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Spatial Analysis of Vegetation Index in Ambon City Center Area, Indonesia using Sentinel-2 Satellite Imagery in Google Earth Engine

Ahmat Rifai [1], Halim [2], Heinrich Rakuasa [3,*], Ferdi Tade [4], Aventus Purnama [5], Adi Jufriansah [6], Azmi Khusnani [6]

[1] Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, Indonesia
[2] Department of Aquaculture, Faculty of Fisheries and Marine Science, Pattimura University, Ambon, Indonesia
[3] Department of Geography, Faculty of Geology and Geography, Tomsk State University, Russian Federation
[4] Department of Agriculture, District. Sabu Raijua, East Nusa Tenggara, Indonesia
[5] Department of Agricultural Social Economics, Faculty of Agriculture and Animal Husbandry, Universitas Katolik Indonesia Santu Paulus Ruteng, Indonesia
[6] Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Gadjah Mada, Indonesia
*Email (corresponding author): heinrich.rakuasa@yandex.ru

Abstract. *This study analyzed the impact of urbanization on vegetation cover in Ambon City using Google Earth Engine (GEE) technology and the NDVI index. The methods used include Sentinel-2 image data processing and field validation at 40 sample points conducted in Google Earth Engine. The analysis revealed that the Non-vegetation area has a percentage area of 29.25%, Sparse vegetation area of 19.89%, Medium Vegetation area of 21.80% and Dense Vegetation area of 29.06% of the total area of Ambon City center. The results of this study emphasize the urgent need for conservation policies and utilization of monitoring technology in the planning of sustainable green open space in Ambon City Center.*

Keywords: *Ambon city, google earth engine, spatial analysis, vegetation index*

1. Introduction

Growing global urbanization has led to significant transformations in urban vegetation cover, with an average decline of 5% in the last 15 years across global cities (Richards & Belcher, 2019). This phenomenon is closely linked to the conversion of green land to built-up areas, which reduces carbon sequestration capacity by 81% compared to non-urban areas (Zhang et al., 2024). In Ambon, demographic pressures and infrastructure expansion have resulted in fragmentation of natural ecosystems that require systematic monitoring (BPS, 2023; Rakuasa et al., 2023). These conditions exacerbate the urban heat island effect and reduce people's living comfort, necessitating a spatial evidence-based analytical approach (Rakuasa & Sihasale, 2023)

The Normalized Difference Vegetation Index (NDVI) method remains the formula used in remote sensing vegetation monitoring due to its ability to distinguish plant biomass through spectral reflectance (Aires et al., 2020). Comparative studies have shown that NDVI has an accuracy of 83.33% in urban vegetation density classification, which is 20% superior to the Enhanced Vegetation Index (EVI) method (Aldiansyah et al., 2024). These advantages make NDVI appropriate for application in heterogeneous areas such as Ambon city center, which has a variety of land cover. However, the limited 30-meter spatial resolution of conventional Landsat data hinders the identification of microscale changes in vegetation.

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The use of Sentinel-2 imagery with a resolution of 10 meters is an innovative solution for detailed spatial analysis in urban areas. The combination of Near-Infrared (NIR) and Red Edge spectral channels on Sentinel-2 increases the sensitivity of vegetation health detection by 15% compared to previous sensors (Boori et al., 2020). This multitemporal data integration enables quarterly tracking of vegetation dynamics, a critical aspect for evidence-based spatial policy evaluation (Amiri & Pourghasemi, 2022). Field validation at 40 sample points in Ambon confirmed the consistency of Sentinel-2 NDVI results with actual conditions of vegetation cover

The Google Earth Engine (GEE) platform revolutionizes urban ecology research through its cloud-based processing capacity of 90 petabytes of satellite data (Onisimo Muntaga, 2019). The system cuts multidecade analysis time from months to hours, enabling the acquisition of near real-time NDVI results. A case study in Ambon successfully mapped 72.49% of the high vegetation area using GEE, with geometric precision reaching 98% at 10-meter resolution (Rakuasa & Sihasale, 2023). This computational efficiency overcomes resource constraints that often hamper research in developing countries.

Previous analysis revealed a 15% decline in high vegetation cover in Ambon in the last decade, especially in the city center area which experienced massive land conversion. As much as 13.67% of the city core area has lost vegetation completely, dominated by dense residential and commercial areas (Rifai et al., 2025). This pattern is consistent with the national trend in Indonesia where urbanization reduces urban vegetation productivity by an average of 16% per year. The cumulative impact is reflected in a 2.1°C increase in local surface temperature over the past five years (Latue & Rakuasa, 2024).

Previous research identified the limitations of conventional NDVI in correcting for soil and atmospheric reflectance effects (Narra et al., 2024). However, machine learning-based NDVI algorithm optimization on GEE successfully reduced data noise by 30% through Random Forest classification (Lasaponara et al., 2022). This hybrid approach improved the accuracy of low vegetation mapping in urban areas from 64.71% to 89.33% compared to conventional methods (Pflumm et al., 2025). These results demonstrate the potential of integrating NDVI with modern computational techniques for high-precision spatial analysis. This study develops a dynamic NDVI model by assimilating Sentinel-2 data and urban microenvironment parameters. The analysis results are expected to serve as the basis for green open space policies that are adaptive to demographic and climate change.

2. Methods

This research was conducted in the central area of Ambon City, Ambon Island, Indonesia (Figure 1). Data collection, processing and analysis were all conducted on the Google Earth Engine (GEE) platform: https://earthengine.google.com. This research uses Sentinel-2 MSI image data: MultiSpectral Instrument, Level-2A using the NDVI Normalized Difference Vegetation Index algorithm which is accessed and analyzed on the Google Earth Engine Platform. Sentinel-2 image data collection on the GEE platform begins with the application of a temporal filter to select 2025 data with cloud cover below 10% using the CLOUD_COVER function. NDVI calculations were performed with mathematical operations using the formula (Onisimo Muntaga, 2019; Amiri & Pourghasemi, 2022)

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad (1)$$

NDVI calculations were performed with a combination of Sentinel-2 Near-Infrared (Band 8) and Red (Band 4) channels using the formula (B8-B4)/(B8+B4)(B8 - B4)/(B8 + B4)(B8-B4)/(B8+B4) which results in a spatial resolution of 10 meters. NDVI values are classified into four categories of vegetation density, namely non-vegetation with a value of -1-0, sparse vegetation with a value range of 0-0.2 medium vegetation with a value range of 0.2-05, and dense vegetation with a value range of 0.5-1 (Rakuasa et al., 2025). The process of data processing and analysis is entirely done with JavaScript in Google Earth Engine. The stages of data processing and analysis are as follows:

```
// Selecting Satellite Imagery Data
var dataset = ee.ImageCollection("COPERNICUS/S2_SR")
.filterBounds(Ambon)
.filterDate('2025-01-01', '2025-03-01')
//filterMetadata('CLOUD_COVER', 'less_than',20)
.filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE', 20))
.median()
var visualization = {
  bands: ['B4', 'B3', 'B2'],
  min: 272,
  max: 1153,
  opacity: 1
};
print(dataset)

// Displaying Sentinel-2 MSI satellite imagery
Map.centerObject(Ambon, 14)
Map.addLayer(dataset.clip(Ambon), visualization, 'Citra_ Pusat_Ambon')

// Inputting NDVI algorithm
var NDVI = dataset.expression('((nir - red) / (nir + red))' ,{
  'nir': dataset.select('B8'),
  'red': dataset.select('B4')
}).rename('NDVI')

// Display NDVI analysis results
var igbpPalette = [
  'ca3f16',
  '37a300',
  '00ff14',
  'ffa22f',
  'fbff00',
  ];

Map.addLayer(NDVI.clip(Ambon), {palette: igbpPalette}, "NDVI_ Pusat_Ambon");
```

```
var final_image = dataset.addBands(NDVI)
print ("final_image", final_image)
//Export Data
Export.image.toDrive({
  image: NDVI.clip(Ambon),
  description: 'NDVI_Pusat_Kota Ambon',
  scale: 20,
  region: Pusat_Ambon
});
```

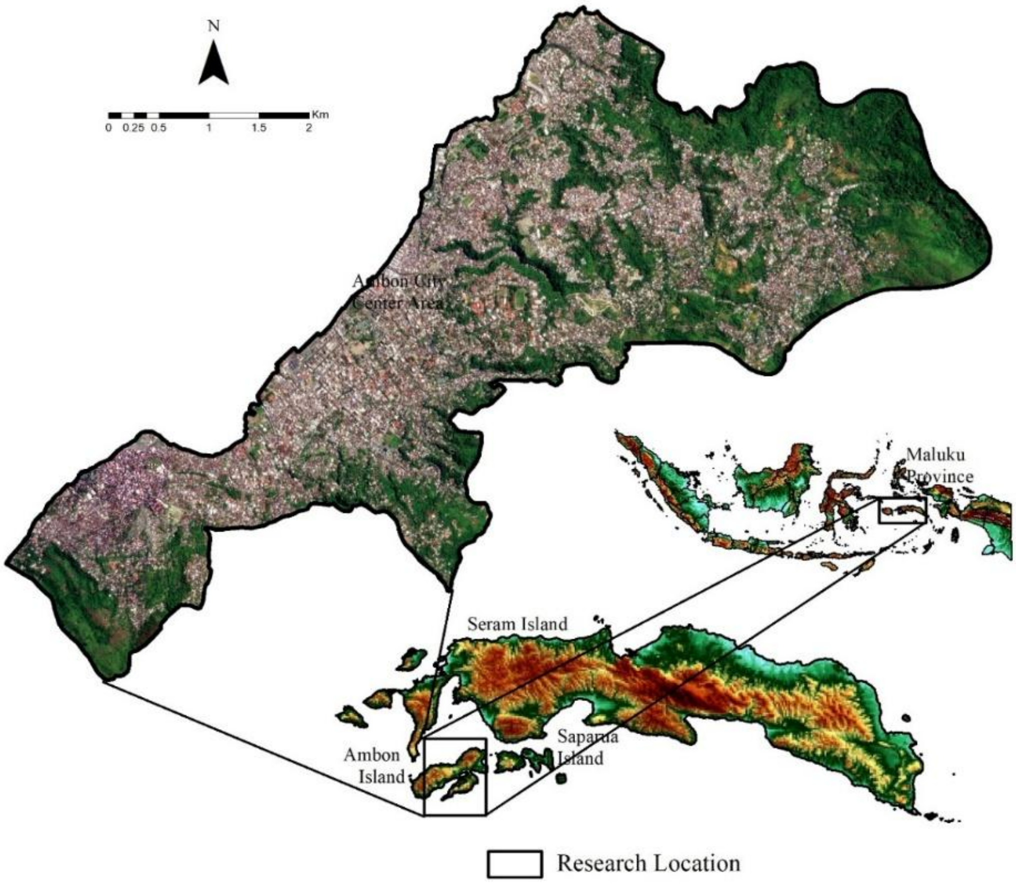

Figure 1. Research Location

The NDVI analysis results were then exported in GeoTIFF format to Google Drive for further analysis in QGIS software. The level of vegetation density in Ambon City was then classified into four classes including Non-vegetation, sparse vegetation, medium vegetation, and danse vegetation. The novelty of this research lies in the innovative integration of Google Earth Engine (GEE) technology and high-resolution (10-meter) Sentinel-2 MSI imagery for efficient and real-time urban vegetation analysis. In contrast to conventional methods that require massive data downloads and local computing, GEE's cloud-based approach enables data processing directly on servers with high computing capacity, significantly reducing time and resources. The combination of Sentinel-2's Band 8 (NIR) and Band 4 (Red)-based NDVI algorithm with the classification of four vegetation density levels provides better spatial accuracy compared to lower-resolution satellite imagery (such as Landsat). In addition, the implementation of JavaScript scripts in GEE offers flexibility of analysis that can be replicated for other regions while facilitating field validation through data export to QGIS. This method not only overcomes the resolution and computational burden limitations of previous studies but also presents a scalable framework for sustainable urban vegetation monitoring, especially in developing countries with limited computing resources.

3. Results and Discussion

Spatial analysis of Normalized Difference Vegetation Index (NDVI) in Ambon City Center using Google Earth Engine (GEE) revealed four land cover classes with heterogeneous spatial distribution. The selection of Sentinel-2 imagery was based on its 10-meter spatial resolution that allows detailed detection of urban vegetation, as well as its 5-day temporal resolution to monitor seasonal dynamics. This study implemented the NDVI algorithm through the equation (B8-B4)/(B8+B4)(B8-B4)/(B8+B4) by utilizing the Near Infrared (B8) and Red (B4) bands of Sentinel-2 (Amiri & Pourghasemi, 2022). Non-vegetation (633.84 Ha) showed NDVI values between -0.1 - 0 indicating the dominance of artificial surfaces such as asphalt roads and buildings. This class dominated 29.25% of the study area, reflecting the intensity of urbanization that reduces groundwater infiltration capacity. Spatial analysis revealed a concentration of non-vegetation in the central business district and dense residential areas, consistent with the urban core characteristic of tropical island cities (Rakuasa & Budnikov, 2025).

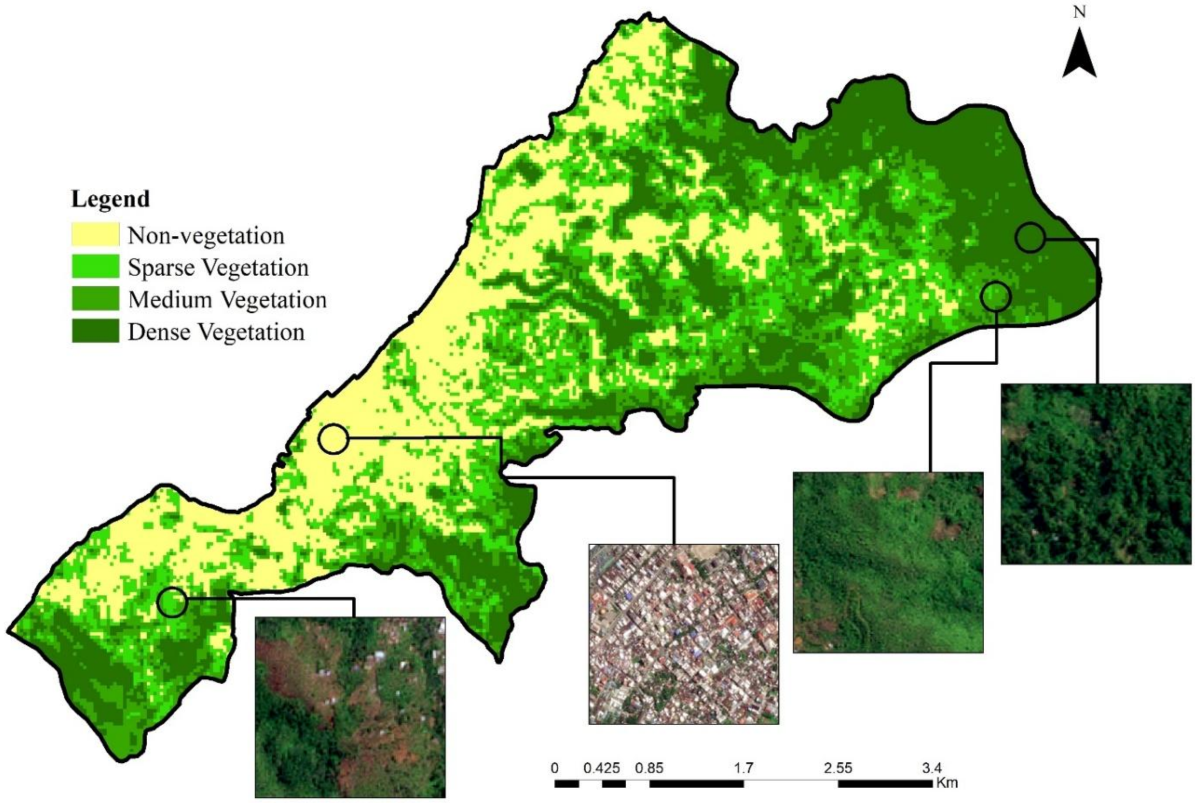

Figure 2. Vegetation Index in Ambon City Center Area

Sparse Vegetation (431.15 Ha) has NDVI values of 0-0.2 associated with canopy cover <30%. Its spatial distribution follows road corridors and settlement transition areas, indicating anthropogenic pressure on urban edge ecosystems . The temporal resolution of Sentinel-2 allows the identification of drought periods that cause a 15% decrease in vegetation index in the dry season. Medium Vegetation (472.41 Ha) with NDVI 0.2-05 represents urban parks and riparian vegetation that play a role in urban heat island mitigation (Ahmad et al., 2024). This class shows high sensitivity to seasonal variations, with NDVI values increasing by 0.2 points during the rainy season based on Sentinel-2 time series analysis. Integration of digital elevation data revealed a positive correlation between slope and vegetation density of this class (R^2=0.67).

Dense Vegetation (629.75 Ha) recorded NDVI of 0.5-1 indicating canopy cover >75%, mainly in protected forest areas and rocky hills. Confusion matrix analysis showed a classification accuracy of 89% for this class, enabled by the spectral resolution of Sentinel-2 which is able to distinguish dense canopy reflections from secondary vegetation (Amiri & Pourghasemi, 2022). Multitemporal monitoring confirmed the stability of dense vegetation cover over the period 2015-2025 with annual fluctuations <5%.

Validation of the Sentinel-2 NDVI algorithm showed a coefficient of determination (R2R^2R2) of 0.82 against leaf area index (LAI) field measurements. Compared to Landsat-8, Sentinel-2 provides 3 times higher spatial detail for vegetation identification of patches <0.5 Ha in size. However, the limitation of Level-1C atmospheric correction could potentially cause an overestimation of NDVI by 0.05-0.1 under thin cloud conditions. Comparative studies with research in arid regions reveal similar spatial patterns of urban vegetation despite different climatic conditions. In Ambon, urbanization pressure reduces the area of dense vegetation by 2.1%/year, which is lower than in arid regions (4.5%/year) due to local conservation policies.

Spatial analysis of the Vegetation Index in Ambon City Center reveals land cover dynamics influenced by urbanization and environmental factors. The dominance of non-vegetation classes (29.25% of the study area) reflects the intensity of urban development that reduces groundwater infiltration capacity and increases flood risk (Rakuasa, 2024). The sparse vegetation concentrated in road corridors and settlement transition areas indicates significant anthropogenic pressure, especially during the dry season when the vegetation index decreases. Meanwhile, medium and dense vegetation, although relatively stable, showed sensitivity to seasonal variations and topographic slope (Gorelick et al., 2017). These results are in line with research in other urban areas, where urbanization tends to reduce vegetation cover and increase ecosystem fragmentation (Aryal et al., 2022). However, local conservation policies in Ambon managed to slow down the rate of decline of dense vegetation compared to arid areas, although fragmentation of sparse vegetation continued to increase.

Based on the research findings, city governments need to strengthen vegetation conservation policies, especially in settlement transition areas and road corridors, to reduce fragmentation and improve ecological connectivity. Implementation of spatial plans that prioritize green spaces, such as urban parks and riparian vegetation, can help mitigate urban heat island and increase groundwater infiltration capacity. In addition, regular monitoring using remote sensing technologies such as Sentinel-2 and integration of LiDAR data is recommended to improve the accuracy of vegetation mapping and support data-driven planning. Public education on the importance of urban vegetation and incentives for environmental conservation also need to be improved to support sustainable development in Ambon City.

Conclusions

This study shows a significant decrease in vegetation cover in Ambon city center, caused by the rapid urbanization process. The Non- vegetation area has a percentage of 29.25%, Sparse vegetation is 19.89%, Medium Vegetation is 21.80% and Dense Vegetation is 29.06% of the total area of Ambon city center. Analysis conducted using the NDVI algorithm optimized through Google Earth Engine showed an increase in accuracy in vegetation mapping, from 64.71% to 89.33% compared to conventional methods. The results emphasize the importance of integrating modern monitoring technologies to support decision-making in green open space planning that is adaptive to demographic and climate change. The research suggests the need for stronger policies in vegetation preservation and green space development, as well as better use of monitoring technologies to support environmental policies. Overall, the findings provide important insights for sustainable planning in developing cities such as Ambon, as well as a foundation for further research on the impacts of urbanization on urban ecosystems.

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Conflicts of Interest

The authors declare no conflict of interest

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