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Research Article

Modelling the Behavior of DVI and IPVI Vegetation Indices Using Multi-Temporal Remotely Sensed Data

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Abstract: Remote sensing techniques are widely used to detect and analyze land cover changes due to their accuracy and cost-effectiveness. Among the various spectral indices derived from the satellite data Difference Vegetation Index (DVI) and Infrared Percentage Vegetation Index (IPVI) vegetation indices applied to model the behavior of the indices in the study of suburb ecosystem vegetation cover over twenty years. To achieve the aim of the study two objectives were formulated; detect Spatial-temporal variations in urban vegetation and how suitable the selected algorithms to study urban ecosystem vegetation. The study area is a rapidly developing area consists of several suburbs including Battaramulla, Malabe, and Kaduwela, Sri Lanka. The study used Landsat data and pre-processing, processing, geometric and atmospheric corrections were performed using ERDAS imagine mapping software and all the mappings were carried out via Arc GIS software. The results show Infrared Percentage Vegetation Index (IPVI) algorithm as the most suitable vegetation index to study suburb ecosystem vegetation than Difference Vegetation Index (DVI) in the study area. Therefore, the study recommends IPVI than DVI to study ecosystem vegetation in sub-urban areas.

Keywords: Change detection, Landsat, Remote Sensing, Sub-urbans, Vegetation indices.

1. Introduction

Vegetation is one of the fundamental as well as a critical component of an urban ecosystem. The role of vegetation is crucial to the survival of the earth and its living beings. The comprehensive ecosystem services provide vegetation does not confine to regulating services, provisioning services, and supporting service. Vegetation is of great importance for aesthetic and recreational services.

Since 1972 the launch of earth resource satellites, numerous studies have been carried out between radiometric responses and vegetation cover or land cover. Obtaining electromagnetic wave reflectance information from canopies using passive sensors vegetation is remotely sensed. Vegetation data in a remotely sensed imagery recorded in terms of its signatures [1]. Spectral, spatial, temporal, angular and polarization are the five recognized signatures representing the features of vegetation in satellite imagery data. Mostly extraction of vegetation data from a remotely sensed imagery focus on using one or two of these signatures. Vegetation cover affects energy interchange near the surface [2]. The extent and the percentage of vegetation cover is an appropriate criterion to identify land degradation and loss of vegetation extent over time in urban areas. There are several spectral vegetation indices derived from satellite data. Vegetation index is a mathematical transformation with ratios or linear combinations of reflectance measurements in various spectral bands [3], Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI), Modified Normalized Difference Vegetation Index (MNDVI), Transformed Normalized Difference Vegetation Index (TNDVI), Perpendicular Vegetation Index (PVI),

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Atmospherically Resistant Vegetation Index (ARVI), Green Vegetation Index (GVI), Soil Line Atmospheric Resistant Index (SLRI), Transformed Soil-Adjusted Vegetation Index (TSAVI), Type Soil Atmospheric Impedance Vegetation Index (TSARVI), Soil-Adjusted Vegetation Index (SAVI), Modified Soil-Adjusted Vegetation Index (MSAVI), Global Environment Monitoring Index (GEMI), Optimized Soil-Adjusted Vegetation Index (OSAVI), Tasseled Cap Transformation of Greenness Vegetation Index (GVI, Yellow Vegetation Index, Soil Brightness Index), Adjusted Green Vegetation Index (AGVI), Misra Green Degree Vegetation Index (MGVI), Misra Yellow Degree Vegetation Index (MYVI), Enhanced Vegetation Index (EVI), Transformed Chlorophyll Absorption in Reflectance Index (TCARI), Photochemical Reflectance Index (PRI), Visible-Band Difference Vegetation Index (VDVI), Wide Dynamic Range Vegetation Index (WDRVI), Chlorophyll Absorption Ratio Index (CARI), Crop Water Stress Index (CWSI), Transformed Vegetation Index (TVI), Corrected Transformed Vegetation Index (CTVI), Normalized Ratio Vegetation Index (NRVI) [4], Infrared Percentage Vegetation Index (IPVI), and Visible Atmospherically Resistant Index (VARI) [5]. Vegetation indices are classified into two types 1) Slope-based vegetation indices and 2) Distance-based vegetation indices.

Vegetation indices belong to the first category are including RATIO, NDVI, SAVI, RVI, NRVI, TVI, CTVI, TTVI and EVI. The second category comprised of PVI, AVI, DVI, TSAVI, MSAVI and WDVI [4]. Another study grouped vegetation indices into ratio-based (ARVI, EVI, IPVI, MSAVI, MSAVI2, NDVI, NDVI-offset, RVI, SAVI, TSAVI) and orthogonal/perpendicular (DVI, PVI, WDVI) categories [6]–[9]. While some categorized as soil resistant (MSAVI, MSAVI2, SAVI, TSAVI) and atmospherically resistant (ARVI, EVI) indices [10]. Various studies paid attention to different vegetation indices in line with the objectives of the respective study [11]–[14].

The current study focused on urban vegetation within the suburbs derived as a result of suburbanization phenomena. Suburbanization is the growth and spatial reorganization of a city. Suburbs rise out of the administrative borders of the city and connected on the city via commuting. This functional connection between the city and suburb generally pressurizes the urban environment. Hence, urban vegetation may alter within time and space.

The study aims to study the behavior of DVI and IPVI vegetation indices over ecosystem vegetation cover in suburbs in the Kaduwela Divisional Secretariat Division (Figure1) which is among the rapidly urbanizing regions. To achieve the aim of the study i) detect spatial and temporal variations in urban vegetation and ii) signify how DVI and IPVI suitable for vegetation detection in urban ecosystems.

2. Research Methods

2.1. Location Study

Colombo District in Sri Lanka comprised of several suburbs including Sri Jayawardenapura, Battaramulla, Maharagama, Kesbewa, Kaduwela, Homagama, Athurugiriya, Malabe, Kelaniya, Moratuwa, Dehiwala - Mt. Lavinia, Kolonnawa, Kotikawatta, Ja-Ela and Ragama [15].

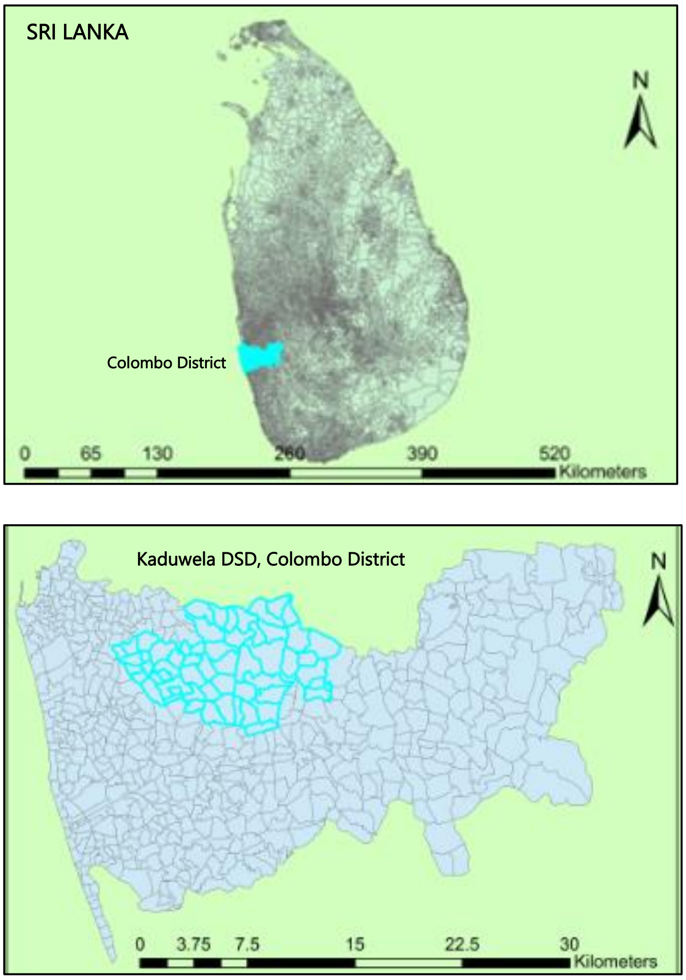

Figure 1. Titles placed below numbered sequentially.

2.2. Data Collection

Remotely sensed data images used in the study are Landsat 5, 7 and 8 images acquired between January and February, downloaded from USGS Earth Explorer site. Using Arc GIS and ERDAS Imagine mapping software geospatial analysis and spectral image processing of Landsat data to produce all the vegetation maps and calculations were made. The study focused on ratio type and orthogonal type indices. DVI is an orthogonal and distance-based vegetation index while IPVI is a ratio index

[4], [16], [17]. A recent study has classified DVI as a slope-based vegetation index [13], [18]–[20].

2.3. Difference Vegetation Index (DVI)

DVI appears as NDVI cited in [21], [22], they refer to its common use, so it has been certainly introduced earlier, but they have not given a specific reference. DVI is an easier vegetation index that weights the near-infrared band due to the slope of the soil line [5 and 4]. DVI calculating algorithm is;

$$DVI = \frac{SWIR1}{R} \quad (1)$$

Zero values of DVI stands for bare soil and positive values indicate vegetation. Negative values specify water [4]. DVI is not suitable for densely vegetated areas so it is typically suitable for urban vegetation analysis if the vegetation cover is not denser [14]. The DVI is the simplest vegetation index, is sensitive to the amount of vegetation, distinguishes between soil and vegetation, and does not relate to differences between reflection and exposure caused by atmosphere or shadow.

2.4. Infrared Percentage Vegetation Index (IPVI)

Crippen [23], found that the reduction in NDVI was irrelevant, and offered this index to improve the vegetation index calculation. The range of IPVI values is only 0 - 1, different from NDVI, which ranges from -1 to 1 [5]. This index aims to eliminate negative values from NDVI. IPVI and NDVI are functionally the same. The algorithm is as follows;

$$IPVI = \frac{NIR}{NIR + Red} \quad (2)$$

Using ERDAS Imagine v.14 pre-processing; geometric and atmospheric corrections performed. Arc GIS software used for mapping vegetation cover from 2000 to 2020. The estimation of the rate of vegetation change was computed on the following formulas [3 and 4]. Vegetation changes calculated between two successive periods using ‘before image-after image’ algorithm.

Equation 1: % Vegetation Change (%VC)

$$\% \, VC = \frac{Area_{i \; year \; x} - Area_{i \; year \; x+1}}{\Sigma_{i=1}^{n} Area_{i \; year \; x}} \times 100 \quad (3)$$

Equation 2: Annual Rate of Change (ARC)

$$ARC = \frac{Area_{i \; year \; x} - Area_{i \; year \; x+1}}{t_{years}} \quad (4)$$

Equation 3: % annual rate of change (%ARC)

$$\% \, ARC = \frac{Area_{i \; year \; x} - Area_{i \; year \; x+1}}{Area_{1 \; year \; x} \times t_{years}} \times 100 \quad (5)$$

Area $_{i\text{-year } x}$ is the area of cover *i* at the first data;
Area $_{i\text{-year } x+1}$ is the area cover *i* on the second date;
$\Sigma_{i=1}^{n}$ Area $_{i\text{-year } x}$ is the total cover area on the first date;
t $_{years}$ is the period in years between the first and second scene acquisition dates.

3. Result and Discussions

The results of the vegetation indices shown in figure 2-6 and 7-11. Figure 2-6 shows the spatial behavior of DVI from 2000 to 2020 for five consecutive years with a five-year gap. Figure 7-11 shows the spatial behavior of IPVI from 2000 to 2020 for five consecutive years with a five-year gap.

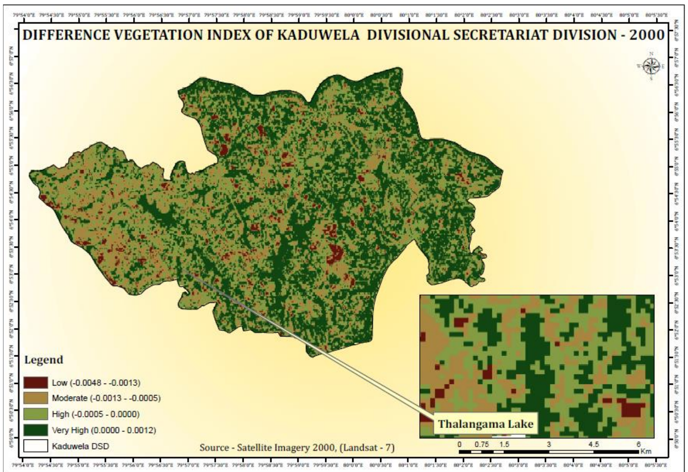

Figure 2. The Vegetation Cover of Kaduwela DSD using DVI Algorithm in 2000

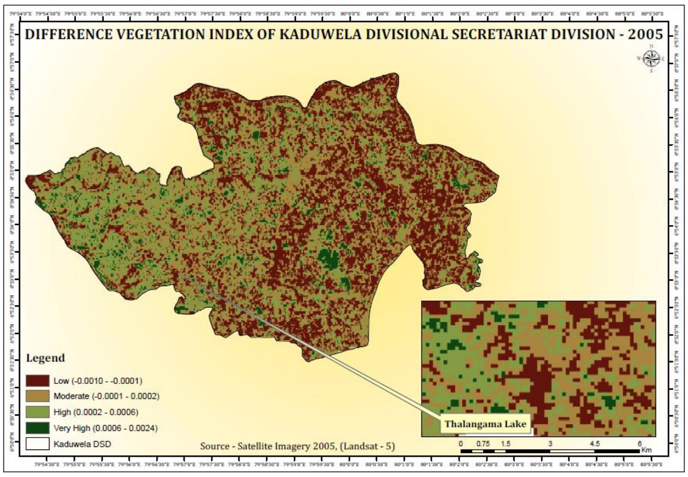

Figure 3. The Vegetation Cover of Kaduwela DSD using DVI Algorithm in 2005

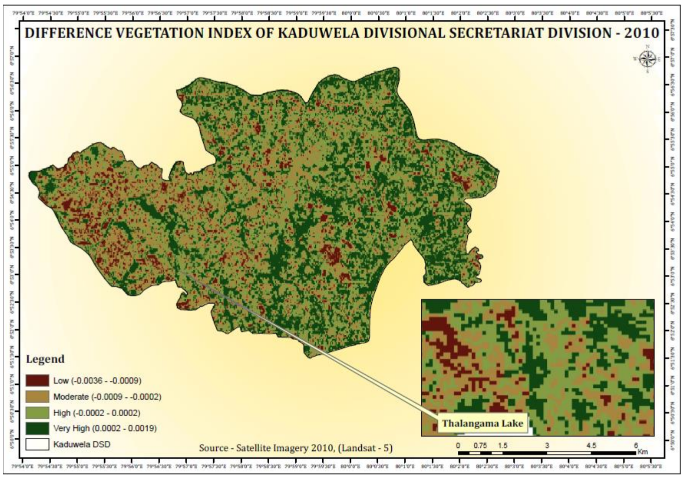

Figure 4. The Vegetation Cover of Kaduwela DSD using DVI Algorithm in 2010

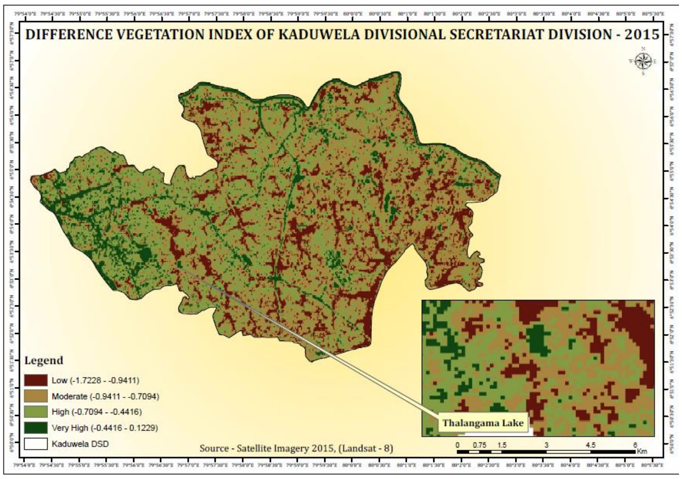

Figure 5. The Vegetation Cover of Kaduwela DSD using DVI Algorithm in 2015

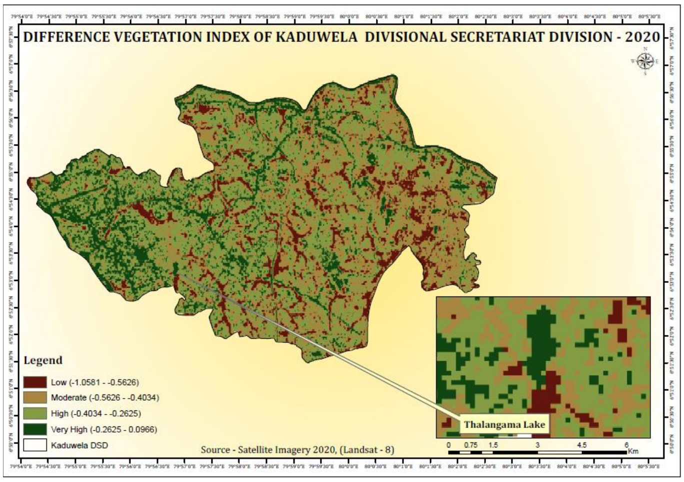

Figure 6. The Vegetation Cover of Kaduwela DSD using DVI Algorithm in 2020

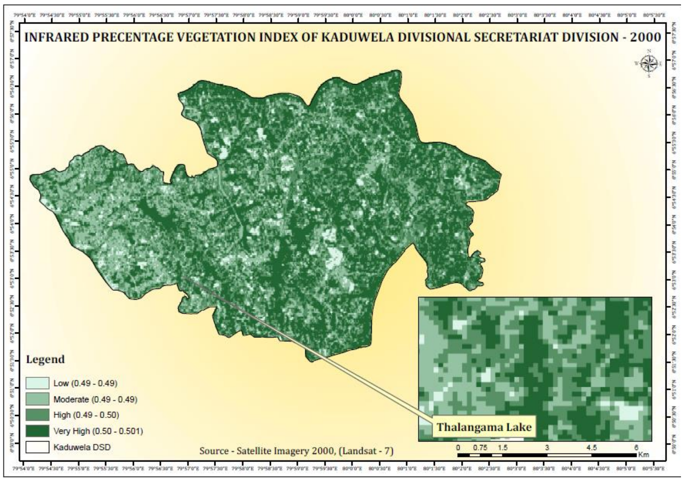

Figure 7. The Vegetation Cover of Kaduwela DSD using IPVI Algorithm in 2000

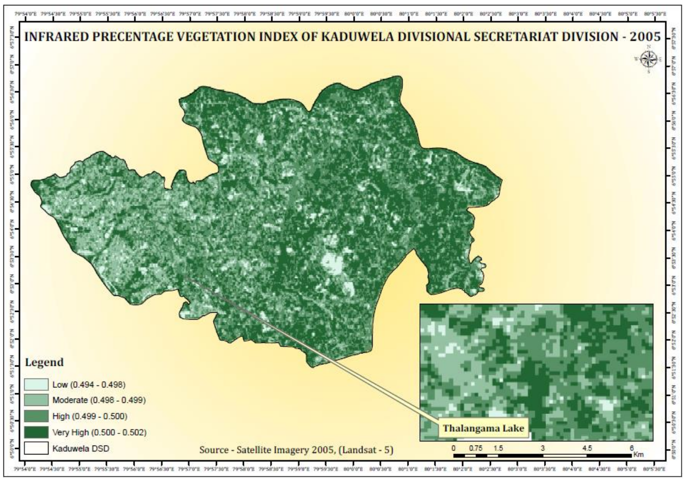

Figure 8. The Vegetation Cover of Kaduwela DSD using IPVI Algorithm in 2005

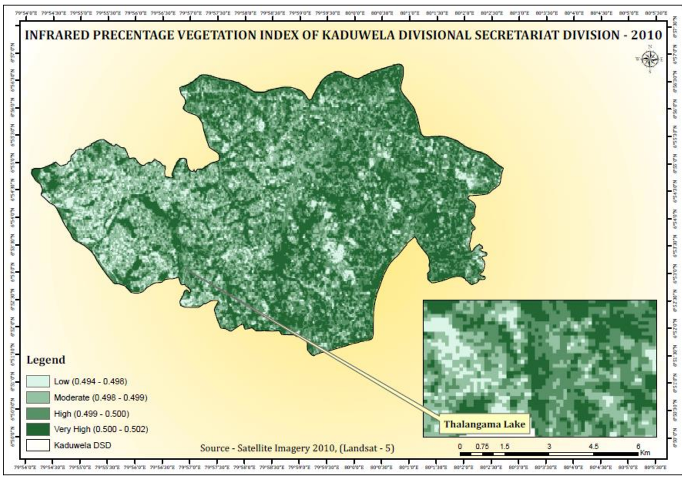

Figure 9. The Vegetation Cover of Kaduwela DSD using IPVI Algorithm in 2010

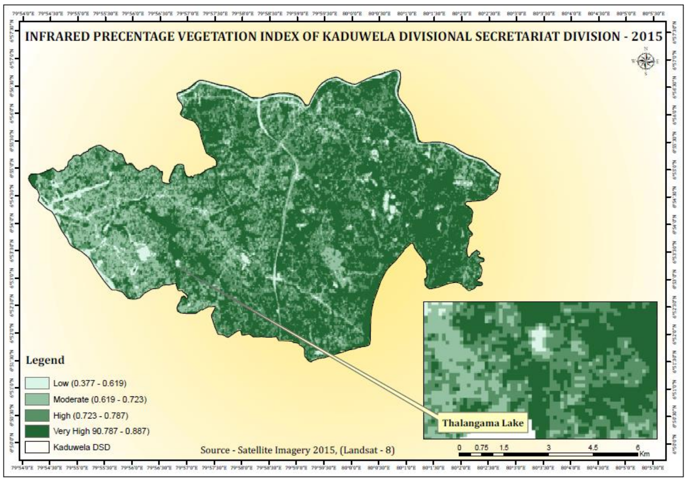

Figure 10. The Vegetation Cover of Kaduwela DSD using IPVI Algorithm in 2015

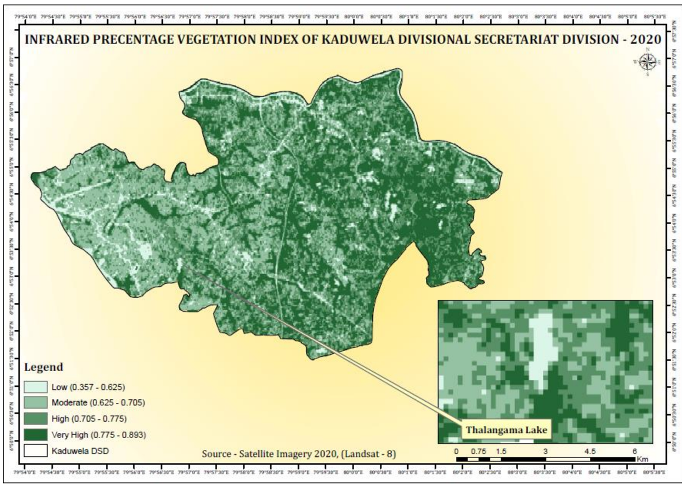

Figure 11. The Vegetation Cover of Kaduwela DSD using IPVI Algorithm in 2020

Table 1. Vegetation Cover Using IPVI in Kaduwela DSD in 2000 - 2020

Vegetation class	2000			2005			2010			2015			2020		
	Pixel count	Km^2	%	Pixel count	Km^2	%	Pixel count	Km^2	%	Pixel count	Km^2	%	Pixel count	Km^2	%
Low	3520	3.168	3.606	3939	3.545	4.035	7373	6.636	7.553	3589	3.230	3.676	5760	5.184	5.900
Moderate	21483	19.335	22.007	20880	18.792	21.389	24628	22.165	25.228	17885	16.097	18.321	28226	25.403	28.914
High	35949	32.354	36.825	38991	35.092	39.941	36285	32.657	37.169	33640	30.276	34.459	34375	30.938	35.213
Very High	36669	33.002	37.563	33812	30.431	34.636	29335	26.402	30.050	42508	38.257	43.543	29258	26.332	29.972
Total		87.859	100		87.860	100		87.859	100.000		87.860	100.000		87.857	100.000

Table 2. Vegetation Cover Changes in Kaduwela DSD based on IPVI Results in 2000 - 2010

Vegetation class	2000-2005				2005-2010			
	Area change (km^2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)	Area change (km2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)
Low	-0.377	-0.429	-0.075	-2.381	-3.091	-3.518	-0.618	-17.436
Moderate	0.543	0.618	0.109	14.034	-3.373	-3.839	-0.675	-3.590
High	-2.738	-3.116	-0.548	-1.692	2.435	2.772	0.487	1.388
Very High	2.571	2.927	0.514	1.558	4.029	4.586	0.806	2.648

Table 3. Vegetation Cover Changes in Kaduwela DSD based on IPVI Results in 2010 - 2020

Vegetation class	2010-2015				2015-2020			
	Area change (km^2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)	Area change (km2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)
Low	3.406	3.876	0.681	10.264	-1.954	-2.224	-0.391	-12.098
Moderate	6.069	6.907	1.214	5.476	-9.307	-10.593	-1.861	-11.564
High	2.381	2.709	0.476	1.458	-0.662	-0.753	-0.132	-0.437
Very High	-11.856	-13.494	-2.371	-8.981	11.925	13.573	2.385	6.234

Table 4. Vegetation Cover Using DVI in Kaduwela DSD

Vegetation class	2000			2005			2010			2015			2020		
	Pixel count	Km^2	%	Pixel count	Km^2	%	Pixel count	Km^2	%	Pixel count	Km^2	%	Pixel count	Km^2	%
Low	3528	3.175	3.614	33813	30.432	34.637	7417	6.675	7.598	16997	15.297	17.411	11793	10.614	12.081
Moderate	19804	17.824	20.287	37156	33.440	38.061	24585	22.127	25.184	36513	32.862	37.403	30520	27.468	31.264
High	34986	31.487	35.839	21892	19.703	22.425	36285	32.657	37.169	34354	30.919	35.191	39536	35.582	40.500
Very High	39302	35.372	40.267	4761	4.285	4.877	29335	26.402	30.050	9757	8.781	9.995	15770	14.193	16.155
Total		87.858	100.000		87.860	100.000		87.860	100.000		87.859	100.000		87.857	100.000

Table 5. Vegetation Cover Changes in Kaduwela DSD based on DVI Results in 2000 - 2010

Vegetation class	2000-2005				2005-2010			
	Area change (km^2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)	Area change (km2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)
Low	-27.257	-31.023	-5.451	-171.684	23.756	27.039	4.751	15.613
Moderate	-15.617	-17.775	-3.123	-17.524	11.314	12.877	2.263	6.767
High	11.785	13.413	2.357	7.485	-12.954	-14.744	-2.591	-13.149
Very High	31.087	35.383	6.217	17.577	-22.117	-25.173	-4.423	-103.230

Table 6. Vegetation Cover Changes in Kaduwela DSD based on DVI Results in 2010 - 2020

Vegetation class	2010-2015				2015-2020			
	Area change (km^2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)	Area change (km2)	Change (%)	The annual rate of change (km^2/year)	% annual rate of change (%/year)
Low	-8.622	-9.813	-1.724	-25.833	4.684	30.617	0.937	6.123
Moderate	-10.735	-12.219	-2.147	-9.703	5.394	16.413	1.079	3.283
High	1.738	1.978	0.348	1.064	-4.664	-15.084	-0.933	-3.017
Very High	17.620	20.055	3.524	13.348	-5.412	-61.628	-1.082	-12.326

Table 1 and 4 shows the extent of vegetation cover and table 2, 3, 5 and 6 present the cover changes including percentage area change and percentage annual rate of change. Both DVI and IPVI results demonstrate the vegetation cover of the eastern sphere is higher in 2000. According to DVI very high vegetation cover has dropped by approximately 31.023 percent in 2005. In contrast, IPVI shows only 0.429 per cent reduction of vegetation cover for the year 2005. Vegetation cover reduction behavior demonstrates a lower magnitude using IPVI algorithm for the last two decades. Also, the eastern sphere possesses very high vegetation cover over the last twenty years. Only the western sphere vegetation cover has declined within the period

It is further evident when to pay attention to mass road development and expansion along with suburban area expansion over the period. The linear patterns show in the vegetation map (Figure 7-11) represents the main roads and road accessibility. Especially after 2015 linear patterns are much visible and sequentially the vegetation cover in the western sphere has declined. However, the DVI results show contradiction when compared to IPVI results. Particularly the linear patterns classified as very high vegetation areas by DVI. Besides, the extent of vegetation cover fluctuated and very high vegetation cover as per the DVI shifted from east to west and demonstrates moderate to high vegetation cover all over the area. The spatial and temporal variations of vegetation cover of the area indicate the regular evolution and expansion of the urban area especially in the western-most periphery and the urban pressure filtered towards the inner parts of the DSD which is clear with IPVI. Hence, the IPVI results are compatible with the current phenomena in the area.

Among the urban ecosystems, this study has selected an environmentally protected Thalangama wetland to study either DVI or IPVI suitable for vegetation detection in small urban ecosystems. DVI for very small urban wetland ecosystem vegetation detection classified waterbody under negative values and mostly the negative values are distributed within the study area. Thus, it is rather difficult to classify the exact wetland ecosystem vegetation cover using DVI. When compared to DVI, IPVI is better to identify and classify small urban wetland vegetation cover. At last, the results show that IPVI is suitable for detecting, classifying, and modelling of urban vegetation cover and small urban ecosystem vegetation cover in the study area. Accordingly, recommend IPVI for modelling and prediction/change detection of urban vegetation.

4. Conclusion

Remotely sensed data and remote sensing techniques are the rapid and accurate access to the detailed information on the vegetation cover and vegetation change detection. In the study area, vegetation cover over twenty years has studied in both spatial and temporal aspects using DVI and IPVI algorithms. Though DVI is good for urban vegetation cover study the behavior of DVI in Kaduwela DSD area shows that IPVI is much suitable for vegetation analysis in lowland urban area.

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