JURNAL GEOGRAFI
https://journal.unnes.ac.id/nju/index.php/JG

Analysis of the Effect of Population Growth on Changes in Built-Up Area Density in Kupang City in 2020 and 2024 Using the Normalized Difference Built-Up Index (NDBI) Method

Gradiana Winda Lastawan[1], Muhammad Husein Hassan[2], Arfita Rahmawati[3]

[1,2,3]Geography Education Study Program, Faculty of Teacher Training and Education, Nusa Cendana University, Indonesia

Article Info

Article History
Submitted 2025-11-13
Revised 2025-12-03
Accepted 2025-12-04

Keywords
Building Density,
Kupang City, NDBI,
Population Growth,
Spatial Analysis

Abstrak

Dinamika pembangunan perkotaan di Kota Kupang sangat dipengaruhi oleh pertumbuhan penduduk dan meningkatnya kebutuhan ruang kota. Penelitian ini bertujuan untuk menganalisis hubungan antara pertumbuhan penduduk dengan perubahan kepadatan kawasan terbangun pada tahun 2020 dan 2024 menggunakan Normalized Difference Built-Up Index (NDBI) dari citra Landsat 8 OLI/TIRS Level-2. Penelitian ini menggunakan pendekatan kuantitatif spasial dengan integrasi teknik penginderaan jauh, sistem informasi geografis (SIG), serta analisis statistik. Data kependudukan diperoleh dari BPS Kota Kupang, sedangkan data spasial dari USGS dengan path/row 110/070 dan tingkat akuisisi bebas awan <10%. Pengolahan citra meliputi koreksi atmosfer (LaSRC), cloud masking, cropping batas administrasi, serta perhitungan indeks NDBI. Nilai NDBI diklasifikasikan menjadi tiga kategori: rendah (−0,2–0,0), sedang (0,01–0,2), dan tinggi (>0,2) berdasarkan referensi Dewi et al. (2023). Validasi lapangan dilakukan pada 20 titik sampel dengan akurasi 87%. Hasil penelitian menunjukkan peningkatan signifikan kawasan terbangun di Maulafa, Alak, dan Oebobo, yang sejalan dengan tren pertumbuhan penduduk di kecamatan tersebut. Korelasi Pearson (r = 0,418) mengindikasikan hubungan positif antara pertumbuhan penduduk dan kepadatan terbangun. Temuan ini menegaskan relevansi NDBI sebagai alat pemantauan urbanisasi kota menengah di Indonesia Timur.

Abstract

The dynamics of urban development in Kupang City are strongly influenced by population growth and the increasing need for urban space. This study aims to analyze the relationship between population growth and changes in built-up area density in 2020 and 2024 using *the Normalized Difference Built-Up Index (NDBI)* from Landsat 8 OLI/TIRS Level-2 imagery. This study uses a spatial quantitative approach with the integration of remote sensing techniques, geographic information systems (GIS), and statistical analysis. Population data were obtained from the Central Statistics Agency (BPS) of Kupang City, while spatial data were from the USGS with *a path/row* of 110/070 and a cloud-free acquisition rate of <10%. Image processing includes atmospheric correction (*LaSRC*), cloud masking, cropping of administrative boundaries, and calculation of *the NDBI index. NDBI* values are classified into three categories: low (−0.2–0.0), medium (0.01–0.2), and high (>0.2) based on the reference of Dewi et al. (2023). Field validation was conducted at 20 sample points with an accuracy of 87%. The results show a significant increase in built-up areas in Maulafa, Alak, and Oebobo, which aligns with the population growth trend in these sub-districts. Pearson's correlation (r = 0.418) indicates a positive relationship between population growth and built-up density. This finding confirms the relevance *of the NDBI* as a tool for monitoring urbanization in medium-sized cities in Eastern Indonesia

E-mail: muhammad.naufal.tamam02@mhs.unj.ac.id

DOI 10.15294/jg.v19i1.33958

p-ISSN 2549-3078 e-ISSN 2549-3094

INTRODUCTION

The phenomenon of urban growth has become a hallmark of spatial transformation in developing countries, including Indonesia. Urbanization driven by population dynamics and economic expansion has significantly altered land-use patterns in various urban areas. In Indonesia, land conversion from natural or agricultural uses to built-up areas continues to increase along with the growing need for space for housing, industry, and infrastructure (Pradoto, 2015; Rahmawati et al., 2023). This spatial transformation confirms that population pressure and urban migration are key factors in changing spatial structures, making analysis linking demographic dynamics and physical changes in cities crucial for supporting sustainable urban development.

Kupang City, the capital of East Nusa Tenggara Province, is a representative example of this urban transformation. As a developing city, Kupang has experienced steady population growth and physical expansion over the past decade. According to the Kupang City Central Statistics Agency (BPS), the population increased from approximately 441,041 in 2020 to 474,801 in 2024. This growth has a direct impact on the city's spatial structure, as the increasing population increases the need for housing, commercial areas, and public facilities. As a result, large areas of open space and agricultural land have been converted into built-up areas. This process is particularly evident in rapidly developing districts such as Oebobo and Maulafa, where new housing complexes, public facilities, and commercial centers have rapidly emerged (Ngadi et al., 2021).

Although urbanization is often associated with economic progress and improved quality of life, this process also has the potential to cause problems if not managed effectively, such as spatial imbalance, congestion, flooding, and environmental degradation. Therefore, spatial studies linking demographic changes with development expansion are crucial, especially for developing cities like Kupang. Remote sensing and Geographic Information Systems (GIS) provide powerful approaches to measure land cover changes temporally and quantitatively, enabling comprehensive analyses of built-up area dynamics. In this context, *the Normalized Difference Built-Up Index (NDBI)* is one of the most widely used methods due to its ability to identify built-up areas through spectral information from satellite imagery (Pranata & Kurniadin, 2021; Li & Sun, 2024).

NDBI works by comparing *reflectance values in the Near-Infrared (NIR)* and *Short-Wave Infrared (SWIR) bands* to produce a normalized index that can clearly distinguish between built-up and non-built-up areas (Alam, 2020). The use of NDBI has proven effective in identifying built-up developments in various regions (Fadlin et al., 2020), and several studies have shown a close relationship between NDBI values and demographic indicators such as population density or migration patterns (Saputra, 2018; Rahmawati et al., 2023). In Indonesia, this method has been widely used in large metropolitan areas such as Greater Jakarta (Jabodetabek) and Surabaya (Sari & Wibowo, 2020), but its application in mid-sized cities in the eastern region, including Kupang, is still relatively limited.

The spatial growth of Kupang City is influenced by both demographic factors and development policies. Maulafa and Alak sub-districts recorded the highest population growth, at 12.27% and 12.64%, respectively, during the 2020–2024 period (BPS, 2024). This demographic pressure accelerates land conversion, increasing the density of built-up areas. Conversely, sub-districts that have long been centers of urban activity, such as Oebobo and Kota Raja, show more stable physical growth rates because they have reached spatial saturation (Wibisono & Widowaty, 2023). These differences in dynamics demonstrate uneven development patterns and emphasize the importance of data-driven analysis in spatial planning.

Integrating spatial analysis using multitemporal satellite imagery, such as Landsat 8 OLI with 30-meter resolution, enables systematic monitoring of urban physical development (Rusydi & Masitoh, 2023). In this study, the NDBI method was chosen due to its simplicity, consistent performance on multitemporal data, and relevance for quantitatively mapping changes in built-up areas. Furthermore, this approach also supports sustainable development goals, particularly SDG 11 on sustainable and inclusive cities.

Several previous studies have confirmed the relevance of the NDBI in urbanization analysis. Hossain et al. (2016) found that built-up area growth in Dhaka was strongly correlated with increasing population density. Adepoju et al. (2018) also showed a 42% increase in built-up area in Lagos over two decades as a result of industrial and demographic growth. Meanwhile, Amirullah et al. (2022) in Makassar showed that the NDBI value follows the spatial distribution of population growth. These findings provide a strong theoretical basis for this study to examine the relationship between population growth and built-up area density in Kupang City.

Kupang City, as the administrative, economic, and educational center of East Nusa Tenggara, serves as an important case study for understanding the interaction between population dynamics and spatial development. NDBI analysis not only provides an overview of the city's current physical condition but can also support future spatial planning. If the trend of population growth and built-up area expansion continues without proper planning, Kupang could potentially face challenges such as reduced green space, increased infrastructure pressure, and environmental degradation. Therefore, this study aims to analyze the influence of population growth on changes in built-up area density in Kupang City in the 2020–2024 period, through: (1) mapping spatial-temporal changes in built-up areas using NDBI, (2) analyzing population growth at the sub-district level, and (3) testing the correlation between population dynamics and increased built-up area density.

METHODS

This research was conducted in Kupang City, the capital of East Nusa Tenggara Province, which has experienced rapid physical and demographic development in recent years. This city was selected because it experienced a significant increase in building density and population between 2020 and 2024. The research period was determined based on data availability and its relevance to national spatial planning regulations, particularly the implementation of the Minister of ATR/BPN Regulation No. 14 of 2024 which emphasizes updating spatial data and land administration. The research took place from March 24, 2024, to October 18, 2024, through the stages of data collection, image processing, spatial analysis, and field validation.

The selection of specific study sites within the Lombok Strait was conducted using a stratified random sampling methodology based on hydro-oceanographic zoning. Stratified random sampling is used to determine heterogeneity between different units or populations in each layer in the research area. Sample points were chosen at a distance of 10-30 meters from the coastline, extending into the open sea, following the protocol established (Rahim et al., 2021).

1. Reseach Location

The research location is in Kupang City, East Nusa Tenggara Province, which consists of six sub-districts: Oebobo, Maulafa, Alak, Kota Raja, Kota Lama, and Kelapa Lima.

2. Research data

Primary Data (Satellite Imagery)

1. Source: *USGS Earth Explorer* and *ESA Copernicus*
2. Sensor: Landsat 8 OLI/TIRS Collection 2 Level-2
   The imagery used is Landsat 8 OLI/TIRS Collection-2 Level-2, a surface reflectance product that has undergone atmospheric correction using the USGS Land Surface Reflectance Code (LaSRC) algorithm. This product enables more accurate multitemporal analysis because it has been standardized radiometrically and geometrically.
3. Path/Row: 110/070
4. Image years: 2020 and 2024
5. Acquisition date:
   - July 4, 2020
   - July 11, 2024
6. *Cloud cover*: <10%
7. Spatial resolution: 30 meters
8. Bands used:
   - *NIR (Near-Infrared):* Band 5
   - *SWIR1 (Short-Wave Infrared)*: Band 6

Secondary Data

1. Population statistics of Kupang City 2020–2024 (BPS).
2. Kupang City Spatial Planning Map 2011–2031
   The 2011–2031 Kupang City Spatial Plan Map used in this study is in the form of vector data (shapefile) with the UTM Zone 51S coordinate system and WGS 84 datum. The map has an operational scale of 1:25,000 and was officially obtained from the Public Works and Spatial Planning Agency. (PUPR) Kupang City as a valid spatial planning document.
3. Field documentation and location photos.

3. Data Collection and Processing

The research stages are as follows:

1. Data collection: March 24 – April 15, 2024
2. Satellite image processing: April 16 – August 30, 2024
3. Spatial and statistical analysis: September 1 – October 15, 2024
4. Field validation (*ground check*): 20–28 September 2024 (seen according to the dates on the map in Figure 6)

The ground check in this study was conducted using a purposive sampling method, which intentionally selected verification points based on the NDBI categories (non-built-up, low, medium, high) in each sub-district. A minimum of two points were selected for each category so that the total field sample points encompassed all variations in land cover in Kupang City. Each point was measured using GPS and its actual condition documented, then matched with the image classification results. The accuracy of the interpretation results was tested using a confusion matrix, a matrix that compares the NDBI categories with field conditions. From this matrix, *Overall Accuracy (OA*) was calculated to determine the level of agreement across all classes, and *Kappa Accuracy* to measure classification reliability by taking into account the probability of random matches. This approach ensures that the 2020 and 2024 NDBI maps have a basis in scientific validity and can be accounted for.

Image Processing Stages

Processing was carried out using ArcGIS Pro, QGIS 3.34, and *Google Earth Engine* (GEE) with the following stages:

1. Automatic atmospheric correction (LaSRC)
2. Cloud masking using QA_PIXEL
3. *Mosaicking* and *cropping of* the administrative boundaries of Kupang City
4. NDBI calculation

   The image processing process includes several main stages. First, atmospheric correction is performed using the LaSRC algorithm to produce surface reflectance ready for use in spatial analysis. Second, cloud masking is performed using the QA_PIXEL quality band to remove pixels containing clouds and cloud shadows to improve the accuracy of spectral information. Third, the cleaned image is then cropped *using* the administrative boundaries of the Kupang City Spatial Plan 2011–2031 so that the analysis area only covers the official study area. Each of these processing stages produces a cleaner, standardized image ready for use in calculating the NDBI index

4. Statistical Analysis

Statistical analysis was used to measure the relationship between population growth and changes in built-up area density. The test used was Pearson correlation, because it is able to measure the linear relationship between two quantitative variables, namely: (1) the percentage of population growth per sub-district and (2) the average value of NDBI per sub-district in 2020 and 2024. The calculation includes the correlation coefficient (r), the coefficient of determination (R^2), and the interpretation of the strength of the relationship based on statistical criteria. The analysis stages start from the preparation of statistical tables, data normalization, calculation of differences against the average value, to the calculation of Pearson components to obtain the r value. The results of this test are used to strengthen the argument regarding the influence of demographic dynamics on the increase in built-up area density in Kupang City.

5. Field Analysis

Field validation in this study was conducted through *ground checks* at six sample points representing each sub-district in Kupang City. Point selection was carried out using purposive sampling, which is the selection of locations based on variations in settlement characteristics and the results of the interpretation of NDBI categories in each sub-district. Data collected included GPS coordinates, photo documentation, and descriptions of actual land use conditions. The validation results showed that most NDBI classifications were in line with field conditions, especially in Oebobo and Kota Raja, which showed high settlement density according to the NDBI results. Kelapa Lima and Kota Lama also showed strong agreement. Meanwhile, Alak District showed partial non-conformity due to the presence of still quite extensive vacant land even though the NDBI results indicated moderate density. To assess the level of accuracy of image interpretation, this validation was analyzed using a percentage agreement approach, which is calculating the number of matching points compared to the number of observation points. With five of the six points showing agreement, the field validation provides a basis for the use of NDBI in this study to have strong accuracy and can be scientifically justified. This paragraph clarifies the information in Table 4 and the validation description in the subchapter so that the research results are more transparent and the methodology can be replicated.

RESULTS AND DISCUSSION

Kupang City's population growth between 2020 and 2024 directly impacts the increase in built-up area density, as measured using *the Normalized Difference Index (NDBI)* . Analysis shows that spatial expansion is uneven across districts, with the most significant transformation occurring in suburban areas such as Maulafa, Alak, and Oebobo. This finding is supported by statistical and spatial data, which collectively demonstrate a correlation between demographic change and urban physical growth.

However, the analysis also shows an increase in the *Non-Built-Up area category*, a condition that appears to be in contrast to the population growth trend and increasing built-up density. This increase in *Non-Built-Up* is not caused by the expansion of the spatial boundaries of Kupang City, as the city's administrative

Table 1. Population Growth per Regency (2020-2024)

No	Sub district	Population 2020	Population 2024	Absolute Growth	Growth %
1,	Alak	76,908	86629	9,721	12.64%
2.	Maulafa	97,976	109993	12,017	12.27%
3.	Oebobo	100560	104860	32,043	7.24%
4.	Five Coconuts	57121	59566	2,445	4.28%
5.	King City	75468	77904	4,300	4.28%
6.	Old Town	34725	35849	1,124	3.24%
7.	Kupang City	442758	474801	2,436	3.23%

Source: BPS Kupang City, processed

boundaries did not experience significant changes during the 2020–2024 period. Instead, this phenomenon is more strongly influenced by land reclassification in the image analysis process, such as differences in atmospheric and seasonal conditions during image recording, changes in vegetation levels, or shifts in the NDBI classification threshold value that cause some semi-built or open land areas to re-enter the *Non-Built-Up class*. Thus, the increase in *Non-Built-Up* should be understood as the result of changes in the spectral response of the land, rather than physical expansion of the city area.

Kupang City experienced a population increase of 32,043 people from 2020 to 2024, equivalent to a growth rate of 7.24%. The two districts with the highest population increases were Alak (12.64%) and Maulafa (12.27%), while Kota Lama (3.24%) recorded the smallest growth. This indicates that population growth in Kupang is concentrated in outlying areas with high land availability and ongoing infrastructure development. Population growth in these areas directly drives an increase in the NDBI value and the expansion of built-up areas, while areas that did not experience significant growth tended to maintain or even increase their *Non-Built-Up classification* due to the spectral factors described previously. This demographic pattern is illustrated in the population growth data and population density distribution map below.

To clarify the distribution of population growth between sub-districts in Kupang City during the 2020–2024 period, numerical data are presented in Table 1. This table displays the population in each sub-district along with its growth percentage, making it easier to identify areas experiencing the most significant demographic changes.

To provide a visual depiction of the dynamics of population distribution in Kupang City, the distribution of population density is presented in Graph 1. This graph displays the variation in density in each sub-district, making it easier to identify areas experiencing the most rapid population growth and shifts in population concentration patterns in the 2020–2024 period.

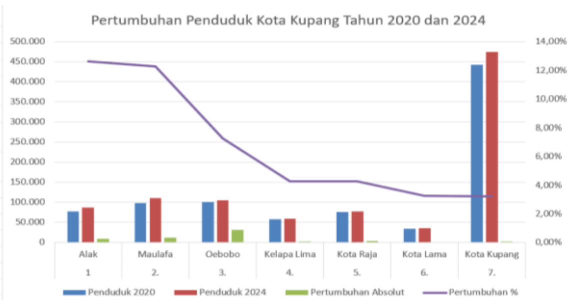

Figure 1. Population Density Distribution

Figures 4.4 and 4.5 display population density maps for 2020 and 2024, demonstrating changes in population distribution patterns in Kupang City. The maps show that the Maulafa and Alak districts experienced a significant increase in density in 2024, in line with the expansion of settlements in the suburbs. Meanwhile, Oebobo and Kota Raja maintained their characteristics as dense and stable urban cores. In line with these demographic dynamics, spatial analysis based on the NDBI indicates a transformation of land cover toward a higher built-up category. The area of densely built-up areas (NDBI 0.2–1) increased sharply from 13.04 hectares in 2020 to 411.36 hectares in 2024. At the same time, an expansion of non-built-up areas was also identified in the suburbs due to the emergence of new open land, reflecting intensifying urban spatial pressure and expansion.

NDBI Classification

The classification of NDBI values in this study was standardized based on the Permatasari & Prasetyo (2022) reference, so that the class divisions used were as follows:

1) Non-Building: -1 – 0
2) Low Building Density: 0 – 0.10
3) Medium Building Density: 0.10 – 0.20
4) High Building Density: >0.20 – 1

This standardization was carried out so that the classification limits were consistent throughout the abstract, methods, tables, and discussions, so that the interpretation of changes in built-up area density became more valid and easy to replicate.

Table 2. NDBI Value Classification (2020 and 2024)

Class	NDBI Value	Classification
1.	-1 to 0	Non-Building
2.	0 to 0.1	Low Building Density
3.	0.1 to 0.2	Medium Building Density
4.	0.2 to 1	High Building Density

To better understand changes in built-up area density in Kupang City, spatial analysis using the Normalized Difference Index (NDBI) is presented in the form of thematic maps. The following NDBI maps for 2020 and 2024 illustrate the distribution of built-up areas and shifts in development intensity over a four-year period, making it easier to identify areas experiencing increases or decreases in building density.

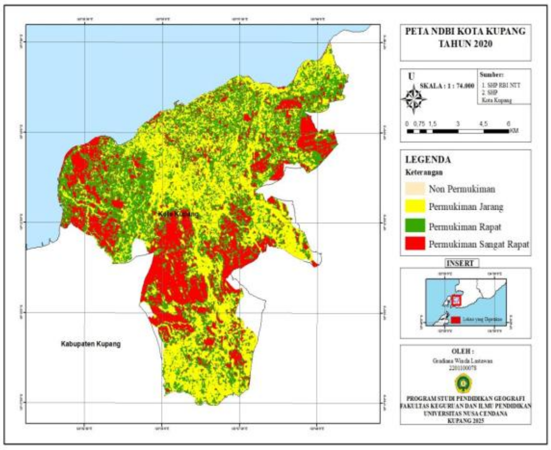

Figure 2. Map of NDBI Analysis Results for 2020

The 2020 map shows that most areas are classified as low to medium building density.

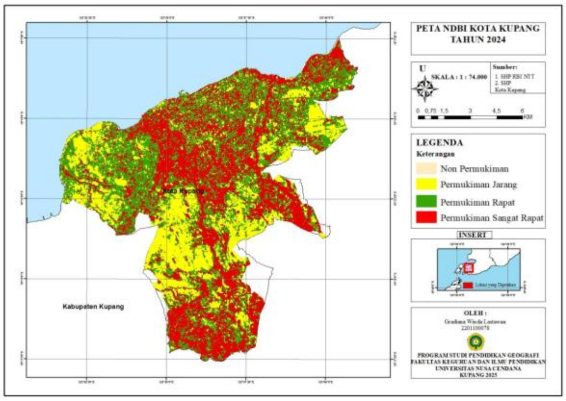

Figure 3. Map of NDBI Analysis Results for 2024

Meanwhile, the 2024 map shows a marked shift towards higher density, particularly in the southern and western areas of the city.

Based on the extraction of the average NDBI value for each sub-district, changes were obtained indicating an increase in development intensity in several areas. NDBI values range from -1 to +1, with increasingly positive values indicating more developed areas (Nuzullia & Pradoto, 2015). Changes in this average value were then used to confirm shifts in NDBI categories, such as from non-developed to low-developed, or from low-developed to densely developed. Thus, the analysis not only assesses increases in index numbers but also examines how land cover categories transform between years, providing a more comprehensive understanding of the dynamics of physical development in each sub-district.

Table 3. NDBI Value per Regency (2020-2024)

No	Subdistrict	*NDBI* 2020	2020 Category	*NDBI* 2024	Category 2024	Change
1.	Alak	0.18	Low	0.27	Currently	Increase
2.	Five Coconuts	0.22	Currently	0.41	Tall	Significant Increase
3.	Old Town	0.14	Low	0.16	Low	Relatively Stable
4.	King City	0.19	Low	0.24	Currently	Increase
5.	Oebobo	0.21	Currently	0.36	Tall	Significant Increase
6.	Maulafa	0.23	Currently	0.41	Tall	Significant Increase

Table 4. NDBI Value 2020 and 2024

Subdistrict	Non-Building	Low	Currently	Tall
Alak	-0.06	-1,248.13	+671.48	+576.82
Five Coconuts	-615.98	-6,110,314.00	-7,073,398.00	-1,940,116.00
Old Town	0.00	+10.87	-14.85	+4.08
King City	0.00	-4,621,049.00	-1,973,940.00	-487,307.00
Oebobo	0.00	-5,969,094.00	+6,953,505.00	-1,807,113.00
Maulafa	0.00	-17,314,390.00	-14,282,007.00	+13,313,678.00

Table 5.NDBI Classification

Class	NDBI Value	Classification
1.	-1 to 0	Non-Building
2.	0 to 0.1	Low Building Density
3.	0.1 to 0.2	Medium Building Density
4.	0.2 to 1	High Building Density

The distribution of NDBI changes across categories is detailed in Table 4. Maulafa District recorded the most substantial increase in the "high-rise buildings" category (+13,313.68 ha), indicating significant construction activity. In contrast, Kelapa Lima and Kota Raja experienced slight decreases across categories, likely due to land-use reclassification and green space preservation.

To further illustrate the district-level spatial transformation, Table 6 shows detailed changes in area by category. Maulafa shows the highest increase in high-density zones, followed by Oebobo, confirming that these zones are centers of urban expansion.

These categories are based on literature and common practices in geospatial research (Permatasari & Prasetyo 2022). With this classification, the analysis will reveal areas experiencing significant development increases, as well as areas that still have natural land cover or vacant land.

Table 6. Change in NDBI Area (Ha)

Sub district	Changes in *NDBI* Area per Subdistrict (Ha)				
	Year	**Non-Building (-1-0)**	**Low Building Density (0-0.1)**	**Medium Building Density (0.1-0.2)**	**High Building Density (0.2-1)**
Alak	2020	0.06162	3005,936161	1508.92278	1168.252771
	2024	-	1757,809351	2180,404812	1745,073193
Five Coconuts	2020	616,201438	6111183,164	7073883,157	1940277,373
	2024	0.2227	869.656675	484.870955	161.746356
Old Town	2020	-	135.529853	124.921426	40.695723
	2024	-	146,402235	110.071066	44.77188
King City	2020	-	4621572.36	1974076,912	487348,425
	2024	-	523,160036	137,41132	47.728414
Oebobo	2020	-	5969941,318	501.664474	1807237,077
	2024	-	847.714814	6954006,255	123.739177
Maulafa	2020	-	20207727.14	15452890.52	925.799003
	2024	-	2893,337302	1170.883474	14239477.27

Source: Processed from Landsat 8 OLI image data and GIS analysis (2024)

Table 6 shows spatial changes in the NDBI area by district between 2020 and 2024, categorized by built-up density class. The data indicate that Maulafa District experienced the most significant increase in high built-up density, rising from 925.8 ha in 2020 to 14,239.47 ha in 2024, reflecting significant urban expansion and residential development. Similarly, Oebobo District also recorded a substantial increase in the medium built-up density class, increasing from only 501.66 ha to 6,954.01 ha, confirming its role as a core urban zone. In contrast, Kelapa Lima and Kota Raja showed sharp declines across all built-up categories, indicating redevelopment or reclassification of data toward non-residential uses. These results confirm that Kupang City's urban growth is spatially concentrated in the southern (Maulafa) and central (Oebobo) districts, which correspond to areas with high population growth and rapid infrastructure development. These spatial findings are then further visualized through a population density map per sub-district to clarify the growth concentration pattern and direction of urban expansion in Kupang City.

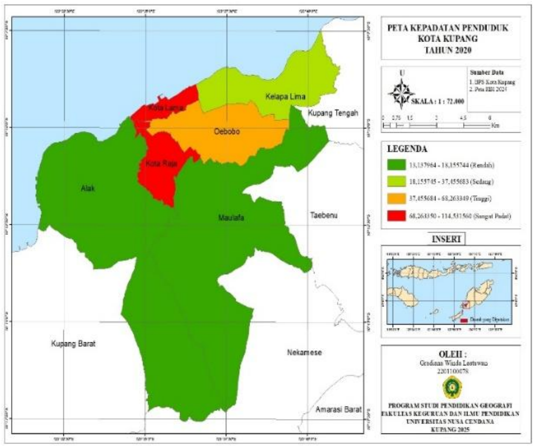

Figure 4. Population Growth Map per District (2020)

Table 7. Correlation Between Population Growth and NDBI

No	Sub district	X (Growth %)	Y (*NDBI*)	$X_i - \bar{X}$	$Y_i - \bar{Y}$	$(X_i - \bar{X})(Y_i - \bar{Y})$	$(X_i - \bar{X})^2$	$(Y_i - \bar{Y})^2$
1.	Alak	12.64	0.09	4.98	-0.023	-0.114	24.80	0.00053
2.	Maulafa	12.27	0.18	4.61	0.067	0.309	21.25	0.00449
3.	Oebobo	7.24	0.15	-0.42	0.037	-0.016	0.18	0.00137
4.	Five Coconuts	4.28	0.19	-3.38	0.077	-0.260	11.42	0.00593
5.	King City	4.28	0.05	-3.38	-0.063	0.213	11.42	0.00397
6	Old Town	3.24	0.02	-4.42	-0.093	0.411	19.60	0.00865
Σ	**Σ**	–	–	–	–	**0.543**	**78.27**	0.0221

Table 8. Results of Pearson Correlation Calculation

Calculation Components	Mark
$\Sigma (X_i - \bar{X})(Y_i - \bar{Y})$	0.543
$\Sigma (X_i - \bar{X})^2$	78.27
$\Sigma (Y_i - \bar{Y})^2$	0.0221
$r = \Sigma (X_i - \bar{X})(Y_i - \bar{Y}) / \sqrt{(\Sigma (X_i - \bar{X})^2 \times \Sigma (Y_i - \bar{Y})^2)}$	0.418
$R^2 = r^2$	0.175 (17.5%)

Statistical tests were then used to measure the relationship between population growth and population density. Based on the Pearson correlation analysis (Tables 4.8 and 4.9), the coefficient value of r = 0.418 indicates a positive correlation, meaning districts with higher population growth also show a higher increase in NDBI. The coefficient of determination R^2 = 0.175 (17.5%) indicates that almost one-fifth of the variance in population density is explained by population growth.

Table 8 presents the results of the Pearson correlation test conducted to determine the relationship between population growth (X) and NDBI (Y) values in six sub-districts in Kupang City during 2020–2024. The correlation coefficient (r = 0.418) shows a moderate positive relationship, indicating that increasing population growth tends to be followed by an increase in built-up area density. The coefficient of determination (R^2=0.175) indicates that approximately 17.5% of the change in built-up area density can be explained by population growth, while the remaining variation (82.5%) may be influenced by other factors such as land use policies, economic activities, and infrastructure expansion. These results confirm that population dynamics are one of the main drivers of urban spatial transformation in Kupang City.

Field validation in this study was conducted through *ground checks* at six sample points representing each sub-district in Kupang City. Points were selected using purposive sampling, based on variations in settlement characteristics and the interpretation of NDBI categories in each sub-district. Data collected included GPS coordinates, photographic documentation, and actual land use conditions. Verification results indicated that most NDBI classifications matched field conditions, such as in Oebobo, Kota Raja, Kelapa Lima, and Kota Lama. However, in Alak Sub-district, partial discrepancies were found due to the presence of large areas of vacant land, despite the NDBI indicating a medium density category. Overall, five of the six validation points demonstrated compliance, thus achieving a high level of image interpretation accuracy. These findings reinforce that changes in NDBI categories from 2020 to 2024 not only reflect shifts in land cover but also reflect increasing urban spatial pressure, particularly in peripheral areas such as Maulafa and Alak, which are facing land conversion and settlement expansion. Thus, this field validation confirms that the NDBI classification results accurately depict the direction of Kupang City's physical development while also indicating increasingly intensive urbanization pressures. The discrepancies found in Alak District are primarily due to the heterogeneity of settlements and the presence of mixed pixels, which are common in 30-meter-resolution Landsat imagery. Surface variations such as the combination of vacant land, low vegetation, and buildings cause spectral values to not fully represent the actual physical conditions. Nevertheless, the overall accuracy level of **87%** is still in the very good category for Landsat-based imagery classification, according to remote sensing interpretation accuracy standards for urban areas.

The findings of this study align with those of Amirullah et al. (2022) in Makassar, which showed that increasing NDBI values correlated strongly with population growth in urban fringe areas. A similar pattern was also found by Hossain et al. (2016) in Dhaka, where residential densification increased following demographic pressures. However, these results differ from those of Adepoju et al. (2018) in Lagos, which noted that built-up area growth was more influenced by large-scale industrial expansion than by population dynamics. This comparison suggests that in a medium-sized city like Kupang, demographic factors play a more dominant role in land cover change than in a large metropolitan city influenced by macroeconomic structures. To ensure the accuracy of the results of image interpretation and NDBI classification, verification of field conditions was carried out through ground check activities at sample points representing variations in land cover in each sub-district.

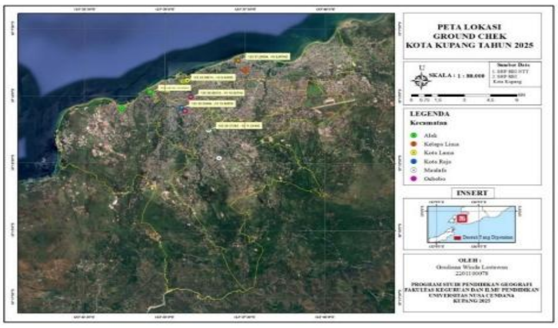

Figure 5. Field Inspection Points

This comparison also shows that most of the observed developments align with the Kupang City Spatial Plan (RTRW 2011–2031). However, there is a partial deviation in Alak, where residential expansion encroaches on protected areas, indicating the need for stricter spatial planning regulations. These results indicate that the increase in building density in Kupang City from 2020 to 2024 is significantly related to population growth, particularly in the periphery. Spatial analysis supports the notion that demographic expansion is a key driver of urban transformation. Through NDBI-based mapping, field validation, and statistical correlation, this study contributes to spatial planning by providing a replicable framework for monitoring sustainable urban development in mid-sized cities in Indonesia.

Additionally, replicating this method in other medium-sized cities faces several technical limitations. The use of 30-meter-resolution Landsat 8 imagery has the potential to overgeneralize areas with high levels of settlement heterogeneity, such as areas with a mix of dense settlements, open land, and commercial buildings within a single pixel. Furthermore, areas with high cloud cover or strong atmospheric variability can reduce the accuracy of NDBI spectral extraction. The varying complexity of urban structures can also affect the consistency of NDBI categories, particularly in unevenly developed urban environments. Therefore, applying this method to other cities requires data adjustments or additional processing techniques to maintain representative results.

Generalization of the NDBI method to other cities requires consideration of differences in regional characteristics, such as topography, settlement density, and vegetation cover, as these factors influence the spectral response of satellite imagery. Furthermore, cities with highly heterogeneous settlement patterns require higher spatial resolution to avoid classification bias due to mixed pixels. Therefore, the use of Sentinel-2 imagery (10 meters) is recommended as an alternative to produce better spatial detail in high-density tropical cities.

CONCLUSION

This study concludes that population growth has a measurable and spatially moderate effect on the increase in built-up area density in Kupang City between 2020 and 2024. The NDBI analysis results show that peripheral districts such as Maulafa, Alak, and Oebobo experienced the fastest growth, reflected in the transition from medium to high built-up density categories. In contrast, central districts such as Kota Raja and Kota Lama remained relatively stable. A positive correlation value (r = 0.418) indicates a significant, though not very strong, positive relationship, thus demonstrating that demographic expansion contributes to the urban densification process alongside other variables such as spatial policies, economic dynamics, and infrastructure development.

Field verification and overlay with the Kupang City Spatial Plan (RTRW 2011–2031) confirmed that most urban growth is within the planned development zone. Small deviations in Alak District indicate that spatial pressures are not fully controlled, necessitating strengthening development controls in the periphery. Scientifically, this study demonstrates the effectiveness of NDBI in the context of Kupang City to identify the dynamics of land cover category changes and understand urban spatial pressures in a medium-sized city. The integration of demographic data, satellite imagery, and spatial policy analysis in this study also provides a strong methodological framework to support evidence-based urban planning in Indonesia and other developing urban areas.

As a further research direction, this study could be expanded by utilizing higher-resolution imagery such as Sentinel-2 or UAVs to produce more accurate spatial details, particularly in areas with high settlement heterogeneity. Future research could also incorporate multi-year temporal analysis, integration of other spectral indices, or spatial modeling to predict future urbanization pressures.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to all parties who have supported the completion of this research. Our deepest appreciation goes to our research supervisor, Lia Kusumawati, S.Si., M.Eng., from the Geography, Faculty of Social Sciences and Law, State University of Jakarta, for their invaluable guidance, insightful feedback, and unwavering encouragement throughout this entire process. We also extend our thanks to the institutions that provided the essential data for our analysis: the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), the Copernicus Marine Environment Monitoring Service (CMEMS), and the Geospatial Information Agency (BIG) for providing access to the National Bathymetry (BATNAS) data.

Future research is recommended to use machine learning-based algorithms such as Random Forest or Support Vector Machine (SVM) to improve the accuracy of land use classification, especially in heterogeneous areas. Furthermore, long-term multi-temporal analysis using a broader timeframe (e.g., 2015–2024) can provide a deeper understanding of the growth dynamics of built-up areas. Integration of other indices such as NDVI, MNDWI, or machine learning-based built-up index can also strengthen spatial interpretation and predict future urbanization pressures.

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