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Journal of Engineering and Science Application

journal homepage:
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Spatial Analysis of Vegetation Density Using MSARVI Algorithm and Sentinel-2A Imagery in Ternate City, Indonesia

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Article Info

Keywords:

Ternate,
Sentinel-2A,
MSARVI,
Vegetation Density

ABSTRACT

This study aims to analyze vegetation density in Ternate City, Indonesia, using the Modified Soil-Adjusted and Atmospherically Resistant Vegetation Index (MSARVI) algorithm and Sentinel-2A images processed through Google Earth Engine. The analysis results show that the vegetation density index values range from -0.54 to 1.16, with normalization resulting in four density classes: low, medium, dense, and very dense. Ternate Island sub-district had the largest area of very dense vegetation (4,133.12 hectares), while Ternate Tengah sub-district showed the lowest vegetation density, reflecting the significant impact of urbanization. This study revealed that despite anthropogenic pressures, Ternate Island remains an ecologically critical zone. These findings emphasize the importance of conservation efforts and afforestation initiatives to improve environmental resilience amidst the growing challenges of climate change and urban development.

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1. INTRODUCTION

Vegetation plays a critical role in maintaining the balance of urban ecosystems, especially in volcanic island regions such as Ternate City, which face anthropogenic pressures and unique environmental dynamics [1]. The change in land cover from vegetation to settlements, reaching 2 km² over the past five years, indicates the urgency of spatially-based vegetation density monitoring [1]. The geographical conditions of volcanic islands with steep slopes and soil-volcanic interactions demand vegetation analysis approaches capable of accommodating complex spectral characteristics and atmospheric disturbances typical of coastal areas [2].

Advances in multispectral remote sensing technology, particularly Sentinel-2A imagery, offer a spatial resolution of 10-20 meters and 13 spectral channels, making it ideal for urban vegetation detection [3],[4],[5]. A study by Umarhadi & Syarif (2018) demonstrated an accuracy of >80% for the NDVI-Sentinel-

2A linear regression model in mapping mangrove canopies, although it remains limited to specific ecosystems [6]. The main challenge lies in the spectral interference from volcanic soil backgrounds and atmospheric water vapor, which are dominant in tropical island regions, necessitating more adaptive vegetation indices [7].

The Modified Soil and Atmospheric Resistant Vegetation Index (MSARVI) algorithm is derived from the modification of SARVI, while SARVI itself is formed from a vegetation correction factor derived from the SAVI index and the blue channel normalization of ARVI. The entire calculation process of MSARVI is fully conducted using remote sensing software. MSARVI has been proven to perform well under various atmospheric conditions across different soil backgrounds. A series of statistical tests were conducted to analyze the influence of atmospheric disturbances on the pixel values of unchanged vegetation cover. The MSARVI algorithm has a higher value range and lacks a fixed benchmark like the NDVI (Normalized Difference Vegetation Index), where the lowest density value is (-1) and the highest vegetation density value is (+1). Thus, values approaching (-1) can be interpreted as low vegetation density, while values approaching (+1) can be interpreted as high vegetation density. [7], [8].

Modified Soil-Adjusted and Atmospherically Resistant Vegetation Index (MSARVI) emerged as a solution through dual spectral correction: suppression of soil influence through L parameter and Rayleigh scattering correction [6],[7]. Research in Cihanjuang Rahayu showed MSARVI produced a 4-class vegetation density classification with higher precision than MSAVI under heterogeneous soil conditions [7]. Although NDVI accuracy remained superior in mangrove ecosystems (81.66%), MSARVI showed better consistency (78.72%) in environments with significant atmospheric disturbances [6].

The integration of Google Earth Engine (GEE) enables efficient processing of satellite big data through cloud-based computing capacity and multi-petabyte data catalogs [9]. The platform has been tested in temporal analysis of regional-scale vegetation through automation of radiometric correction, temporal compositing, and vegetation index calculation [10]. A study of urban biomass in China proved the GEE-Sentinel-2A-based step-by-step regression model achieved an R^2 of 0.853 for low vegetation [4], indicating the potential for replication of the methodology in island regions.

This research addresses the academic gap through MSARVI-Sentinel-2A-GEE synergy for vegetation density mapping in the unique volcano-urban environment of Ternate City. The combination of multiple spectral correction algorithms, high temporal resolution (5 days), and cloud computing capacity will produce a more precise spatial model than conventional approaches [11]. The findings of this research provide an important scientific framework for formulating adaptive spatial policies in volcanic island regions. Based on the description above, this research aims to determine the Vegetation Density in Ternate City, Indonesia by Using MSARVI Algorithm and Sentinel-2A Image.

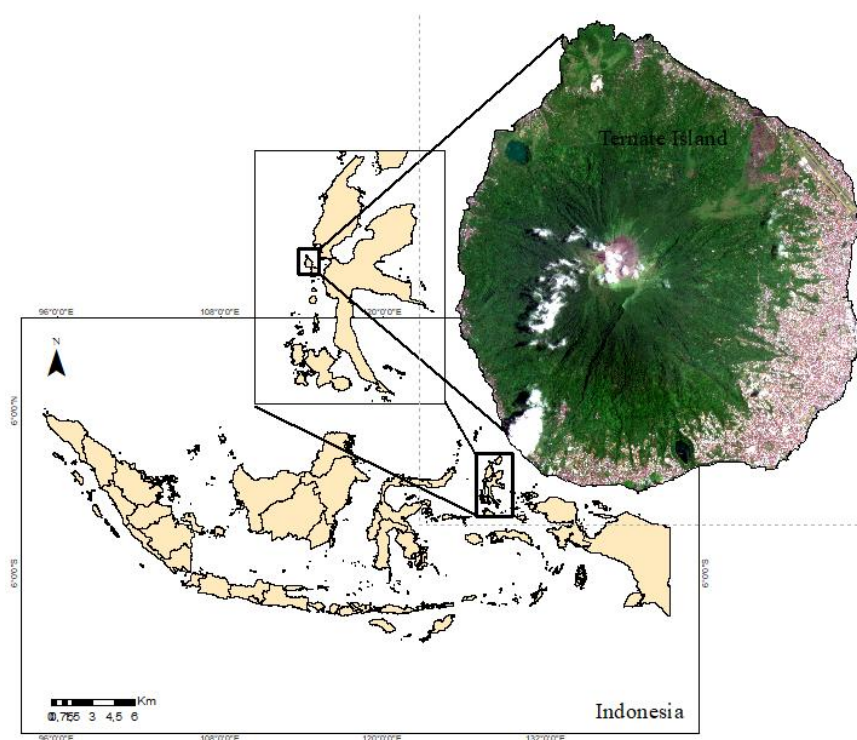


Figure 1. Research Location

2. RESEARCH METHOD

The research was conducted in Ternate City, North Maluku Province, Indonesia (Figure 1). This study used Sentinel 2 MSI image data: Multispectral Instrument, Level 2A. The method used is the MSARVI (Modified Soil Adjusted Vegetation Index) algorithm method. The platform used in analyzing the MSARVI algorithm is Google Earth Engine (<https://earthengine.google.com/>). Sentinel-2A multispectral imagery with 10-20-meter spatial resolution and 13 spectral bands was acquired for Ternate City from the Google Earth Engine (GEE) platform on March 24, 2024. Image selection was based on cloud cover (<10%) and temporal relevance to the study period. The pre-processing stage included atmospheric correction using the Sen2Cor processor to reduce the effects of Rayleigh scattering and aerosol interference, which are highly significant in coastal and volcanic regions [12]. In addition, geometric correction was applied to align the image with the Universal Transverse Mercator (UTM) coordinate system of Zone 52 North. The processed data was then cropped according to the Ternate City boundary using the built-in geospatial tool GEE.

Modified Soil-Adjusted and Atmospherically Resistant Vegetation Index (MSARVI) is a vegetation index designed to overcome the influence of soil background and atmospheric disturbances on vegetation density measurements. MSARVI is a modification of the Soil and Atmospherically Resistant Vegetation Index (SARVI), which combines elements from the Soil Adjusted Vegetation Index (SAVI) and Atmospherically Resistant Vegetation Index (ARVI) to improve accuracy under complex conditions, such as areas with volcanic soils or unstable atmospheres. The MSARVI formula (Equation 1, [13]) and the one used in Google Earth Engine for this study are equation 2 [7].

$$2\rho NIR + 1 - \sqrt{((2\rho NIR + 1)^2 - \gamma(\rho NIR - \rho r b))/2} \quad (1)$$

$$'((2 * NIR + 1 - (((2 * NIR + 1) ** 2) - (1 * (NIR - (Red - (1 * (Blue - Red)))))) ** 0.5) / 2)' \quad (2)$$

After that, it is normalized with the following equation [8]:

$$Normalisasi\ MSARVI = \frac{(MSARVI - Min)}{(Max - Min)} \quad (3)$$

Min value is defined as the smallest vegetation value of MSARVI image and Max value is defined as the largest vegetation value of MSARVI image. The results of the MSARVI vegetation index analysis were then calcified into 4 classes including Low Vegetation Density, Medium Vegetation Density, Dense Vegetation Density, and Very Dense Vegetation Density (Table 1).

Table 1. MSARVI Index Classification

MSARVI Value	Class
> -0.40	Low
0.41 - 0.60	Moderate
0.61 - 0.80	Dense
>0.80	Very Dense

3. RESULTS AND DISCUSSIONS

The analysis results show that the vegetation density index value of Ternate City processed using the MSARVI algorithm has the lowest value of -0.54 and the highest is 1.16. The comparison of the MSARVI vegetation index histogram value and the histogram of the normalized MSARVI index value can be seen in Figure 2 and Figure 3. The results of normalizing the vegetation density index value are then calcified into MSARVI 4 classes, namely low density class, medium density class, dense density class, and very dense density class.

The results of the analysis show that Ternate Island sub-district shows the highest proportion of very dense vegetation, covering 4133.12 Ha, which is the majority of vegetation cover in the sub-district. This is in line with the volcanic topography of the island which favors dense vegetation due to fertile soil and favorable climatic conditions. The dense vegetation class covers 472.76 Ha, while medium and low vegetation densities are relatively smaller, 220.23 Ha and 283.57 Ha respectively. The dominance of very dense vegetation indicates that Ternate Island remains an ecologically critical zone despite increasing anthropogenic pressures.

The analysis shows that in North Ternate, very dense vegetation covers 744.56 Ha, indicating the presence of significant forested areas. However, the sub-district also has a sizable area of low vegetation density (383.87 Ha), likely due to urban expansion and land conversion for settlements. The medium and dense

vegetation classes are relatively smaller, 211.96 Ha and 240.81 Ha respectively. This distribution underscores the impact of urbanization on vegetation cover in this sub-district.

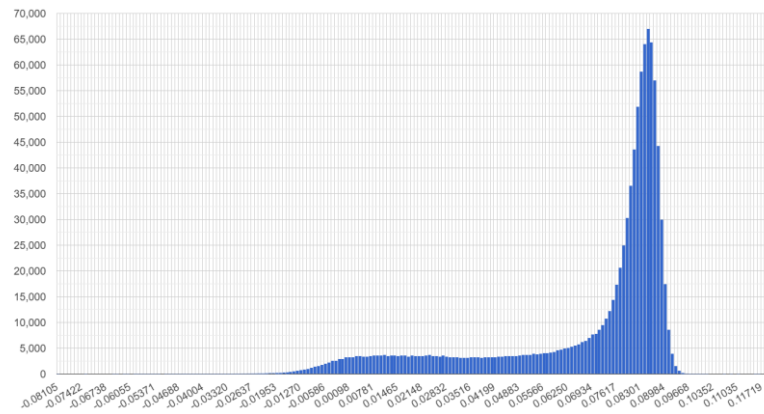


Figure 2. Histogram Values Before Normalization

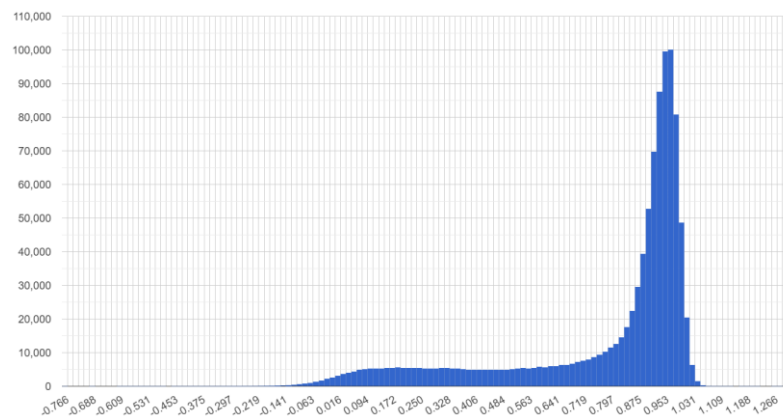


Figure 3. Histogram Values After Normalization

South Ternate sub-district shows a similar pattern, with very dense vegetation covering 1254.88 Ha. However, it has the largest area of low vegetation density (471.40 Ha) among all sub-districts, reflecting the impact of land use change and anthropogenic activities. Medium and dense vegetation classes are smaller, 157.41 Ha and 166.52 Ha respectively. The high proportion of low vegetation density confirms the need for targeted reforestation and conservation efforts in this area.

Ternate Tengah has the smallest area of very dense vegetation (925.46 Ha) compared to other sub-districts, possibly due to being the urban center and high population density. Low vegetation density covers 314.04 Ha, while medium and dense vegetation classes are the smallest among all sub-districts, 84.41 Ha and 80.94 Ha respectively. This pattern is in line with the sub-district's role as the administrative and economic center of Ternate City, where urban development has significantly altered the natural landscape [14],[15].

The results show a clear gradient in vegetation density from the city center (Central Ternate) to peripheral areas (Ternate Island). Ternate Island, with its remote location and limited urban development, retains the highest proportion of very dense vegetation. In contrast, Central Ternate, as the city center, has the lowest vegetation density, reflecting the trade-off between urbanization and environmental conservation. North and South Ternate show an intermediate pattern, with significant areas of very dense and low vegetation, indicating a transition zone between urban and natural landscapes [16].

The application of the MSARVI algorithm proved effective in capturing these spatial variations, especially in overcoming the spectral challenges posed by the volcanic soil and atmospheric conditions in Ternate City. The integration of Sentinel-2A imagery and Google Earth Engine (GEE) facilitated efficient processing of large-scale spatial data, enabling precise mapping of vegetation density across the study area.

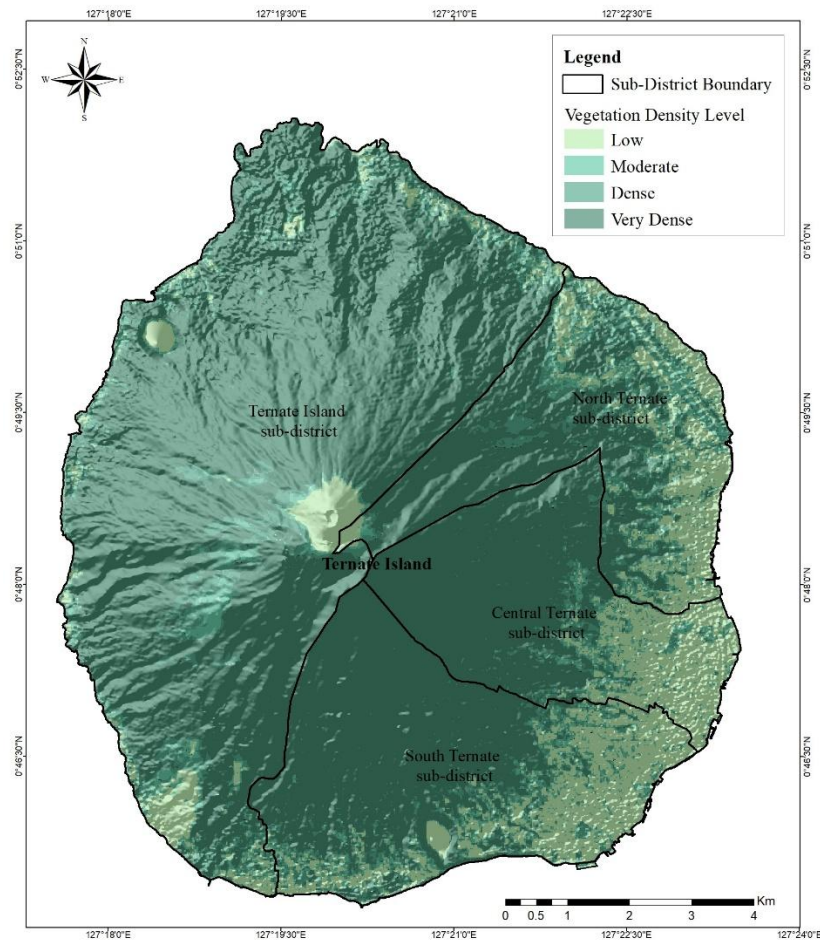


Figure 4. Vegetation Index Map of Ternate City

The findings of this study have important implications for urban planning and environmental management in Ternate City (Figure 4). The high proportion of very dense vegetation on Ternate Island emphasizes its ecological significance and the need for strict conservation measures to protect these areas from further anthropogenic pressures. In contrast, the low vegetation density in Central Ternate highlights the urgency of urban greening initiatives to increase the city's resilience to climate change and improve residents' quality of life. The transition patterns observed in North and South Ternate suggest that these areas are vulnerable to land use change. Targeted interventions, such as reforestation and sustainable land use planning, are essential to balance urban development with environmental conservation in these sub-districts.

4. CONCLUSION

Analysis of vegetation density in Ternate City conducted using the Modified Soil-Adjusted and Atmospherically Resistant Vegetation Index (MSARVI) algorithm showed a range of index values from -0.54 to 1.16, which were then normalized for classification into four density classes: low, medium, dense, and very dense. These findings indicate that Ternate Island sub-district has the largest area of very dense vegetation, at 4,133.12 hectares, which is due to the volcanic topography that supports optimal soil fertility and climatic conditions. In contrast, Ternate Tengah sub-district, as the center of urbanization, shows the lowest vegetation density, reflecting the trade-off between urban development and environmental conservation. The study also noted significant areas of low vegetation density in North and South Ternate sub-districts, most likely influenced by urban expansion and land conversion. The effectiveness of the MSARVI algorithm in capturing spatial variation amidst the challenges posed by volcanic soils is highly visible, thanks to the integration of Sentinel-2A imagery and Google Earth Engine that enables efficient processing of large-scale data. The findings of this study have important implications for urban planning and environmental management in Ternate City, emphasizing the need for targeted conservation efforts and urban greening initiatives to increase resilience to climate change while maintaining ecosystem integrity.

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