Journal of
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JOURNAL OF SPATIAL INFORMATION SCIENCES
VOL.1, ISSUE 1, PP 60–73, 2024
PUBLISHED 10-10-2024
www.journals.unizik.edu.ng/jsis

A SPATIO-TEMPORAL ASSESSMENT OF THE GREENERIES WITHIN ENUGU URBAN USING GIS AND REMOTE SENSING

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Abstract

This study addresses the imperative of preserving green spaces in urban environments amidst escalating urbanization, impacting greenery and posing environmental and societal concerns. Leveraging remote sensing data, particularly the Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI), the research employs advanced Geographic Information System (GIS) methods to assess greenery within Enugu Urban. The NDVI and SAVI being crucial for monitoring vegetation health in diverse contexts, are applied to high-resolution Landsat images, facilitating a precise evaluation of greenery trends. The study reveals a continuous decline in greenery. While the NDVI analysis reveal reduction in greeneries area from 65% to 12% between 1999 and 2022, the SAVI analysis shows similarly trend reducing from 53% to 6% within same period. These alarming reduction rate and trend as obtained from both NDVI and SAVI analyses, highlights the urgent need for afforestation initiatives within Enugu Urban. The consistency in the results obtained from both the NDVI and SAVI indices indicate their suitability for monitoring vegetation health and presence in urban and mixed land-use environments.

Keywords: green spaces, urbanization, NDVI, SAVI, remote sensing, GIS, Enugu Urban, afforestation.

1.0 Introduction

Global initiatives, such as the Bonn Challenge and UNFCCC, and local efforts (exemplified by the Greener Tropical Built Environment Research group), emphasize the significance of collaborative approaches in preserving green spaces in urban environments (UN, 2015). The evaluation of greenery is essential for monitoring vegetation in diverse environments. The rapid urbanization and consequential reduction in green spaces have raised significant environmental and societal concerns. While greenery provides diverse benefits, including oxygen production, air purification, shading, cooling, and noise reduction, the escalating urbanization threatens these advantages. Ensuring a well-vegetated environment contributes not only to visual appeal but also enhances air quality through photosynthesis, positively impacting cognitive function and biodiversity (Nowak et al., 2014; Berman et al., 2008). Furthermore, greenery plays a crucial role in mitigating the urban heat island effect and reducing energy consumption.

The utilization of remote sensing data with high spatial and temporal precision enables large-scale surveillance of vegetation variation (Ning et al., 2023). Notably, the Normalized Difference Vegetation Index (NDVI) serves as an effective indicator for monitoring surface vegetation variation and assessing regional vegetation coverage and growth status (Zhu & Liu., 2015; Wang et al., 2021). NDVI, with various spatial and temporal resolutions, finds widespread applications in desertification evaluations, soil erosion monitoring, and land-cover changes (Harris et al., 2014; Tamene & Le, 2015; Udoma-Michaels & Akinola, 2022). Researchers have successfully employed NDVI in diverse geographical contexts to assess vegetation health conditions, such as in the Niger Delta region of Nigeria (Udoma-Michaels & Akinola, 2022), the Northern Ethiopian Highlands (Ahmed, 2016), and areas facing drastic changes in greenery density due to rapid urbanization (Huma et al., 2017; Bhambure et al., 2018; Palmer et al., 2018).

The utilization of the Soil Adjusted Vegetation Index (SAVI) is another crucial approach for urban vegetation assessment, addressing the limitations posed by soil background influences in densely built environments (Huete, 1988). Urban landscapes, characterized by impervious surfaces and structures, present challenges for traditional vegetation indices like NDVI. SAVI, incorporating a soil-adjustment factor, effectively compensates for soil reflectance, enhancing its accuracy in areas with mixed vegetation and impervious surfaces (Huete et al., 1997). This adjustment proves invaluable in urban contexts, allowing for a more precise representation of vegetation health and density.

In order to consolidate previous research efforts aimed towards quantifying the rate of greenery loss within the urban environment, there is need for more precise and current information on vegetation cover. This study seeks to address this gap by employing advanced Geographic Information System (GIS) methods and contemporary remote sensing technology, leveraging newer, high-resolution Landsat images. Remote sensing and GIS-based indices like the Soil Adjusted Vegetation Index (SAVI) and Normalized Difference Vegetation Index (NDVI) provide detailed vegetation information and are used in this study to develop efficient means for assessing greenery within the urban environment.

2.0 Study Area

This study focuses on the Enugu urban metropolis, comprising Enugu North, Enugu South, and Enugu East local government areas in Nigeria's South-Eastern geo-political zone. Positioned at approximately 6º30’ North of the Equator and 7º30’ East of latitude, it shares borders with Imo, Abia, Ebonyi, Benue, Kogi, and Anambra states. Encompassing about 7,161km², the area serves as the administrative capital of Enugu State. Its coordinates range from 6˚22'N to 6˚38'N and 7˚28'E to 7˚37'E, with an estimated population of 722,664 inhabitants as of 2006 (Fed. Gov. Gazette, 2007). Figure 1 visually represents the study area within Nigeria's map, Enugu state's map, and Enugu urban metropolis specifics.

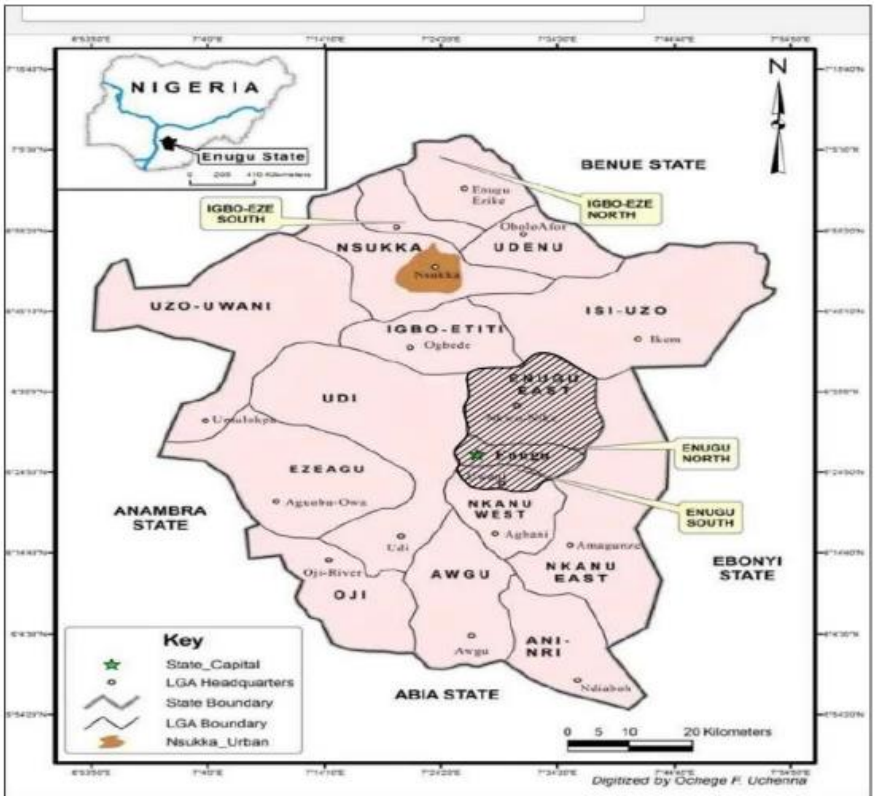


Figure 1: Map of Enugu state (Ochege, 2016)

3.0 Materials and Methods

Materials used in this study were LandSAT imageries covering the years that were considered in the study. The imageries used and their details are provided in Table 1.

Table 1: LandSAT images used for the study

S/N	DATA TYPE	DATE OF ACQUISITION	SCALE	SOURCE
1	Landsat ETM+	1999	30	USGS
2	Landsat ETM+	2007	30	USGS
3	Landsat ETM+	2016	30	USGS
4	Landsat OLI & TIRS	2022	30	USGS

Figure 2 present the work flow diagram illustrating the procedures and processes that were undertaken in this study. The raw LandSAT imageries as stipulated in Table 1 were collected and preprocessed. Radiometric and atmospheric corrections for top of atmosphere (TOA) reflectance of the Landsat satellite data was done using the models for the individual Landsat satellite sensor as given in equations (1) and (2). The formula for the conversion from DN to TOA reflectance for LandSAT 8 is given by (1) while that for converting from DN to TOA reflectance for LandSAT 7 ETM+ is given by (2a).

$$\boldsymbol{\rho_\lambda = \frac{[(M_p \times Q_{cal}) + A_p]}{\sin(SE)}} \quad (1)$$

Where;

$\boldsymbol{\rho_\lambda}$ = TOA planetary reflectance with correction for solar angle
$\boldsymbol{M_p}$ = Band-specific multiplicative rescaling factor from the metadata for the different bands
$\boldsymbol{Q_{cal}}$ = Satellite imagery (DN)
$\boldsymbol{A_p}$ = Band-specific additive rescaling factor from the metadata for each band
SE = Local solar elevation

$$\boldsymbol{\rho_\lambda = \frac{\pi \times L_\lambda \times d^2}{ESUN_\lambda \times \cos\theta_s}} \quad (2a)$$

Where;

$\boldsymbol{\rho_\lambda}$ = Unitless planetary reflectance
$\boldsymbol{L_\lambda}$ = Spectral radiance (from ‘(3.2)’)
d = Earth-Sun distance in astronomical units
$\boldsymbol{ESUN_\lambda}$ = Mean exo-atmospheric solar irradiance
$\boldsymbol{\theta_s}$ = Solar zenith angle
$\boldsymbol{L_\lambda} = [\text{Band Specific Gain} \times \text{DN}] + \text{Band Specific Bias} \quad (2b)$
‘$\boldsymbol{L_\lambda}$’ = Radiance

The TOA reflectance was then processed in ArcMAP to obtain the NDVI and SAVI using equations (3) and (4) respectively. From the obtained NDVI and SAVI values, zonal statistics was computed in ArcMAP to extract the trend of the generated NDVI and SAVI values.

$$\boldsymbol{NDVI = \frac{(NIR - R)}{(NIR + R)}} \quad (3)$$

Where
NIR = Near InfraRed
R = Red

L = Soil factor

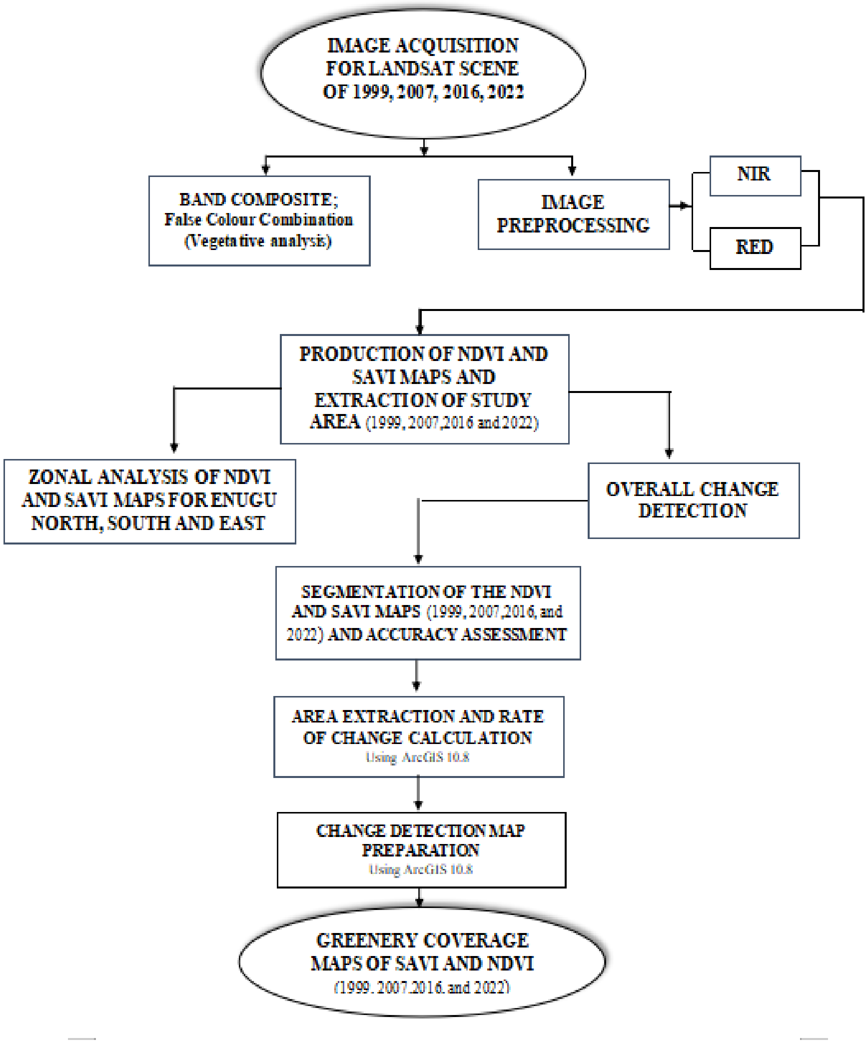


Figure 2: Workflow diagram

The obtained NDVI and SAVI were then subjected to come form of supervised Boolean classification to delineate areas that correspond to greeneries from other land uses.

The measurement of greenery change from year to year in the classified image was thereafter executed by NDVI and SAVI differencing. This technique compares the total area covered in square meters for greenery in a particular year with respect to another year. For this study, the NDVI 1999 greenery coverage was subtracted from NDVI 2007, NDVI 2007 greenery coverage was subtracted from NDVI 2016, and NDVI 2016 greenery coverage was subtracted from NDVI 2022.The rate of change is shown in the equation (5)

$$\textbf{Greenery Change} = \left[\frac{\textbf{Greenery Coverage}_{2016} - \textbf{Greenery Coverage}_{2022}}{\textbf{Total Area}}\right] \times \mathbf{100} \qquad (5)$$

To identify the 'Total Area of Change' in square meters, the results obtained from the 'Greenery Coverage Differencing' was used to estimate the 'Total Area of Change' in Greenery Cover.

4.0 Results and Discussion

The mean, maximum and minimum values of the NDVI and SAVI obtained in all local governments within the study area are presented in Tables 2(a) – (d). This was obtained using the zonal statistics in the Arc Toolbox.

Table 2(a): Zonal Statistics for 1999 of the Study Area on NDVI and SAVI Models

VEGETATIVE INDEX	LGA	AREA	MIN	MAX	MEAN
NDVI	Enugu East	329875200	-0.0418	0.579916	0.314862
	Enugu North	157510800	0.0600	0.575134	0.26908
	Enugu South	70171200	-0.0978	0.604445	0.280213
SAVI	Enugu East	329875200	-0.0189	0.41163	0.190009
	Enugu North	157510800	0.0353	0.409336	0.166257
	Enugu South	70171200	-0.0524	0.428003	0.173262

Table 2(b): Zonal Statistics for 2007 of the Study Area on NDVI and SAVI Models

VEGETATIVE INDEX	LGA	AREA	MIN	MAX	MEAN
NDVI	Enugu East	329875200	0.110616	0.521246	0.335501
	Enugu North	157510800	0.100735	0.484302	0.276065
	Enugu South	70171200	0.105745	0.509969	0.306842
SAVI	Enugu East	329875200	0.059742	0.317263	0.178485
	Enugu North	157510800	0.053627	0.293436	0.161106

	Enugu South	70171200	0.057272	0.322231	0.174625

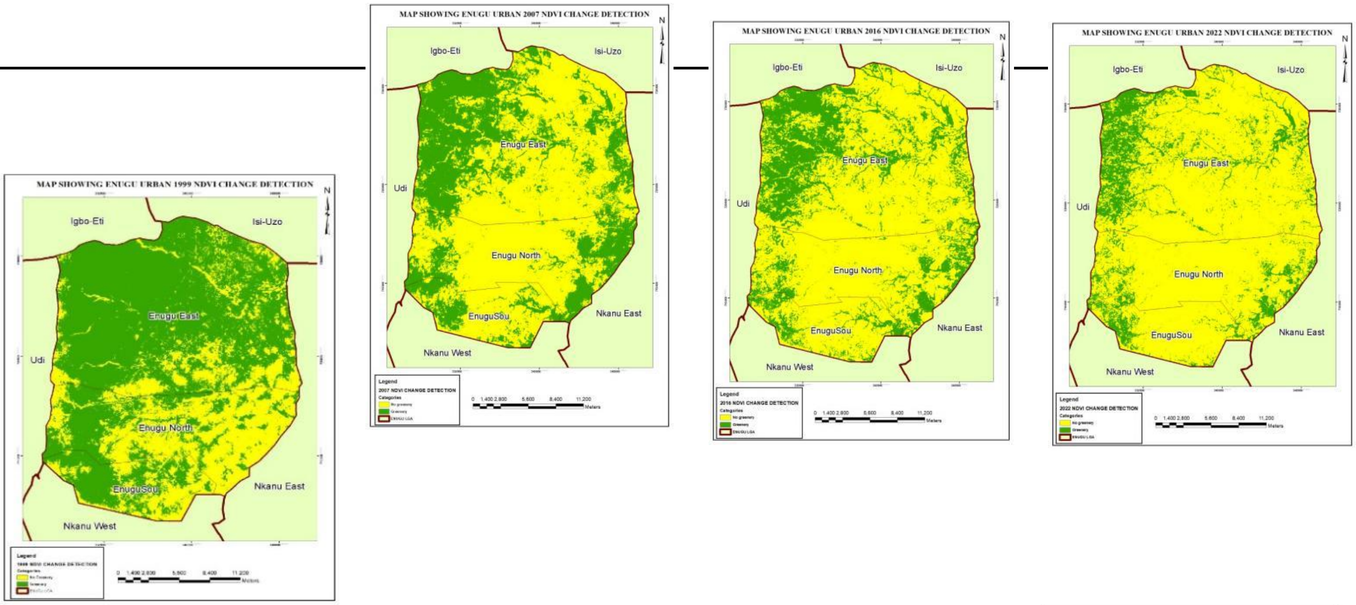
VEGETATIVE INDEX	LGA	AREA	MIN	MAX	MEAN
NDVI	Enugu East	329875200	0.039671	0.348608	0.182584
	Enugu North	157510800	0.032157	0.393844	0.162236
	Enugu South	70171200	0.036567	0.366503	0.171628
SAVI	Enugu East	329875200	0.015042	0.137799	0.069534
	Enugu North	157510800	0.012259	0.147516	0.062898
	Enugu South	70171200	0.013674	0.138434	0.065887

Table 2(c): Zonal Statistics for 2016 of the Study Area on NDVI and SAVI Models

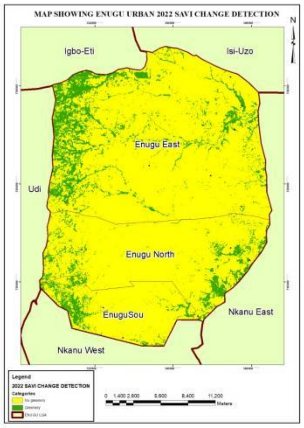
VEGETATIVE INDEX	LGA	AREA	MIN	MAX	MEAN
NDVI	Enugu East	329875200	-0.0219	0.5646	0.2857
	Enugu North	157510800	0.0592	0.5455	0.2386
	Enugu South	70171200	-0.0716	0.5710	0.2443
SAVI	Enugu East	329875200	-0.0103	0.3853	0.1716
	Enugu North	157510800	0.0310	0.3872	0.1467
	Enugu South	70171200	-0.0339	0.4139	0.1513

Table 2(d): Zonal Statistics for 2022 of the Study Area on NDVI and SAVI Models

Using the NDVI and SAVI values, equation (5) was applied to the obtained classified maps for each year and the results thus obtained (indicating the greeneries change) from NDVI and SAVI are as shown Figures 3(a) – (h)



(a) NDVI in 1999 (b) NDVI in 2007 (c) NDVI in 2016 (d) NDVI in 2022



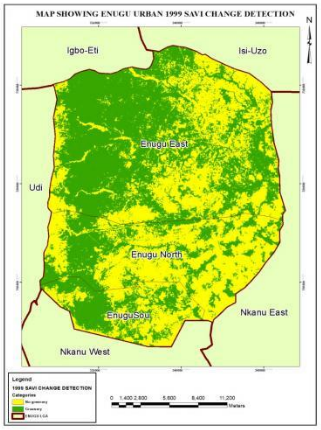
(e) SAVI in 1999 (f) SAVI in 2007 (g) SAVI in 2016 (h) SAVI in 2022

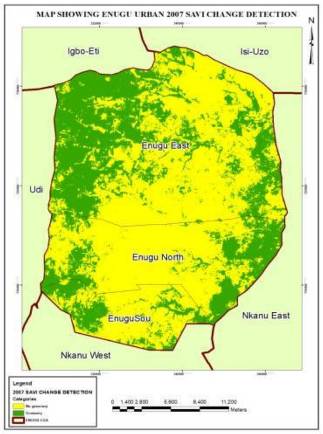
Figure 3(a – h): Change detection by NDVI and SAVI in different seasons

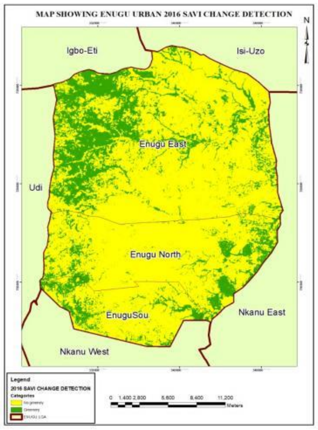
The graphically depicted changes are similarly numerically presented in Tables 3(a) and (b).

YEARS	ENUGU EAST	ENUGU NORTH	ENUGU SOUTH
1999-2007	19%	12%	23%
2007-2016	28%	29%	24%
2016-2022	58%	63%	55%

Table 3(a): percentage change in area covered by Greenery obtained from NDVI







YEARS	ENUGU EAST	ENUGU NORTH	ENUGU SOUTH
1999-2007	33%	14%	27%
2007-2016	12%	9%	18%
2016-2022	39%	33%	25%

Table 3(b): percentage change in area covered by Greenery obtained from SAVI

A summary of the results obtained from the image classification of the NDVI and SAVI values is also presented in Figure 4.

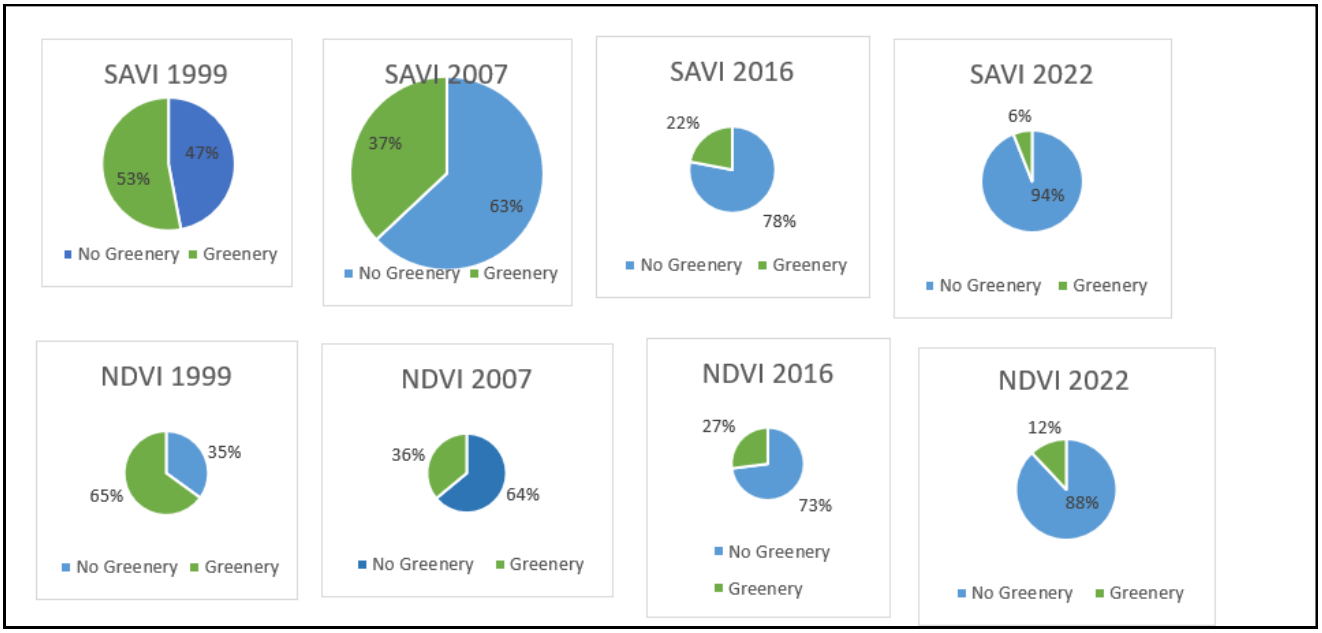


Figure 4: NDVI and SAVI Pie Charts Showing % of Greenery and Non-greenery in Enugu Urban from 1999-2022

The presented data (as encapsulated in Tables and Figures), unequivocally signifies a persistent and alarming decline in the greenery area within the study area, as unveiled through comprehensive analyses using both the Soil Adjusted Vegetation Index (SAVI) and the Normalized Difference Vegetation Index (NDVI). Over the examined period, NDVI highlights a drastic reduction in greenery coverage within Enugu metropolis, plummeting from 65% in 1999 to a mere 12% in 2022. This unsettling trend is echoed in the SAVI values, where greenery diminished from 53% in

1999 to a stark 6% in 2022. This concerning trajectory reveals the necessity for immediate and concerted afforestation initiatives to rejuvenate the greenery profile of the Enugu urban metropolis.

Importantly, the congruence observed in the results from both vegetative indices, NDVI and SAVI, reinforces their robustness and applicability. This consistency not only bolsters their reliability in monitoring vegetation health and presence but also emphasizes their complementary nature in understanding the intricate dynamics of greenery in urban landscapes. These findings align with previous research by Huete et al. (1997), emphasizing the efficacy of SAVI in mitigating the impact of soil background influences in densely built environments, and providing a nuanced perspective on urban vegetation assessment.

5.0 Conclusion

The spatio-temporal assessment of Enugu Urban's greenery reveals a robust correlation between NDVI and SAVI, establishing them as reliable indicators for monitoring vegetation health and moisture content. Supervised classification images and green coverage tables provide valuable resources for urban planners and policymakers, aiding informed decisions on land use and conservation. Change analysis tables highlight the delicate equilibrium between urbanization and greenery preservation, emphasizing the need for sustainable development practices prioritizing green spaces. The observed rate of greenery cover change stresses the necessity for adaptive urban planning, urging city authorities to preserve and enhance green areas. Overall, these results underscore the dynamic nature of Enugu Urban's greenery and advocate for sustainable urban development, emphasizing the crucial balance between growth and greenery preservation to ensure a thriving and environmentally conscious metropolis for future generation

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