Colombo Geographer

Journal of Colombo Geographer

NDVI-Based Assessment of the Relationship between Urban Lowland Areas and Green Space Changes for Sustainable Urban Development

De Alvis T.P.G.R.U[1]*and Vithanage P.G[1]

[1,] *Department of Geography, Faculty of Arts, University of Colombo, Colombo, Sri Lanka.*

Abstract

Normalized difference vegetation index (NDVI) is commonly applied for qualitative and quantitative estimation of vegetation cover and growth activity. Examining the relationship between NDVI and topography is essential for effective environmental management and protecting natural resources. Urban areas often exist in low-elevation regions due to factors like historical development, economic opportunities, and environmental conditions that significantly influence their location. At present, the gradual depletion of urban green spaces is largely due to increasing population pressure and urban expansion. The objective of the study is to investigate the correlation between elevation and urban green space changes as measured by the NDVI to address sustainable urban development strategies. The remote sensing satellite image data derived from USGS from 1995 to 2024 and elevation data derived from a digital elevation model (DEM) with a spatial resolution of 30 m for the Colombo Urban Areas have been utilized. The NDVI was calculated by applying the formula in between Landsat image bands from the raster calculator in ArcGIS software. The random sampling points generated from ArcGIS software have been used to exact NDVI values and elevation of each 230 points. Linear regression analysis of elevation and NDVI extracted from sample points has been carried out to demonstrate how the altitude of green space has been changed to other LULC over the period from 1995 to 2024. This analysis revealed a positive correlation between elevation and NDVI ($r = 0.101$, p-value = 0.05). However, the magnitude of this correlation was relatively weak, suggesting that while elevation exerts some influence on vegetation cover, it may not be the primary driver of green space changes in the study area. While elevation showed a limited correlation with NDVI, it is essential to acknowledge that other factors likely play more significant roles in shaping urban green spaces. Urbanization, infrastructure development, and population growth are major contributors to green space depletion. Green spaces are rapidly declining in suburbs around Colombo, indicating a negative environmental impact. Policymakers and legislation should focus on restoring green areas for sustainable urban management.

Keywords: NDVI, Elevation, Urban green spaces, Deforestation, Sustainable urban management

Corresponding author.
E-mail address: raveenumesha1999@gmail.com (De Alvis T.P.G.R.U)

1. Introduction

Green spaces (GS) play a vital role in mitigating climate change by contributing to carbon sequestration, thermal comfort, reduced energy consumption, storm water regulation, and drought management. Incorporating performance-based planning and optimization of urban adaptive capacity through quality indicators and standards can strengthen planning decisions, and better represent specific urban systems and conditions (Codemo et al., 2022; Woldesemayat and Genovese, 2021). The quality of urban environments is becoming a significant concern, with the extent, composition, and access to green spaces significantly impacting the quality of life of urban populations. The quality of urban green spaces also influences ecosystem services like clean air and water, climate regulation, ecosystem resilience, and biodiversity (Davies et al., 2008). Greenness data from satellite image-based indices, like the normalized difference vegetation index (NDVI), is used by environmental health researchers to define greenness availability exposure. However, due to variations in canopy density and phenology, ground-based remote sensing is often used in burned savannas, where frequent imagery is required to detect vegetation recovery (De, Martinez, and Labib, 2023). The connection between urban green spaces (UGS) and cities is becoming more evident, as they offer numerous social, economic, and environmental advantages (Woldesemayat and Genovese, 2021). The creation of UGS advances efforts to slow down global warming, preserves the environment, enhance local health and well-being, and the quality of cities.

Green spaces in China have been the subject of Chinese research since the 1980s, with studies focusing on ecological green spaces, open spaces, landscapes and greenbelts, and green space systems (Hua Bai, Ziwei Li, HanlongGuo,2022).

2. Literature Review

This literature review looks at current research on urban green spaces. First, Codemo et al. (2022) aim to create a simple method to assess urban green infrastructure (UGI). They want to improve the way we use transparent surfaces and canopy cover in urban planning. Their method uses small plots of land and private gardens. The study has two parts: evaluating their method and exploring how maps can help urban planning. They test the use of NDVI with high-resolution imagery to map transparent areas and canopy cover. They want to see if their method works well in Trento, provide a tool to see permeability and canopy cover, and discuss how this method can be used in planning. On the other hand, Mathew, Khandelwal, and Kaul (2017) want to better understand the urban heat island effect (UHI). They study how it relates to urban landscape features in Jaipur, India. They examine how vegetation, urban growth, and elevation affect land surface temperatures.

They use NDVI and EVI to measure the percentage of vegetation and built-up areas, and another index to measure city growth. This is important for good city planning. Furthermore, Aram et al. (2019) found that large urban green spaces cool and add moisture to the air more noticeably and consistently. Smaller green spaces have a less predictable cooling effect. Studies also show a relationship between the way urban green spaces are arranged and the shape of a city. When buildings are smaller and more spread out, green spaces are larger. This helps reduce the impact of land surface temperatures. This is important because many cities are located in low-lying areas. While many urban areas are located in low-elevation regions, it's important to note that this is not a universal rule. Factors such as historical development, economic opportunities, and environmental conditions play a significant role in determining the location of cities. Many ancient civilizations developed along rivers and coastlines due to access to water for agriculture, trade, and transportation (Food and Agriculture Organization of the United Nations, 2024).

These historical settlements often evolved into modern urban centers (Mcgranahan, Balk and Anderson, 2007). For instance, Shanghai is one of the world's largest cities and is primarily located in a low-elevation coastal plain, along the Yangtze River delta. New York city which is located at the mouth of the Hudson River is a prime example of a major urban center built on low-lying land. On the other hand, the coastal areas provide economic opportunities and coastal areas have traditionally been hubs for trade and commerce, attracting economic activity (Ospino, 2022). Specifically, rivers and coastlines provide natural transportation routes, facilitating trade and connectivity. And also, population growth often has fertile soil suitable for agriculture, making them attractive for settlement. But it should be mentioned that there is a limited understanding of the relationship between elevation and urban green space change using NDVI analysis.

The research was conducted with the objective of investigating the correlation between elevation and urban green space changes as measured by the Normalized Difference Vegetation Index (NDVI) to inform sustainable urban development strategies. It is important because urbanization causes conversion of the natural land cover, having mainly green vegetation and pervious areas, into impervious built-up surfaces. The use of various materials for buildings, roads, and parking lots, such as concrete, bricks, tiles, asphalt, bitumen, and so on, is what primarily contributes to this impervious surface area (Mathew, Khandelwal and Kaul, 2017).

3. Materials and methods

3.1 Study area

The study areas, ie urban areas of Colombo district, are positioned within a geographical coordinate range of 6° 43' 1.2" to 6° 59' 16.8" latitude and 80° 4' 51.6" to 79° 49' 44.4" longitude. The total land area encompassed by these study areas amounts to 335 square kilometers. The average temperature in this region is 26°C, with variations reaching 28°C and 2500 mm of annual precipitation. Notably, the Colombo area is situated at a lower elevation, and in recent times, it has witnessed a significant surge in urbanization (Fig. 1).

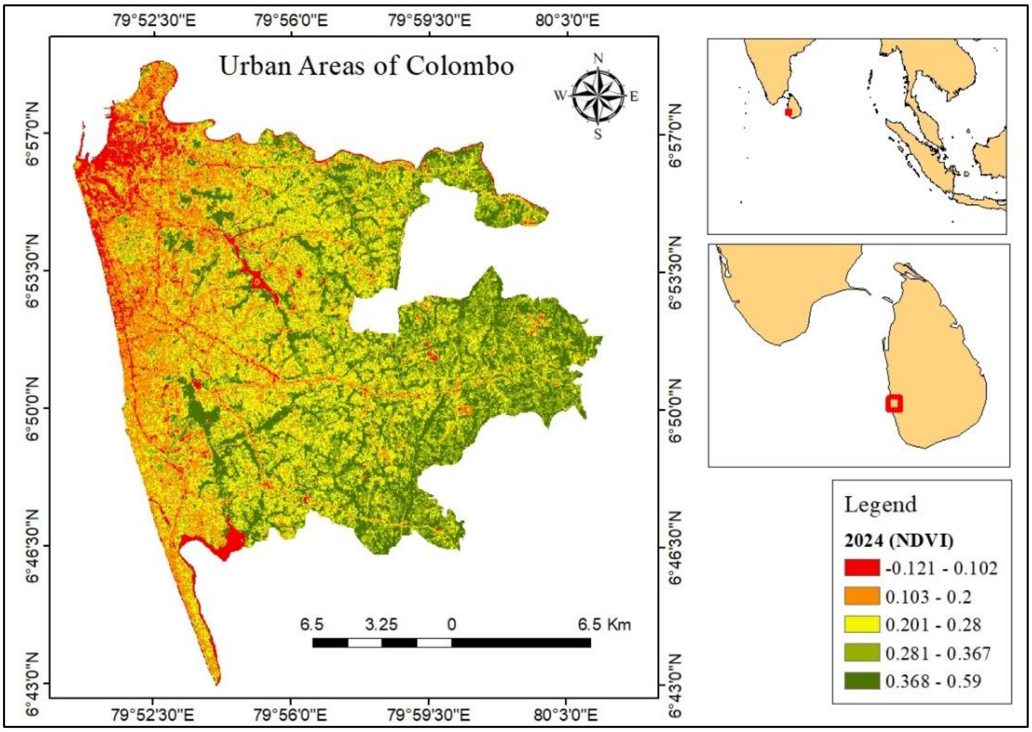


Figure 1: Location of the study area

3.2 Data Collection Methods

The Normalized Difference Vegetation Index (NDVI) was derived from satellite images downloaded from the UDGS 2004 website. Landsat 5 satellite imagery was used for 1995 and 2005, applying the NDVI equation (Band4 − Band3) / (Band4 + Band3) as per Grover and Singh (2015). For 2015 and 2024, Landsat 8 imagery was utilized with the NDVI equation (Band 5 – Band 4) / (Band 5 + Band 4) as described by Kshetri (2018). The digital elevation data were derived from the NASA Shuttle Radar Topography Mission (SRTM) data from 2013. The random sampling point generator tool in ArcGIS software was employed to select sample points, and the NDVI and elevation data were extracted from each of these points.

3.3. Data analysis

Pearson correlation coefficient and linear regression analysis were implemented to investigate the relationships between NDVI and elevation. Simple regression was applied to model the relationship between a dependent variable (NDVI) and independent variables (elevation) (Gao et al., 2013; Trisurat et al., 2019). Scatter plots were created to visualize the relationship between elevation and NDVI to give a preliminary idea of whether a positive or negative linear relationship exists. Then R-squared value and p-value were used to assess the goodness of fit of the model. The temporal changes in the relationship between NDVI and elevation suggest that the influence of elevation on vegetation density or health in the Colombo urban area has decreased over time. In 1995, the relationship between NDVI and elevation was moderately strong, with a positive correlation coefficient (R^2) of 0.1169. This indicates a moderate increase in NDVI with increasing elevation. In 2005, the relationship remained similar to 1995, with a slightly stronger positive correlation (R^2 = 0.0912). In 2015, the relationship weakened further, with a lower positive correlation (R^2 = 0.064). This suggests a weaker association between NDVI and elevation in this year. Finally in 2024, the relationship became even weaker, with a very low positive correlation (R^2 = 0.0103). This indicates a minimal or negligible relationship between NDVI and elevation in study area.

04. Results

4.1Relationship between NDVI and elevation

Fig.2: Relationship between NDVI and elevation in Colombo urban area from 1995 to 2024 In discussing the changes in the vegetation index according to the different height levels of the study area, can examine the salient features of vegetation distribution under three main height categories can be examined. Based on a visual inspection of the scatter plots in figure 2, following trends were observed.

Low Elevation (0-10 meters) - This category would include areas closest to sea level and there might be a relatively high density of data points in this category, suggesting that a larger number of measurements were taken in areas close to sea level. The NDVI values in this category can really differ from one area to another. Some places might have a lush cover of vegetation, while others could be quite sparse. This difference can be linked to various factors, such as land use, the quality of the soil, and proximity to water bodies.

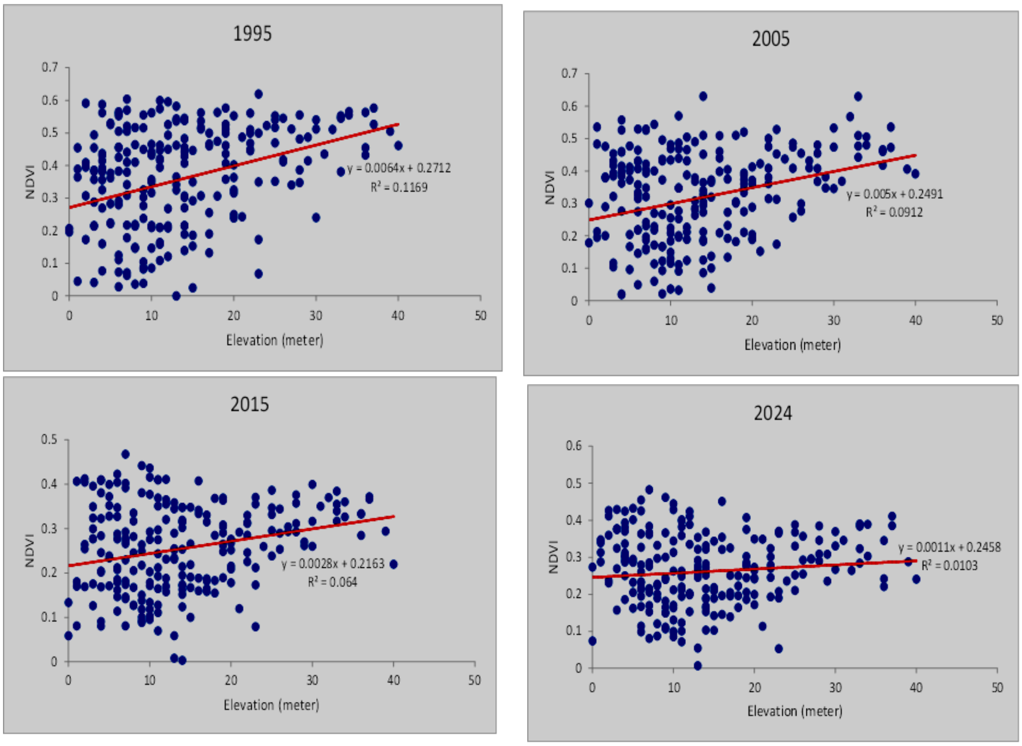


Fig.2 Relationship between NDVI and elevation in Colombo urban area from 1995 to 2024.

Medium Elevation (10-20 meters) - This category would represent areas, which are between 10 and 20 meters above sea level and these mid-elevation areas may have similar levels of greenness (as measured by NDVI) to the lower areas, but they may also show a slight tendency to be greener.

High Elevation (20+ meters) - This category would include areas with the Highest elevations in the study area and the density of data points in this category would likely be the lowest, as higher elevations are generally less suitable for urban development. The NDVI values in this category might be relatively low, reflecting the scarcity of vegetation in these areas. However, there could be exceptions, such as areas with natural parks or protected forests.

4.2. Changes in NDVI in Colombo urban area

Figure 3 shows the temporal and spatial changes in the urban areas of Colombo from 1995 to 2024. As shown in the above maps, the NDVI value has gradually decreased from 0.70 to 0.58 from 1995 to 2024, and accordingly, the amount of green space has declined from 68.69% to 50.41% from 1995 to 2024. This confirms that significant changes have occurred in the urban areas during that period. A gradual decrease in vegetation cover from 1995 to 2024 can be detected in urban lowland areas. NDVI is a measure of vegetation health, with higher values indicating denser and healthier vegetation. The colour scale in each map indicates the range of NDVI values, with green typically representing higher values and brown or grey representing lower values.

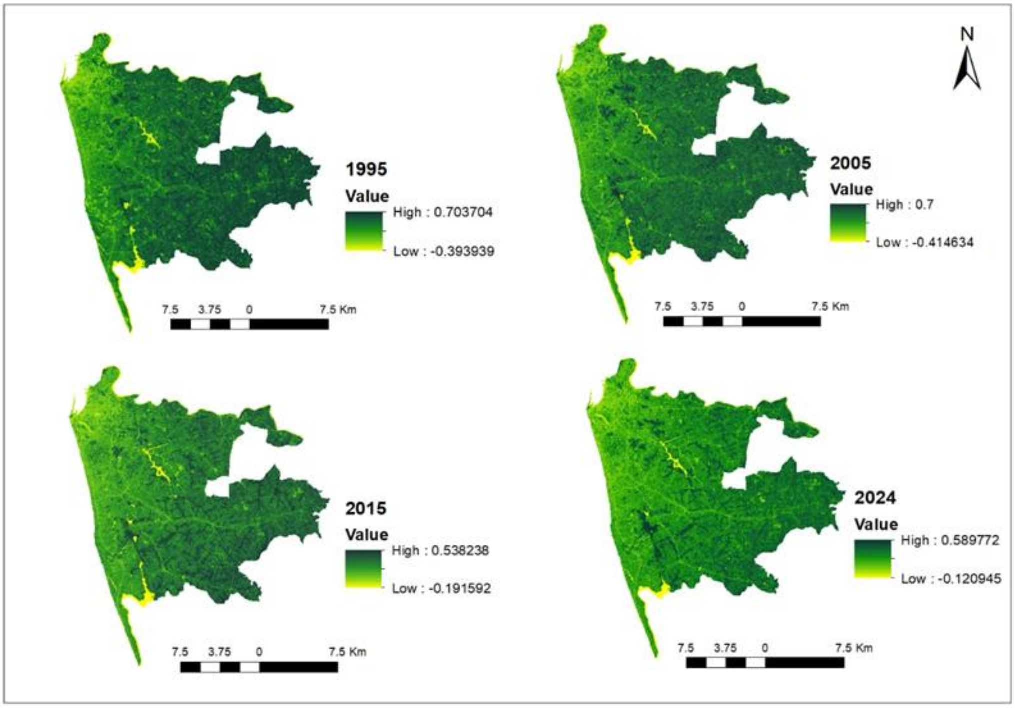
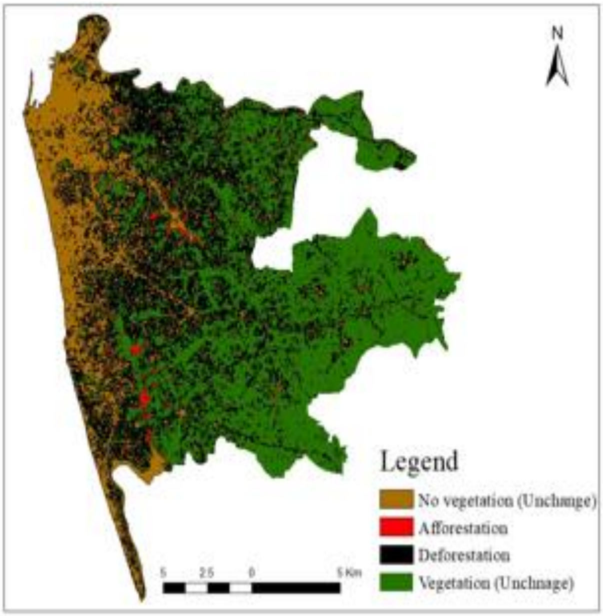


Fig. 3: Temporal changes in NDVI in the Colombo urban area

According to above maps, a general trend of decreasing NDVI values is apparent from 1995 to 2024. This suggests that vegetation cover and health have declined over time in the Colombo urban area. Whilst the overall trend is declining, there are spatial variations in NDVI changes. There are some areas that have experienced more decrease in vegetation cover than others. This can be the result of several factors, such as urban growth, infrastructure development, pollution, deforestation, or land use pattern changes. Comparing the maps, it's evident that the urban area has expanded over the decades.

This would most likely be connected with development activity, which will have positive and negative impacts on vegetation. In some areas, urban expansion will have resulted in declining green spaces, with resulting lower NDVI values. However, in other areas, urban planning initiatives may have included green belts or afforestation schemes, with resulting higher NDVI values. Colombo's coastal areas appear to have experienced drastic alteration in the extent of vegetation cover. This could have been caused either by coastal erosion, rise in sea levels, or changes in coastal management practices.

As shown in above maps, the vegetation cover in Colombo's harbour and coastal lowlands has significantly decreased over time, particularly from 1995 to 2024. This decline is largely attributed to intense development activities, construction expansion and high population pressure in these areas, which have led to habitat destruction and reduced green spaces.



Vegetation change (1995 - 2024)	Area change (km^2)
No vegetation to No vegetation	90.4938
No vegetation to vegetation (Afforestation)	13.8151
Vegetation to No vegetation (Deforestation)	74.7158
Vegetation to Vegetation	154.1289

Fig. 4: Vegetation change in Colombo urban area

4.3. Vegetation changes in Colombo urban area

The following trends can be identified from the visible changes in vegetation distribution in the Colombo urban area from 1995 to 2024 as shown in figure 4. Significant Net Loss of Vegetation: Despite some afforestation efforts, the overall trend indicates a net loss of vegetation in Colombo's urban area. The combined deforestation and "no vegetation to no vegetation" changes far outweigh the afforestation gains. Deforestation as the Primary Driver: Deforestation is the most significant contributor to vegetation loss, accounting for 74.72 square kilo meters of area change. This suggests that clearing of existing vegetation for development or other purposes has been a major factor.

Limited Success of Afforestation: While afforestation efforts have resulted in the creation of new vegetation cover (13.82 square kilo meters), they have not been sufficient to offset the losses due to deforestation and other factors. Stabilization of Existing Vegetation: The "vegetation to vegetation" category indicates that some areas have maintained their existing vegetation cover. However, this does not necessarily imply positive change, as it could simply reflect areas that have not undergone significant development or disturbance.

4. Discussion

Terrain parameters, such as elevation, slope, and aspect, can significantly influence vegetation growth and distribution, while NDVI provides a valuable metric for assessing vegetation health and density. Furthermore, factors such as temperature, soil moisture, solar radiation, and microclimates created by topography can all influence NDVI. This study analysed the correlation between elevation in Colombo city and the level of green vegetation cover. By analysing data on vegetation growth, the study identified that the higher-elevation areas were greener. Especially, the low coastal lands of Colombo, generally below 10 meters above sea level, were much less green compared to higher-elevation areas. The study also noted that the greenness of Colombo has been decreasing gradually from 1995 to 2024. This shows that there may be a long-term change taking place with the vegetation in the area. These findings are consistent with other studies that have investigated the effect of landscape on the sites of plants. Other studies around the world have also explored this correlation between greenness and the elevation. Some research even suggest that climatic factors, such as rainfall and temperature are the main variables that support plant growth (Yang et al., 1997).

Additionally, several studies have shown that terrain factors such as elevation, slope, and aspect also affect vegetation distribution and growth. Walsh et al. (2001) conducted a multi-scale statistical correlation analysis of terrain attributes and NDVI, revealing that the relationships between NDVI and factors such as slope and elevation vary across different spatial scales. Also, using GIS techniques to extract terrain statistical data, the vegetation distribution and the mutual relationships between landforms in the north western part of Sichuan LongMen mountain have been analysed using correlation analysis and factor analysis methods. It has been revealed that there is a significant relationship between landforms and vegetation distribution in their study area Chen et al., 2006). For example, a study conducted in China, analysed how terrain factors affect vegetation changes in four regions of Chongqing.

This study examined the relationship between NDVI and terrain factors (elevation, slope, and aspect) for different physiographic regions of Chongqing using SPOT-VGT images of 2007. The results revealed that terrain strongly influenced the distribution and growth of vegetation in the area. Accordingly, Chongqing was divided into four regions based on terrain characteristics. These were Northeast, West, Central, and South Chongqing. The NDVI values in these divided regions varied according to the terrain. The values of NDVI ranged from 0.5 to 0.8 for north-eastern Chongqing, from 0.15 to 0.6 for western Chongqing, from 0.5 to 0.65 for central Chongqing, and from 0.4 to 0.8 for southern part of Chongqing... The NDVI value in all areas generally increased with altitude, and especially in low-altitude areas, Vegetation was mainly found on 0–25° north-and south-facing slopes in North-eastern Chongqing; on 0 – 9° east- and west-facing slopes in Western Chongqing; on 0–15° slopes in Central Chongqing; and on 0–20° east- and west-facing slopes in Southern Chongqing. (Zhan et al., 2012).

Thus, various studies have identified the correlation between topography and vegetation distribution and many studies indicate that there is a strong positive correlation between topography and vegetation distribution. Also, several studies examining vegetation distribution and green space changes in urban lowland areas has consistently revealed a decline in vegetation cover over time. The expansion of development projects, construction activities, and increasing population density within cities have contributed to a reduction in green spaces, leading to a corresponding decrease in the vegetation index. For example, many of the previous studies have revealed that the proportion of green spaces in South Asia has changed rapidly due to new construction development projects and rapid urban expansion (Nor et al. 2017; Aoshima *et al*. 2018; Thakur et al., 2020) and particularly in Mumbai, India (Sahana et al., 2018; Moghadam and Helbich, 2013). In parallel, reports by 'Environment Policy' and 'Research India' have stated that Mumbai city was covered with green spaces at more than 35% in 1970, but in 2017, that amount has decreased by sixty percent to 13%. Similarly, another study conducted in the Mumbai urban area, with 200 sample green patches has revealed that the proportion of green spaces has decreased from 46.4% to 26.67% (Rahaman et al, 2020).

In comparison with the results of the above studies, this study, conducted in relation to the urban area of Colombo, Sri Lanka, also identified a clear temporal decline in green spaces from 1995 to 2024 and the results clearly show that the NDVI value has decreased from 0.703 to 0.589 from 1995 to 2024, indicating that there has been a drastic transformation of urban green spaces, which has reduced from 68.69% to 50.41% from 1995 to 2024. A gradual decrease in vegetation cover from 1995 to 2024 can be detected in urban lowland areas.

5. Conclusion

The Normalized Difference Vegetation Index (NDVI) was employed to assess the relationship between elevation and urban green space change. This analysis revealed a statistically significant positive correlation between elevation and NDVI ($r = 0.101$, p-value = 0.05). However, the magnitude of this correlation was relatively weak, suggesting that while elevation exerts some influence on vegetation cover, it may not be the primary driver of green space changes in the study area. While elevation showed a limited correlation with NDVI, it is essential to acknowledge that other factors likely play more significant roles in shaping urban green spaces. Urbanization, infrastructure development, and population growth are key drivers of green space depletion.

This study has statistically confirmed that there is a weak positive relationship between the elevation of the land and the vegetation index using the Pearson correlation coefficient and the regression model. However, this correlation can be identified as a rather weak positive correlation. It reveals that not only the elevation but also many other factors affect the spatial distribution of vegetation patterns in the study area. Accordingly, many factors, such as changes in land use patterns, urban population growth, settlement expansion, construction and development projects, etc., affect the variation in the distribution of urban green spaces. Although this research only focuses on the relationship between elevation and the vegetation index, previous studies show that various human activities mentioned above have a direct impact on the change in urban vegetation distribution patterns. Therefore, future research should also consider additional variables, including land use policies, population pressure, and development intensity, to better understand changes in urban green spaces. Integrating such a set of factors will help urban policymakers design more comprehensive strategies for sustainable urban management.

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