Dehiowita Divisional Secretary in Kegalle District [9].

Table 01: Population density details of Dehiowita and Deraniyagala DS Divisions [9]

Population Density			
	D.S. Division 1/	**Rural Human Population**	**Estate Human Population**
2024	Dehiowita	72850	13445
	Deraniyagala	37871	10807
2019	Dehiowita	72149	13135
	Deraniyagala	37507	10730
2014	Dehiowita	68924	12720
	Deraniyagala	35830	10224

Figure 1: Selected site maps:(a) Deraniyagala DS Division; (b) Dehiowita DS Division.



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Spatial Analysis in NDVI, NDWI, and NDBI: point-based analysis.

Analysis of the spatial variation of the land use pattern changes by achieving the objective of further examining the built-up areas, vegetation cover, and water cover using ArcGIS software version 10.8, and is used to analyze the data and collected data sets [10].

Normalized Different Water Indexes (NDWI)

Water indices were obtained to determine the influence of water bodies. The NDWI development was produced using the Landsat NIR Band–6 and green band–3 for analysis [11].

$$\mathrm{NDWI} = \frac{(\mathrm{Green\ Band}(3) - \mathrm{NIR\ Band}(6)}{(\mathrm{Green\ Band}(3) + \mathrm{NIR\ Band}(6)} \quad (2.1)$$

Normalized Difference Vegetation Index (NDVI)

Vegetation indices were calculated to determine the influence of vegetation changes. NDVI was calculated using the Landsat 05 NIR band-3 and the red band–04. An Infrared spectral (IR) 5 Band with Land 8 OIL (TIRS) Red band 4 makeup was modified to the NDVI analysis [7].

$$\mathrm{NDVI(Land\ Sat\ 08)} = \frac{(\mathrm{IR\ Band}(5) - \mathrm{R\ Band}(4)}{(\mathrm{IR\ Band}(5) + \mathrm{R\ Band}(4)} \quad (2.2)$$

Normalized Different Built-up Indexes (NDBI)

Built-up indices were derived to characterize the distribution of built-up areas around the study sites, as well as NDBI variables that influence the assessment of the UHI effect. NDBI development procedure based on the SWIR band-6 and NIR band-5 was used to determine build-up areas [12].

$$\mathrm{NDBI} = \frac{(\mathrm{SWIR\ Band}(6) - \mathrm{NIR\ Band}(5)}{(\mathrm{SWIR\ Band}(6) + \mathrm{NIR\ Band}(5)} \quad (2.3)$$

Plantation temporal data analysis

Data collected by the Department of Census and Statistics from 2014 to 2024 were used to determine land-use changes under crop cultivation in the Deraniyagala and Dehiowita DS divisions. Population distribution data were also used to determine land-use and land-cover changes during this study.

Statistical analysis

Stratified sampling (fish net sampling) was used to extract spatial values in ArcGIS 10.8 to determine NDVI, NDWI, and NDWI change in the Deraniyagala and Dehiowita DS Divisions. Collected data from the ArcGIS software was analyzed using IBM SPSS (Version 25) software [1]

RESULTS AND DISCUSSION

Spatial Land use Change analysis (NDVI, NDWI, and NDBI)

Normalized Difference Vegetation Index Analysis

Deraniyagala vegetation status data show that mean values for 2014, 2019, and 2024 are -0.1988, -0.2130, and -0.2148, respectively (Figure 3.2). The slight decline in means suggests a marginal decrease in vegetation vitality or cover. The range from 0.574 to 0.555 is significant, with the maximum value slightly increasing over the years. The total sums indicate an increase in vegetation measures, possibly reflecting higher density or biomass in some areas. The Dehiowita site shows consistent positive trends, with values rising from just above zero to higher levels, indicating improvement in vegetation conditions. The range within Dehiowita remains stable, with maximum values likely representing localized patches of denser or healthier vegetation, and the total values indicate an increase in

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vegetative biomass or coverage. The study compared vegetation conditions between the two sites, Deraniyagala and Dehiowita. Deraniyagala shows a slight decline in vegetation conditions over the past decade, indicating degradation, and Dehiowita exhibits consistent increases, suggesting improvement with stable conditions. The negative average values in Deraniyagala indicate environmental stress, whereas the positive trend in Dehiowita suggests successful conservation or improved land management. The results are consistent across measurements.

Figure 3.1: Normalized Difference Vegetation Index Analysis Results in Dehiowita (A) and Deraniyagala (B) DS Divisions 2014 – 2024.

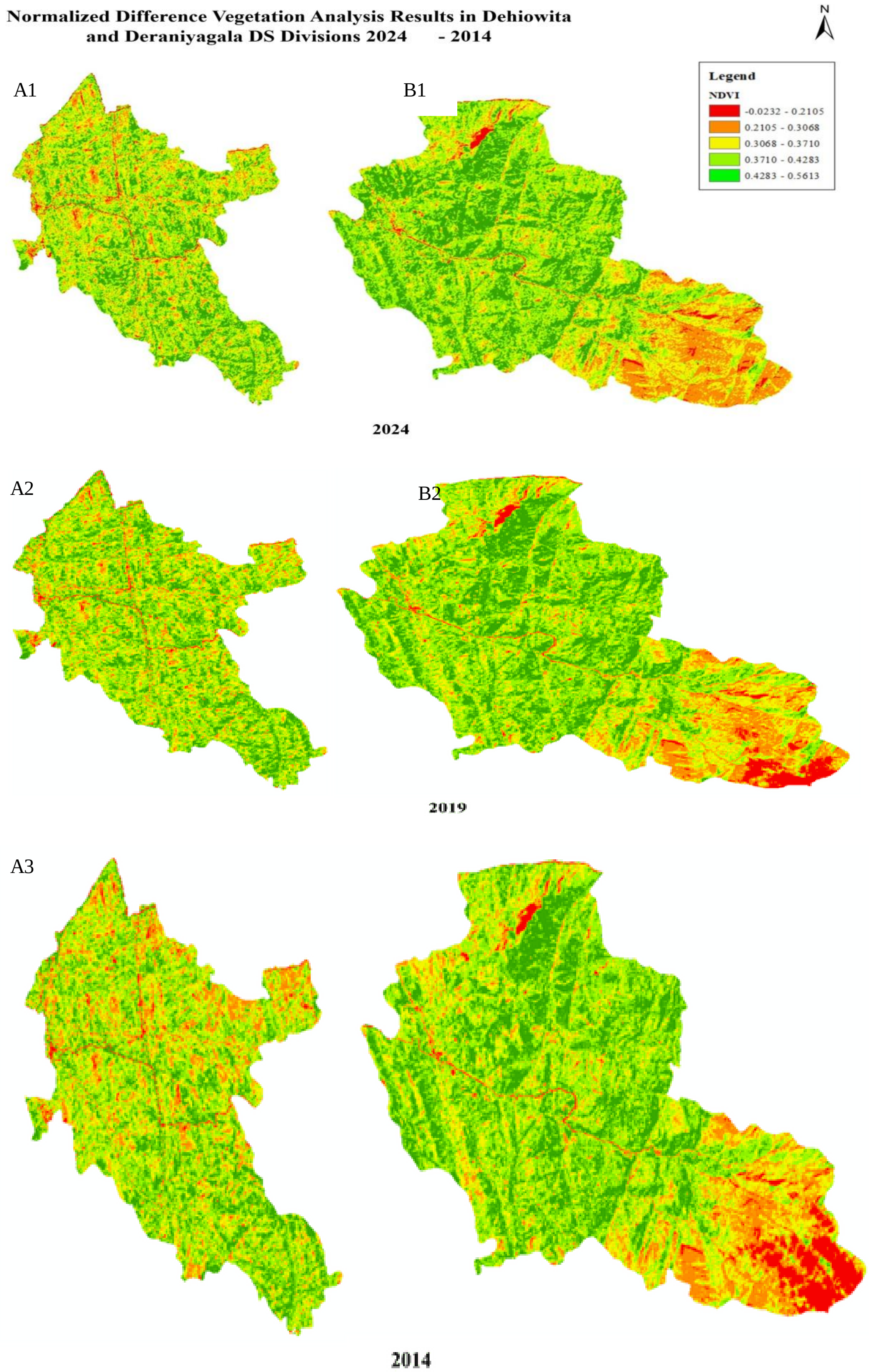

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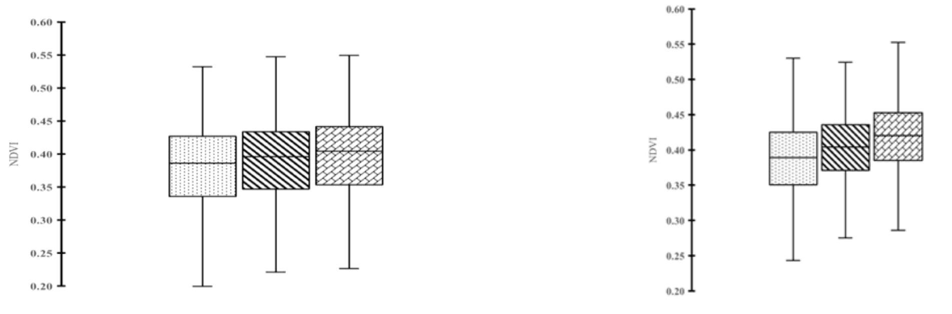
Figure 3.2: Descriptive statistics results in NDVI values, Dehiowita (B) and Deraniyagala (A) DS Division 2014–2024



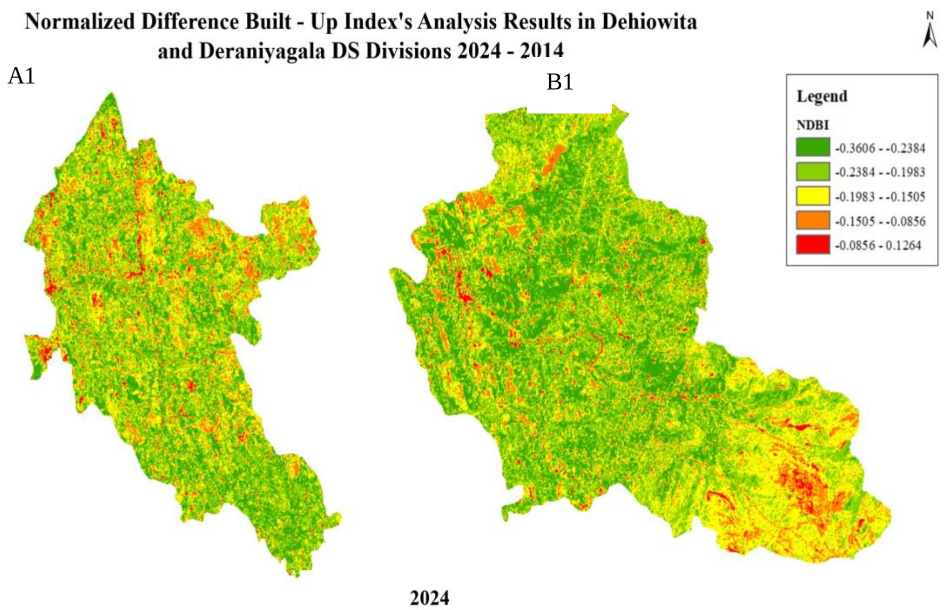
A B

Normalized Difference Build–Up Index Analysis

The Deraniyagala dataset shows a steady increase in the mean build-up index over the past decade, indicating gradual urbanization. The mean index has risen from 0.3724 to 0.3929, suggesting that urbanization is driven by infrastructure development, population growth, or land-use changes. The mean and standard deviation are low, indicating high precision in the estimates. The median values closely match the means, and the range and extremes are slightly higher. The total build-up index increased from 486.3 to 513.5, confirming the trend of urban growth.

The mean value of -0.15 to -0.25 at the Dehiowita site has decreased by 0.035-0.036 units, suggesting a reduction in built-up areas. Data distribution is centered on negative values, with most areas remaining less developed. The range is 0.3679 to 0.4243, indicating that some areas have undergone more significant development. The total build-up value has increased from 486.3 to 513.5, possibly reflecting land use reclassification rather than strictly growth. The study reveals a significant difference between the two urbanization sites, Deraniyagala and Dehiowita, which shows a steady increase in the build-up index over the decade, indicating expanding urbanization or infrastructure development. This could be driven by economic growth, population influx, or land-use policies favoring development. Dehiowita exhibits a decreasing or stagnant build-up index, with more negative mean values over time. Both sites show large portions of their datasets with zero values. This probably means significant parts lack development or are in the early stages of urbanization [10]. The positive shift in Deraniyagala suggests more extensive development activities or urban sprawl, while the relative decline in Dehiowita suggests stabilization or reduction in urban built-up zones.

Figure 3.3: Normalized Difference Build–Up Index Analysis Results in Dehiowita (A) and Deraniyagala (B) DS Divisions 2014 – 2024.



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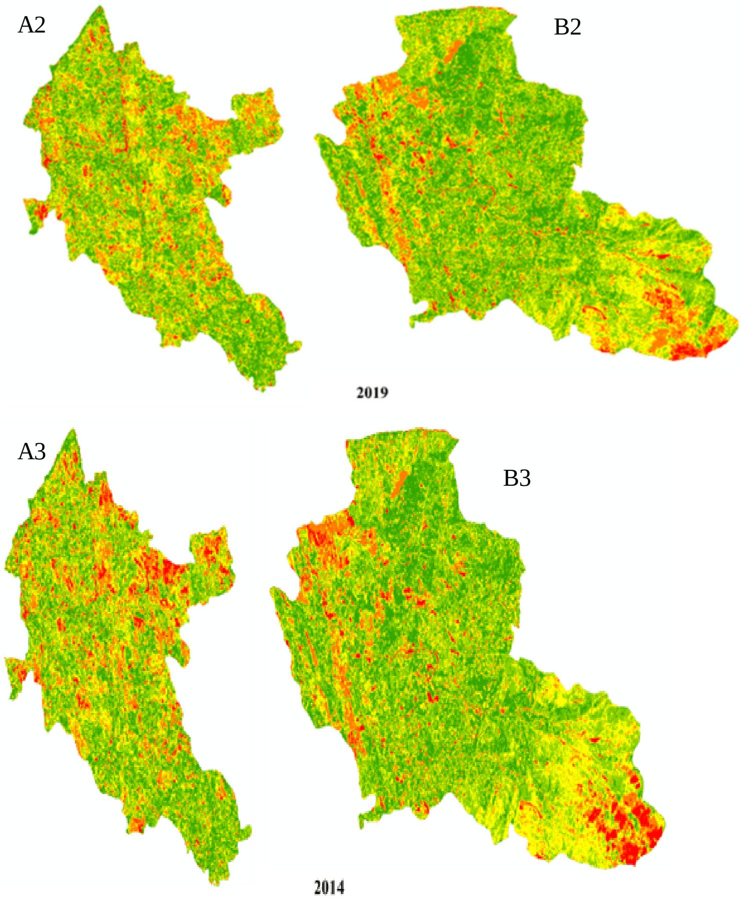
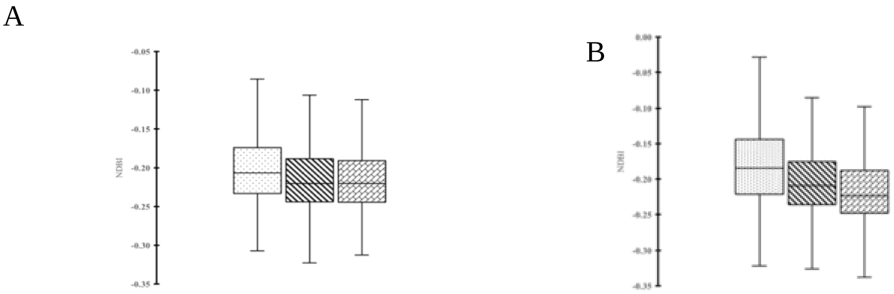


Figure 3.4: Descriptive statistics results in NDBI values, Deraniyagala (A) and Dehiowita (B) DS Division 2014 – 2024



Normalized Difference Water Indexes Analysis

The study reveals a decline in water and moisture conditions in Deraniyagala over the past decade. The mean NDWI values are negative, indicating sparse or low moisture content in water bodies or moist areas. The NDWI range varies, indicating low or negligible water presence. The total water/moisture presence increases from -259.7 to -281.3, indicating a general reduction in water coverage. The dataset in Dehiowita shows a slightly less negative or neutral NDWI value over the past decade, fluctuating between -0.16 and -0.15. Over the same period, the NDWI has increased slightly, indicating a marginal improvement or stabilization. The data is consistent with slight fluctuations, suggesting stable moisture conditions. The NDWI range varies, with the minimum indicating low moisture zones and the maximum indicating occasional water or moisture-rich patches. The total water presence is negative but decreasing over time.

The study reveals contrasting water resource dynamics in two sites, Deraniyagala and Dehiowita. A gradual decline in NDWI values in Deraniyagala suggests a decrease in water bodies or moisture content, possibly due to climate-induced drying trends, water extraction, land-use change, or natural evaporation. Dehiowita shows a slightly improving or stable moisture condition, suggesting better management or natural resilience. Both sites maintain a mode at zero, implying many areas are dry or lack water features. The decline in NDWI in Deraniyagala could

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reflect environmental stress, while Dehiowita may be better managed or more resilient to water fluctuation. Understanding of these trends is crucial for strategic planning, sustainable water resource management, and ecological conservation. The findings highlight the complex interactions between climate, land use, and environmental policies that influence water and moisture [13]. The data in the tables provide a comprehensive overview of crop cultivation and population density across 2014, 2019, and 2024 for the D.S. Division, highlighting significant land-use changes, particularly in the context of highland crop statistics and population dynamics.

Figure 3.5: Normalized Difference Water Indexes Analysis Results in Dehiowita (A) and Deraniyagala (B)DS Divisions 2014 – 2024.

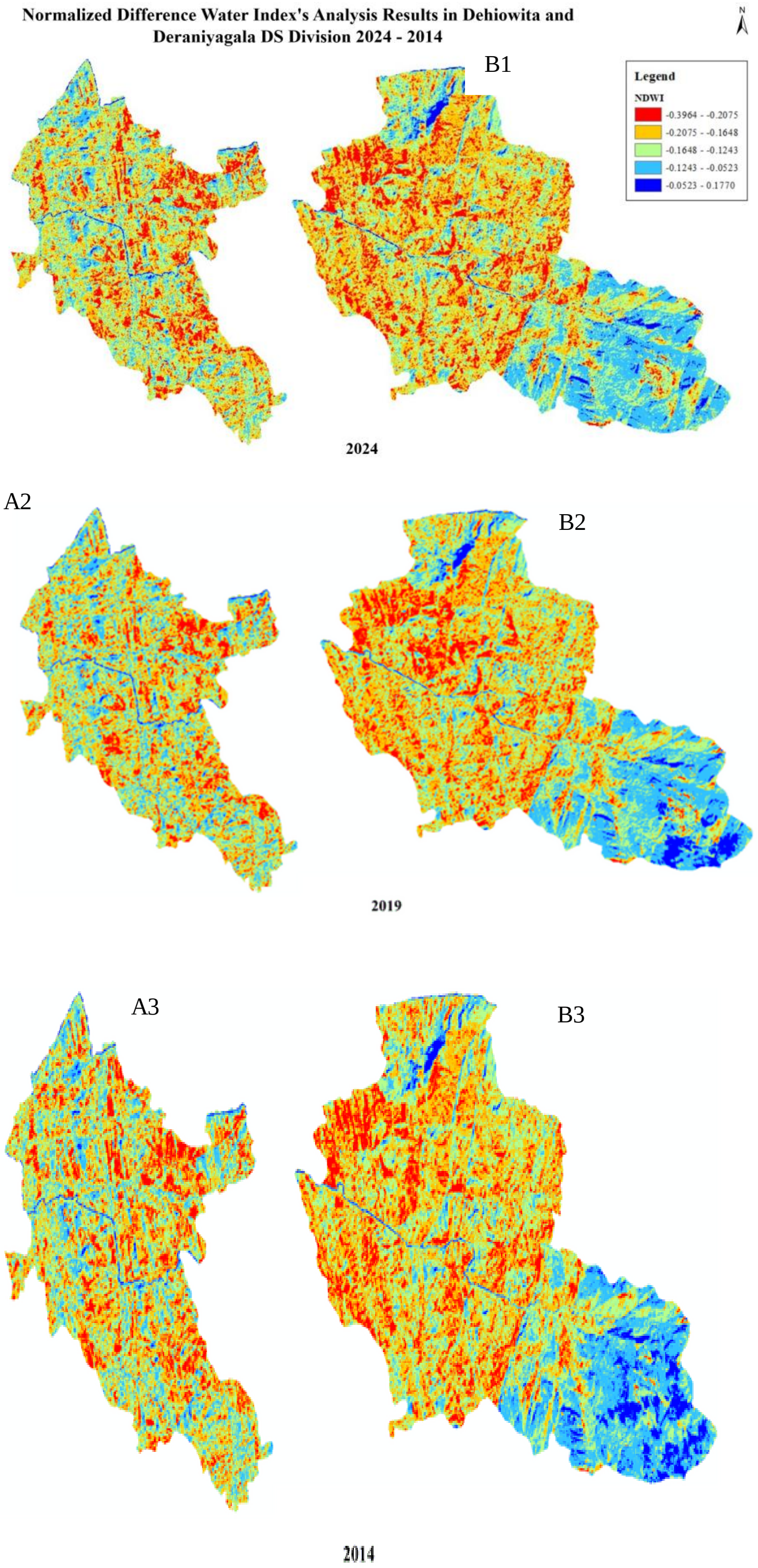

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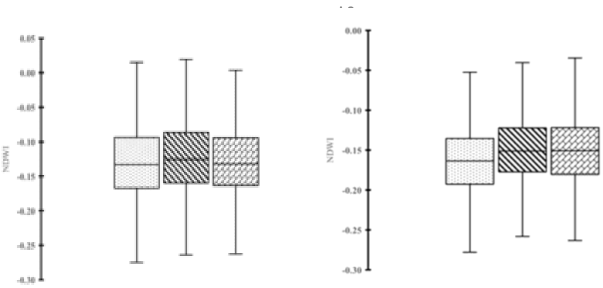
Figure 3.6: Descriptive statistics results in NDWI values, Deraniyagala (A) and Dehiowita (B)DS Division 2014 – 2024

A B



Crop cultivation distribution analysis for Dehiowita and Deraniyagala DS Divisions

Figure 3.7: Crop distribution analysis in Dehiowita (B) and Deraniyagala (A) DS Divisions in hectares in 2014

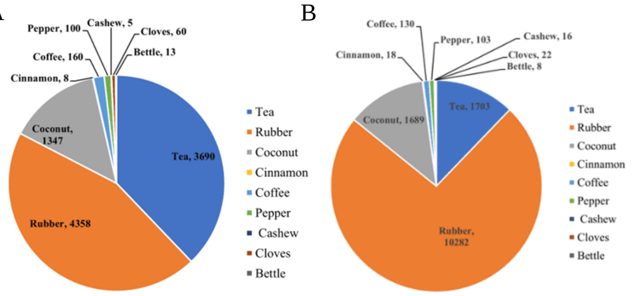


Figure 3.8: Crop distribution analysis in Dehiowita (B) and Deraniyagala (A) DS Divisions in hectares in 2019

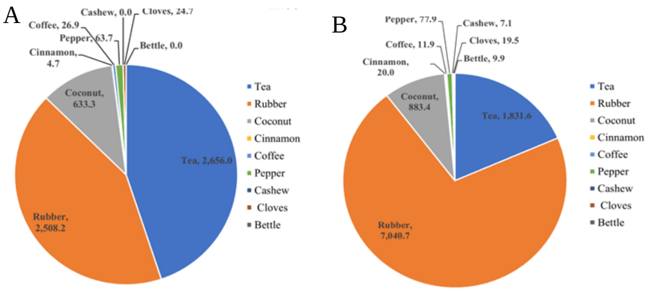
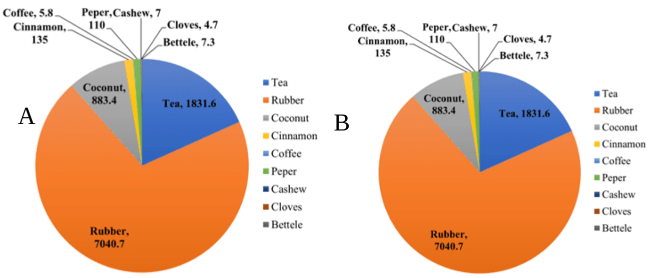


Figure 3.9: Crop distribution analysis in Dehiowita (B) and Deraniyagala (A) DS Divisions in hectares in 2024



Initially, examining data from 2014 shows that the total cultivated land area for key crops was relatively modest, with tea, rubber, coconut, cinnamon, coffee, pepper, cashew, and cloves occupying specific areas (Figures 3.7, 3.8, 3.9). The tea cultivation stood at 1,703 hectares, rubber at 10,282 hectares, coconut at 1,689 hectares, cinnamon at 18 hectares, coffee at 130 hectares, pepper at 103 hectares, cashew at 16 hectares, and cloves at 22 hectares in Dehiowita. During this period, the population density was relatively low, with a rural human population of 68,924 and an estate human population of 12,720. This indicates a landscape where agricultural activities, especially rubber cultivation, appeared to dominate land use, potentially reflecting economic reliance on rubber estates and traditional crop farming practices.

Based on the data from the 2014-2019 period, tea and rubber increased noticeably. The tea cultivation in Dehiowita has increased from 1703 to 1831.6 hectares, and rubber expanded more than 3,000 hectares in a short period. Coconut cultivation followed a similar trend, and cinnamon, coffee, pepper, cashew, and clove showed stabilized conditions, but cinnamon showed a decreasing trend. Coffee increased significantly to 11.9 hectares, and pepper to 7.1 hectares. The primary agricultural land use may be driven by rubber and tea plantations, which offer short-term economic incentives and profitability, or by government policies that support crop cultivation. The rural population in 2018 increased to 72,149, and the estate population reached 13,135. In Dehiowita, population density contributed to changes in land-use patterns. Densely populated areas require more agricultural land to be occupied by high-tech, intensive production systems to meet demand for food and other crops, which are often associated with commercial agriculture. Reaching the land area occupied for food crop cultivation further expanded with tea (1631.6 hectares in 2019 to 1831.6 hectares in 2023), rubber (7040.7 hectare to 2508.2) continues dominance agricultural land use but reaching the 2023 Rubber plantation lands in Dehiowita DS Division decreased more than 3000 hectares showing a highlight of the change of agricultural land use pattern shifting towards other plantations, like coffee and pepper. The parallel increase of crop cultivation and population density indicates an ongoing trend of land use adapted to demographic changes and economic pressures. As population density increases in rural regions, cultivated lands are increasingly pressured to meet food security and financial demands, driving a shift toward the commercialization and monetization of resources in response to market forces. The cultivation transformation to Dehiowita and Deraniyagala DS divisions leads to changes in environmental concerns, such as vegetation cover loss and the loss of water bodies, which are impacted during land-use shifts under unplanned conditions.

Crop cultivation and population density align with the vegetation changes, and water bodies disrupt the ecological balance and diversity [14]. The shift towards cinnamon and coffee under large-scale monoculture plantations leads to soil erosion and reduced water quality due to the loss of dense vegetation cover at both sites [15]. This may lead to long-term sustainability challenges. These concerns underscore the importance of an integrated land-use and water-body management plan that considers population growth and agricultural productivity, fostering a resilient and sustainable rural landscape [16].

CONCLUSION

This study thoroughly examined land-use changes in agricultural and plantation areas within the Deraniyagala and Dehiowita DS Divisions in Sri Lanka, using spatial and temporal data supported by NDVI, NDWI, and NDBI indices. The findings reveal that the two regions have followed different trajectories over the past decade. An increase in built-up areas was observed, with Deraniyagala showing signs of urban pressure and environmental stress, as indicated by declining vegetation vitality and water availability reflected in negative trends in NDVI and NDWI. Conversely, Dehiowita demonstrates better vegetation cover and more stable moisture conditions, although slight declines in built-up areas might suggest reclassification or a status quo rather than new development. Examining crop cultivation over time, tea and rubber plantations appeared during periods of growth and declined before shifting toward coffee and pepper cultivation. These trends align with increasing rural and estate populations exerting pressure on land resources and prompting changes in agricultural practices. The results underscore the significance of local land use patterns, which are shaped by demographic, economic, and land management factors. Overall, this research underscores the value of analyzing remote sensing indices of land use change through spatial analysis to gain insights into these processes at the local level. These trends highlight the requirement for integrated land and water management strategies to support further development of agriculture, urban areas, and ecosystems.

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