Jurnal Teknik Informatika (JUTIF) Vol. 6, No. 6, December, 2025, Page. 5522-5538
P-ISSN: 2723-3863 https://jutif.if.unsoed.ac.id
E-ISSN: 2723-3871 DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

Sentinel-2 NDVI Analysis Using GEE and QGIS for Green Open Space Sustainability Assessment in Kendari City

Sufrianto*[1], Siti Sara Yaacob Zubir[2], Andi Makkawaru Isazarni Jassin[3], Joko Tri Brata[4], Erni Danggi[5], Sulfikar Sallu[6]

[1,3]Department of Civil Engineering, Universitas Sulawesi Tenggara, Indonesia
[2]Department of Civil Engineering, Politeknik Sultan Azlan Shah, Malaysia
[4]Master's Program in Government Science, Universitas Sulawesi Tenggara, Indonesia
[5]Department of Agricultural Product Technology, Universitas Sulawesi Tenggara, Indonesia
[6]Faculty of Teacher Training and Education, Universitas Sulawesi Tenggara, Indonesia

Email: [1]sufriantosaja@gmail.com

Received : Oct 29, 2025; Revised : Nov 9, 2025; Accepted : Nov 22, 2025; Published : Dec 23, 2025

Abstract

Rapid urbanization has profoundly transformed land cover in many growing cities, leading to a substantial decline in Green Open Space (GOS) and a progressive deterioration of ecological functions. The continuous conversion of vegetated zones into impervious and built-up surfaces has reduced the city's ability to absorb carbon, regulate local microclimates, and maintain overall ecological resilience. Consequently, assessing the sustainability and spatial distribution of GOS is crucial for ensuring environmentally balanced urban development and resilience to future land-use pressures. This study aims to evaluate the sustainability of urban green spaces in Kendari City through an integrated geospatial approach that combines remote sensing and open-source cloud computing technologies. Sentinel-2 Level-2A imagery was analyzed in Google Earth Engine (GEE) using the QA60 band for cloud masking and spatial clipping to accurately define the study boundaries. Normalized Difference Vegetation Index (NDVI) values were subsequently processed and classified in QGIS using a reclassification technique to distinguish vegetation density categories. The results indicate that 56.7% of the total land area, equivalent to 15,213 hectares, exhibits high greenness, reflecting dense and healthy vegetation, whereas 32.3% consists of low or non-vegetated surfaces dominated by built-up and barren lands. These findings reveal substantial spatial disparities in vegetation coverage and underscore the importance of sustainable land management and green infrastructure policies. Furthermore, this research contributes to the advancement of geospatial informatics by developing an open, reproducible workflow that integrates cloud-based computation and open-source GIS for urban ecological monitoring and sustainability assessment.

Keywords : *Geospatial Analysis, Google Earth Engine, NDVI Classification, Sentinel-2 Imagery, Urban Green Open Space*

1. INTRODUCTION

The rapid development of urban areas in Indonesia has led to substantial transformations in ecological systems and the environment, particularly in the availability of Green Open Spaces (GOS) within urban regions. Kendari City, serving as the administrative and economic center of Southeast Sulawesi Province, has experienced remarkable physical and demographic growth over the past two decades. Uncontrolled urbanization has resulted in extensive land conversion from vegetated zones to built-up areas, consequently reducing both the quality and quantity of GOS [1] [2]. Green Open Spaces (GOS) play a vital role in maintaining the ecological balance of urban environments. They help moderate microclimatic temperatures, absorb air pollutants, and provide essential habitats for urban flora and fauna [3] [4].

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

Furthermore, the presence of Green Open Spaces contributes to public health by enhancing psychological well-being, reducing stress levels, and providing spaces for social interaction [5]. In the context of sustainable urban spatial planning, Green Open Spaces (GOS) are not merely aesthetic components but also constitute vital green infrastructure with ecological, economic, and social functions. According to the Regulation of the Minister of Public Works No. 5 of 2008, every city is ideally required to allocate at least 30% of its total area for GOS. However, based on several studies and local government reports, this target remains far from being achieved, including in Kendari City. The rapid development of housing, transportation infrastructure, and public facilities without sufficient consideration for green space conservation has become a major factor contributing to the reduction of urban vegetation cover [6].

One of the fundamental challenges in managing Green Open Spaces (GOS) lies in the limited availability of accurate, up-to-date, and easily accessible spatial data for urban planners and policymakers. Conventional monitoring methods, such as field surveys, are not only time-consuming and costly but also constrained in terms of spatial coverage and data timeliness. In this regard, remote sensing technology provides a more efficient, accurate, and systematic approach for monitoring vegetation and analyzing urban green open spaces [7].

Recent studies have refined the efficiency and scalability of NDVI workflows in Google Earth Engine (GEE), particularly when processing Sentinel-2 imagery for urban vegetation monitoring. GEE's cloud-based computation enables automated preprocessing, QA60 cloud masking, and NDVI derivation with minimal hardware constraints [8], [9]. Several workflows have demonstrated the integration of multi-temporal analysis and policy-linked land classification [10], [11], These advances allow urban planners to obtain reproducible vegetation datasets that can be directly linked to ecological policy evaluation, such as Green Open Space (GOS) compliance. In this study, a similar reproducible workflow was developed by combining Sentinel-2 NDVI computation in GEE with QGIS-based reclassification for spatial analysis of Kendari City.

NDVI classification was performed using the Reclassify Plugin in QGIS, which enables the transformation of continuous NDVI raster values into discrete vegetation density categories. Following previous workflows such as those demonstrated [11], the raster output from Google Earth Engine (in GeoTIFF format) was imported into QGIS and reclassified into five vegetation density classes ranging from *non-vegetated* to *high greenness.* The *Reclassify by Table* tool was utilized to assign specific NDVI thresholds (−1.00 to +1.00) according to the classification guidelines of the Indonesian Ministry of Forestry (P.12/Menhut-II/2012). This approach, also adopted in ecological mapping studies [12] [13] effectively enhances spatial visualization, facilitates area-based quantification, and ensures compatibility with other geospatial layers such as land-use maps and administrative boundaries. The resulting thematic NDVI map provides a robust spatial reference for analyzing the sustainability of Green Open Spaces (GOS) in Kendari City.

The Sentinel-2 satellite imagery, developed under the Copernicus initiative and operated by the European Space Agency (ESA), serves as an optimal dataset for monitoring vegetation dynamics. Its high spatial resolution (reaching 10 meters) and specialized spectral bands particularly the red (RED) and near-infrared (NIR) wavelengths make it highly effective for vegetation analysis. Among the various vegetation indices derived from satellite data, the Normalized Difference Vegetation Index (NDVI) is the most commonly utilized. This index measures the contrast in reflectance between the NIR and RED bands to evaluate vegetation vigor and density. NDVI values typically range from –1 to +1, where values close to +1 denote dense and healthy vegetation, whereas values approaching zero or negative indicate non-vegetated features, such as urban areas or water bodies. [14] [15].

Several studies conducted in Indonesia have implemented this approach and demonstrated notable outcomes. [16] carried out a spatial assessment of urban expansion and Green Open Space (GOS) changes in Yogyakarta by employing Sentinel-2 satellite data combined with NDVI analysis. The findings indicated an inverse relationship between urban growth intensity and NDVI values. Meanwhile, [7] utilized Sentinel-2 data through the Google Earth Engine platform to analyze vegetation indices in Ambon City, and the results indicated that areas with low NDVI values predominantly occupy the densely populated city center. Another study in Malang City by [17] ntegrated NDVI and Land Surface Temperature (LST) analysis to demonstrate the Urban Heat Island (UHI) effect, concluding that areas with high vegetation density were able to reduce surface temperatures by approximately 3–5°C compared to sparsely vegetated zones.

Geographically, Kendari City is located in a coastal region characterized by diverse topography and high potential for mangrove ecosystems as well as lowland vegetation. However, development pressures in the form of coastal reclamation, land clearing, and infrastructure expansion have led to the degradation of coastal vegetation. In fact, coastal vegetation such as mangroves plays a strategic role in reducing the risks of tidal flooding, coastal abrasion, and seawater intrusion. The use of algorithms that facilitate a series of automated vegetation monitoring processes including automatic filtering and selection, cloud masking, NDVI operations, and automated visualization of NDVI values in graphical form enhances the efficiency and accuracy of spatial analysis for environmental assessment. [18]. In this context, NDVI analysis derived from Sentinel-2 imagery can be utilized to map the current condition of coastal vegetation while simultaneously identifying priority areas for conservation. [19].

The sustainability analysis of Green Open Spaces (GOS) in Kendari City was conducted through an integrative framework that combines NDVI classification, spatial overlay, and urban policy evaluation. This analytical design enables the identification of areas that meet, exceed, or fall short of the national standard for green open space provision as mandated by Government Regulation No. 26 of 2008 and Law No. 26 of 2007 concerning Spatial Planning.

In this study, the NDVI classification results derived from Sentinel-2 imagery were spatially intersected with official land-use layers and zoning maps using QGIS. This overlay process aimed to determine the correspondence between actual vegetation density and designated GOS zones in the city's Spatial Plan (RTRW). The evaluation followed a multi-criteria framework emphasizing quantitative adequacy (≥30% of city area), spatial distribution equity, and ecological functionality as proposed by Agustiyara [6] and Pratomo [20].

While Rifai [7] applied GEE in Ambon and Hasyim [17] integrated NDVI-LST in Malang, no previous study has combined GEE preprocessing, QGIS classification, and GOS policy overlay for Kendari. This integrative approach represents a methodological innovation by linking cloud-based vegetation analysis with legal spatial planning instruments. The workflow ensures that high-NDVI zones are not only identified ecologically but also evaluated within the policy framework of urban green governance. As suggested by Hang [21] coupling geospatial indicators with regulatory benchmarks enables a shift from descriptive mapping toward *evidence-based policy assessment*.

From a governance perspective, the integration of GEE and QGIS within the GOS policy framework allows for a reproducible and transparent monitoring mechanism. As highlighted by Onasis [22] such spatial evidence is crucial for tracking policy compliance and optimizing green infrastructure planning in mid-sized Indonesian cities. By applying this hybrid model, Kendari City can identify priority areas for ecological restoration, particularly in urban cores with NDVI values below 0.2 and limited formal GOS allocation.

Overall, this study demonstrates that integrating remote sensing outputs with statutory urban plans enhances the analytical depth of sustainability assessments. Beyond mere vegetation quantification, this policy-linked approach supports adaptive spatial planning, aligns with Sustainable Development Goals (SDG 11 and SDG 15), and provides actionable insights for local government decision-making in the pursuit of resilient and inclusive green urban development.

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

This study aims to generate NDVI-based vegetation maps using Sentinel-2, Google Earth Engine (GEE), and QGIS to evaluate the sustainability of Green Open Spaces (GOS) in Kendari City.

2. METHOD

This study employs a descriptive quantitative approach based on remote sensing data to evaluate vegetation conditions in Kendari City through the calculation of the Normalized Difference Vegetation Index (NDVI) derived from Sentinel-2 satellite imagery. This method was chosen for its ability to produce spatial information that is accurate, efficient, and temporal in nature, thereby providing a dynamic representation of vegetation changes and Green Open Space (GOS) conditions within the urban area. [6] [3]. The city represents a rapidly urbanizing region where vegetation dynamics and the sustainability of Green Open Spaces (GOS) are of increasing concern. All spatial datasets were projected in WGS 84 / UTM Zone 51S to ensure spatial consistency across software environments.

2.1. Research Location

The study was conducted within the administrative area of Kendari City, Southeast Sulawesi, which covers approximately 295.89 square kilometers. The region consists of eleven districts with diverse topographical characteristics, ranging from lowlands and coastal zones to hilly areas. The selection of Kendari City as the study area was based on its high level of urbanization, ecological dependence on green spaces, and the limited number of NDVI-based studies that specifically examine vegetation dynamics in this region.

2.2 Data Sources

The primary dataset used in this study was multispectral Sentinel-2 Level-2A imagery, which has undergone atmospheric correction (Bottom-of-Atmosphere reflectance), obtained from the Copernicus Open Access Hub platform. Sentinel-2 provides 13 spectral bands; however, only two bands were utilized in the NDVI calculation Band 8 (Near-Infrared/NIR) with a spatial resolution of 10 meters and Band 4 (Red) with the same 10-meter resolution. [3] [23] In addition, comparative datasets such as the administrative map of Kendari City, land-use data obtained from the Geospatial Information Agency of Indonesia (BIG), and Google Earth imagery were used for visual validation.

Several previous studies have also recommended the use of Sentinel-2 imagery over Landsat due to its superior spatial and temporal resolution [24]. This makes Sentinel-2 more suitable for vegetation monitoring at the urban scale. The main dataset consisted of Sentinel-2 MSI imagery (Level-2A) acquired from 2023, obtained through the Google Earth Engine (GEE) data catalog. Supporting data included Kendari's Rencana Tata Ruang Wilayah (RTRW) and administrative boundary shapefiles from the Indonesian Geospatial Agency (BIG). The software and tools used were:

- Google Earth Engine (GEE) Code Editor for image selection, cloud masking, and NDVI computation.
- QGIS 3.34 Prizren for raster reclassification, spatial overlay, and visualization.
- Microsoft Excel 2021 for data tabulation and area statistics.

2.3 Data Collection and Processing Techniques

Data processing was carried out systematically using QGIS and Google Earth Engine (GEE) software. GEE was employed because of its capability to efficiently handle large-scale satellite datasets and support cloud-based processing without the need for high-performance local hardware [7] [25]. The data processing procedures were carried out through the following steps:

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

2.3.1 Image Preprocessing

The image preprocessing stage serves as a critical foundation in remote sensing analysis, particularly when utilizing multispectral data from the Sentinel-2 satellite for vegetation monitoring purposes. Without proper preprocessing, the data used for calculating vegetation indices such as the Normalized Difference Vegetation Index (NDVI) may be distorted by atmospheric interference, cloud shadows, or sensor artifacts, which directly affect the accuracy of spatial analysis results. Therefore, each preprocessing step must be carried out systematically and adhere to established data quality protocols as recommended in relevant literature [26] [19].

The first step in the preprocessing stage was the selection of Sentinel-2 imagery that met both spatial and temporal suitability criteria. For the study area, Kendari City, the imagery was obtained from the Copernicus Open Access Hub repository using key parameters such as the most recent acquisition date, cloud cover below 10%, and full spatial coverage of the administrative boundaries of Kendari City. Sentinel-2 Level-2A data were selected because they had undergone surface atmospheric correction (Bottom-of-Atmosphere reflectance/BOA), making them more suitable for spectral calculations such as the Normalized Difference Vegetation Index (NDVI) [6].

After the appropriate imagery was obtained, the next stage involved clipping the image using a shapefile (SHP) of Kendari City's administrative boundary. This clipping process was carried out to ensure that the dataset covered only the relevant study area while reducing the data processing load on the analytical platforms. The SHP format was obtained from the Geospatial Information Agency (BIG) and was used to crop the raster using the ee.Image.clip() function in Google Earth Engine (GEE) or the *Clip Raster by Mask Layer* tool in QGIS.

One of the major challenges in optical satellite image analysis is the presence of clouds and cloud shadows, which can obscure vegetation areas and lead to biased or invalid NDVI values. To overcome this issue, cloud-free imagery was filtered by selecting scenes with less than 10% cloud cover. Although Kendari City has a tropical climate with high rainfall and frequent cloud formation, careful temporal selection such as choosing imagery from the dry season or transitional months can help obtain clearer and more reliable scenes for analysis [27].

However, to ensure that noise caused by clouds was completely removed, the next step involved applying a cloud masking algorithm. On the Google Earth Engine (GEE) platform, the QA60 band available in Sentinel-2 Level-2A imagery contains pixel quality information, including cloud indicators. This band consists of bit values that can be interpreted using bitwise logical functions to identify pixels affected by clouds and their shadows.

The masking process produces a cleaner image in which pixels covered by clouds or cirrus are set to zero (excluded from further analysis). Previous studies have validated that the QA60-based cloud masking approach is highly effective in improving the accuracy of vegetation classification and NDVI values [17] [7].

In addition to QA60, more advanced cloud masking algorithms such as s2cloudless and Sen2Cor are also available and widely used in studies requiring higher accuracy. However, in this context, the QA60-based approach was deemed sufficient since the analysis focused on regional-scale patterns rather than individual pixels or machine-learning-based classifications.

The preprocessing stage also included spatial and temporal alignment of imagery, particularly when using multitemporal datasets (for example, in vegetation trend analysis). Alignment was ensured by maintaining a consistent coordinate reference system (WGS 84 / UTM Zone 51S for Kendari) and uniform spatial resolution across all images. All processes were conducted in a standardized, reproducible, and well-documented manner to enable replication for future analytical periods.

Overall, the image preprocessing procedures in this study were designed to ensure that the resulting NDVI values accurately represent actual vegetation conditions rather than atmospheric

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

disturbances or image artifacts. This step also enhances the precision of spatial analysis, particularly when comparing vegetation conditions across districts in Kendari City or overlaying NDVI results with spatial planning and land-use maps [3].

2.3.2 NDVI Calculation

NDVI was calculated using the standard formula as follows:

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

Explanation:

- NIR (Near Infrared) – refers to the near-infrared radiation band of a pixel, typically corresponding to Band 8 in Sentinel-2 imagery. Healthy vegetation reflects a large portion of radiation in this band.
- RED – refers to the red light radiation band of a pixel, usually corresponding to Band 4 in Sentinel-2 imagery. Vegetation absorbs most of the red light for photosynthesis processes.

The resulting NDVI values range from –1 to +1, with the general interpretation as follows:

- Values approaching +1 → indicate dense, healthy, and vigorous vegetation.
- Values around 0 → represent sparse or mixed vegetation cover.
- Negative values (< 0) → correspond to non-vegetated surfaces such as water bodies, built-up areas, rocks, or bare soil.

Based on the reference from the Regulation of the Minister of Forestry of the Republic of Indonesia No. P.12/Menhut-II/2012, which is used in assessing vegetation greenness and post-mining land reclamation success as cited in [3] , NDVI values are classified into five categories, as shown in the following table 1:

Table 1. NDVI Classification Based on Vegetation Greenness

Class	NDVI Range	Description
1	-1.00 to -0.03	Non-vegetated land
2	-0.04 to 0.15	Very Low Greenness
3	0.16 to 0.25	Low Greenness
4	0.26 to 0.35	Moderate Greenness
5	0.36 to 1.00	High Greenness (Dense Vegetation)

Source: Regulation of the Minister of Forestry of the Republic of Indonesia No. P.12/Menhut-II/2012

2.3.3 Classification and Visualization

The NDVI raster was then classified into five categories using the *Reclassify* function in QGIS. The classification results were visualized in the form of a thematic NDVI map for Kendari City. The color palette followed the standard vegetation gradient, ranging from dark green (dense vegetation) to red or brown (non-vegetated areas), as commonly applied in vegetation mapping studies using the NDVI index [12] [13]

The area of each NDVI class was calculated in hectares to determine the proportion of vegetation cover. The spatial distribution of vegetation was then analyzed in relation to the existing land-use conditions to examine the correlation between the actual Green Open Spaces (GOS) and their vegetative characteristics [3] [28]. The analysis was conducted for the entire area of Kendari City and compared with the minimum standard requirement of 30% urban Green Open Space (GOS) from the total city area, as stipulated in Government Regulation No. 26 of 2008 concerning Spatial Planning (Ministry of Public Works and Housing, 2008).

This method is consistent with various studies that employ NDVI reclassification and thematic mapping in QGIS for vegetation cover analysis and green space planning in urban areas of Indonesia [29] [30].

2.3.4 Analysis of Green Open Space (GOS) Sustainability

The sustainability analysis of Green Open Spaces (GOS) was conducted following the classification results of the Normalized Difference Vegetation Index (NDVI) and the spatial distribution of vegetation across Kendari City. This stage aimed to evaluate the extent to which the current vegetation conditions support the city's ecological sustainability and align with the ideal GOS standard as stipulated in Government Regulation No. 26 of 2008 concerning the National Spatial Planning Policy, which mandates a minimum of 30% of the total urban area to be allocated for green open spaces. The analytical approach adopted in this study was based on the method developed by [6], which involved comparing the area of high NDVI vegetation (NDVI > 0.6) with the ideal GOS area requirement, identifying zones with low NDVI values that have the potential to be developed as new green open spaces, and performing an overlay analysis between NDVI data and urban development zones to detect urbanization pressure on vegetation.

This process was carried out using QGIS software through the *Raster Calculator* and *Reclassify* functions, which enabled spatial mapping of vegetation density levels. High NDVI values indicate areas with dense vegetation cover that generally function as active green zones, whereas low NDVI values signify regions experiencing vegetation degradation, which have the potential to be restored or developed into Green Open Spaces (GOS) [13] [12] By overlaying the NDVI map with the existing land-use map, areas with high NDVI values but located within zones of intense development pressure were categorized as priority conservation areas. Conversely, regions with low NDVI values yet spatially strategic positions were identified as potential sites for greening programs or the development of new Green Open Spaces (GOS) [28] [31].

This approach also takes into account the concept of *ecological resilience*, as described by [3] and [30], which highlights the capacity of urban ecosystems to adjust and regenerate in response to disturbances triggered by anthropogenic activities, including land-use changes and the expansion of impervious or built-up zones. Within the framework of Green Open Spaces (GOS), the concept of ecological resilience is reflected through the evaluation of vegetation connectivity, spatial ecological accessibility, and the ecosystem's ability to sustain microclimatic stability in urban environments.

Research conducted by [32] indicates that the interconnection among vegetated areas plays a crucial role in sustaining urban ecological functions, whereas [17] assert that an increase in the NDVI index is inversely correlated with rising surface temperatures (the Urban Heat Island phenomenon). Therefore, the existence of sustainable GOS can play a significant role in mitigating microclimatic impacts.

Furthermore, the results of the green open space (GOS) sustainability analysis are also employed to assess the balance between ecological, spatial, and social aspects in urban landscape management. A study by [20] in Samarinda City revealed that areas with low NDVI values located near zones of intensive economic activity tend to experience higher environmental pressure, thus requiring priority in urban green planning. [33] integrated the analysis of the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Soil Adjusted Vegetation Index (SAVI) to evaluate the interactions between vegetation cover and the expansion of built-up areas in Indonesian urban regions.

Jurnal Teknik Informatika (JUTIF)
P-ISSN: 2723-3863
E-ISSN: 2723-3871
Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

The overall results of this analysis are expected to produce a thematic map of green open space (GOS) sustainability in Kendari City, illustrating the existing vegetation conditions, development potential, and conservation zones. This information can serve as a foundation for formulating spatial policy recommendations related to greening priorities, vegetation conservation, and medium-term GOS development. Consequently, the analysis not only provides a quantitative depiction of vegetation availability but also integrates ecological and spatial dimensions to support sustainable urban development in alignment with the targets of the Sustainable Development Goals *(SDG 11: Sustainable Cities and Communities and SDG 15: Life on Land*). [16] [33].

2.3.5 Workflow Summary

This study employed an integrated geospatial analysis consisting of two main stages: (1) cloud-based image preprocessing and NDVI generation using Google Earth Engine (GEE), and (2) spatial classification and overlay analysis using QGIS 3.34 Prizren. Sentinel-2 imagery with less than 10% cloud cover was selected, masked using the QA60 band, and clipped to the Kendari City boundary prior to NDVI computation. The resulting NDVI raster was exported in GeoTIFF format and reclassified into five vegetation density classes based on the Indonesian Forestry Regulation P.12/Menhut-II/2012. Subsequently, the reclassified raster was overlaid with the official Green Open Space (GOS) zoning layer from the RTRW to evaluate the adequacy, spatial equity, and ecological functionality of urban vegetation. This integrated workflow ensures reproducible, policy-relevant spatial assessment and provides a transparent framework for sustainable urban planning. the workflow of this study is summarized in Figure 1.

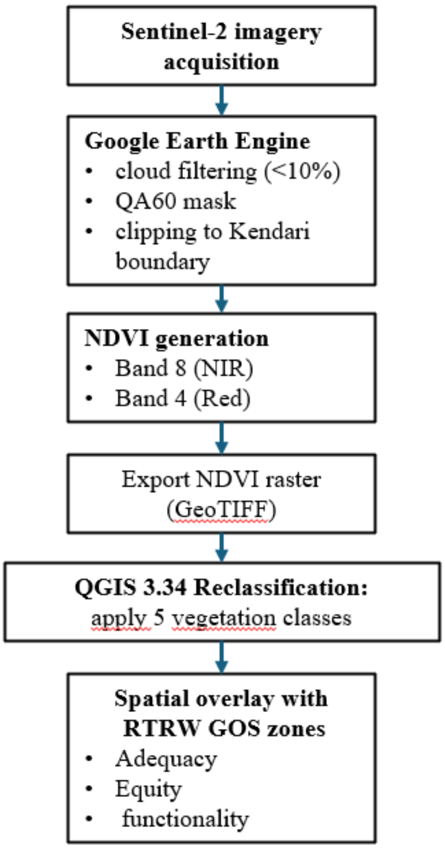

Figure 1. Flowchart NDVI–GOS Evaluation Workflow Using Sentinel-2, GEE, and QGIS

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

3. RESULT

3.1 Atmospheric Correction and Sentinel-2 Data Acquisition Using Google Earth Engine

The processing of satellite imagery for vegetation analysis requires an initial stage of atmospheric correction to eliminate the effects of atmospheric disturbances such as water vapor, aerosols, and other particles that may influence the surface reflectance values. This correction process is essential to ensure that the spectral values used in calculating the Normalized Difference Vegetation Index (NDVI) accurately represent actual land cover conditions rather than atmospheric distortions.

In this study, Sentinel-2 Level-2A imagery was utilized, which represents a satellite data product that has undergone automatic atmospheric correction using the Sen2Cor algorithm developed by the European Space Agency (ESA). This imagery provides surface reflectance values (bottom-of-atmosphere reflectance), making it ready for vegetation index computations such as the NDVI without the need for additional manual correction. [26] [34]. The Level-2A product is available on the Google Earth Engine (GEE) platform.

In the Google Earth Engine (GEE) environment, the acquisition and preprocessing of Sentinel-2 data are performed automatically within a cloud-based system, enabling high efficiency in handling large-scale spatial datasets. The study area was defined by importing the shapefile of Kendari City's administrative boundary, which served as a reference for the image clipping process. Based on the Sentinel-2 image search constrained to the period from August 1, 2023, to September 30, 2025, only one image met the selection criteria of 5% cloud cover, ensuring optimal vegetation conditions during the relatively dry season.

The following is a code snippet used for data acquisition in Google Earth Engine (GEE):

```
// Map the function over one year of data and take the median.
// Load Sentinel-2 TOA reflectance data.
var collection = ee.ImageCollection('COPERNICUS/S2')
    .filterDate('2023-08-01', '2025-05-30')
    .filterBounds(kendari)
    // Pre-filter to get less cloudy granules.
    .filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE',5))
    .map(maskS2clouds)

var composite = collection.median().clip(kendari)

// Display the results.
Map.addLayer(composite, {bands: ['B8','B8'], min: 0, max: 0.3}, 'RGB')

// Export a cloud-optimized GeoTIFF.
Export.image.toDrive({
  image: composite,
  description: 'Citra-kendari',
  scale: 10,
  region: kendari,
  fileFormat: 'GeoTIFF',
  formatOptions: {
    cloudOptimized: true
  }
});
```

The code above executes a cloud-masking function based on the QA60 band, which is used to remove pixels covered by clouds and cirrus. The bitwiseAnd function identifies pixels affected by cloud or cirrus contamination and eliminates them from the final image. This process is crucial to prevent NDVI values from being biased by atmospheric interference, particularly in tropical regions such as Kendari, where cloud frequency is relatively high.

After the masking and area clipping processes were completed, the next step involved calculating the NDVI values using Band 8 (Near-Infrared) and Band 4 (Red) from the Sentinel-2 imagery. The resulting masked and clipped image produced a spatial mosaic with a 10-meter resolution, ready for use in vegetation classification.Visually, the results of atmospheric correction and cloud masking produce imagery with a clear vegetation contrast, revealing distinct differences between forested areas, built-up zones, water bodies, and bare land. This is crucial to ensure that the interpretation of the resulting NDVI values accurately represents the actual vegetation cover in Kendari City. The results of atmospheric correction and cloud masking can be seen in Figure 2.

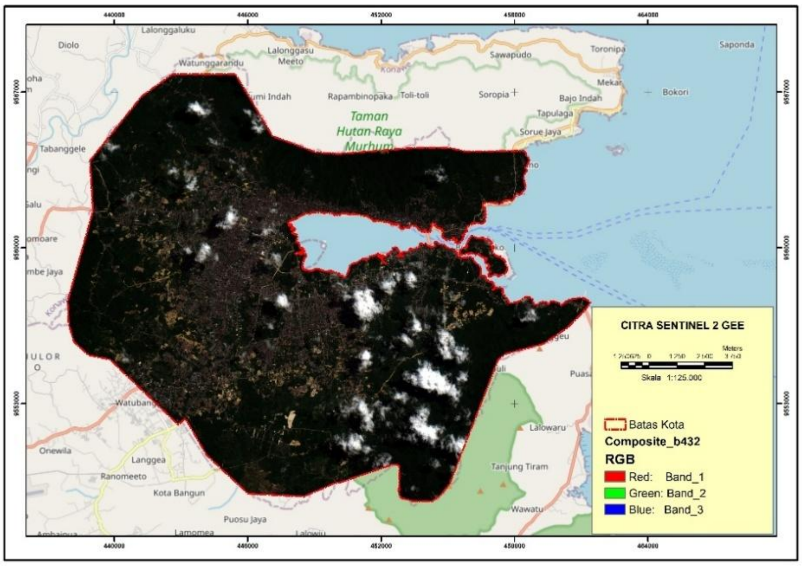

Figure 2. Sentinel-2 imagery from Google Earth Engine (GEE)

3.2 Classification of Sentinel-2 NDVI Data

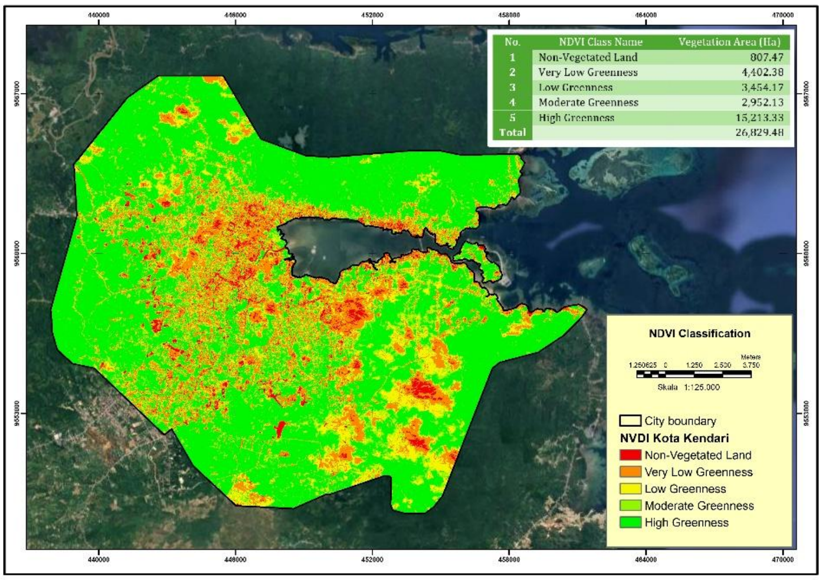

Figure 3. Classified NDVI map of Sentinel-2 imagery processed in Google Earth Engine

Figure 3 is a map of the results of the Normalized Difference Vegetation Index (NDVI) value classification for the administrative area of Kendari City with a scale of 1:125,000. This map represents the distribution and density of vegetation conditions based on the results of Sentinel-2 image processing and NDVI calculations, which are then classified into five categories: Non-Vegetable Land, Very Low Greenness, Low Greenness, Medium Greenness, and High Greenness.

The dominance of light and dark green tones across most areas indicates that, in general, Kendari City still maintains a relatively good level of vegetation cover. Areas classified as having moderate to high greenness are widely distributed in the northern, eastern, and parts of the western regions, particularly in zones located farther from dense residential concentrations. This distribution reflects the

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

presence of forested areas, natural shrublands, and conservation zones that remain relatively undeveloped.

Conversely, areas represented by yellow, orange, and red colors indicate regions with low to no vegetation cover. The red zones, classified as “Non-Vegetated Land,” are predominantly found in the city center, coastal areas, and along major road corridors. These are most likely regions that have undergone land-use conversion into dense settlements, commercial zones, or public infrastructure. Meanwhile, orange and yellow zones representing very low and low greenness levels are scattered around urban areas and within regions of seasonal dryland agriculture or degraded open land.

This spatial distribution indicates that the processes of urbanization and land-use conversion in Kendari City have significantly influenced the pattern of vegetation cover. The city center exhibits a high concentration of non-vegetated land, which potentially increases the risk of urban heat island (UHI) effects and contributes to the decline of environmental quality. Therefore, these areas should be prioritized in programs aimed at expanding Green Open Spaces (GOS) and implementing greening initiatives based on adaptive local vegetation.

The NDVI classification map can also serve as a valuable reference for local governments, urban planners, and academic institutions in developing spatial planning and green space management policies. By utilizing such spatial data, planning processes can become more targeted, effective, and sustainable.

Overall, the interpretation results suggest that although Kendari City still possesses considerable vegetation potential, efforts toward the preservation, rehabilitation, and expansion of green open spaces in low-vegetation areas are essential to maintain the sustainability of the urban environment. Figure 4 shows this NDVI interval graph.

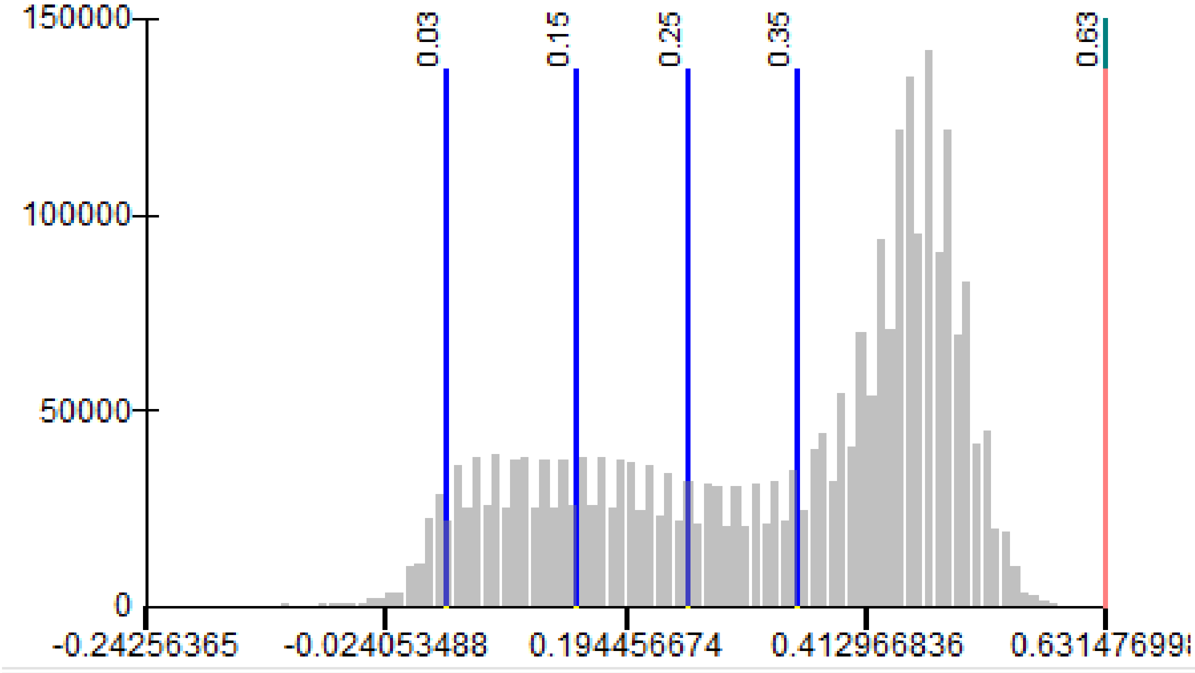

Figure 4. NDVI interval graph

The blue and red vertical lines represent the NDVI class boundaries used for the vegetation reclassification process. They indicate the threshold limits between the NDVI categories that were previously applied. The following is Table 2. Classification of NDVI Analysis Results of Sentinel-2 Images and Table 3. Area Classification of NDVI Analysis Results of Sentinel-2 Images.

Jurnal Teknik Informatika (JUTIF) Vol. 6, No. 6, December, 2025, Page. 5522-5538
P-ISSN: 2723-3863 https://jutif.if.unsoed.ac.id
E-ISSN: 2723-3871 DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

Table 2. Classification Results of NDVI Analysis from Sentinel-2 Imagery

Line Color	NDVI Value	Function / Description	NDVI Category
Blue	0.03	Lower boundary of the very low vegetation class	Non-vegetated → Very Low Greenness
Blue	0.15	Upper boundary of the very low vegetation class	Transition to Low Greenness
Blue	0.25	Upper boundary of the low greenness class	Toward Moderate Greenness
Blue	0.35	Upper boundary of the moderate greenness class	Toward High Greenness
Red	0.63	Highest NDVI threshold observed	Point of Maximum Dense Vegetation

Source: NDVI Analysis Results, 2025

Table 3. Classification Area of NDVI Analysis Results of Sentinel-2 Imagery

No.	NDVI Class Name	Vegetation Area (Ha)
1	Non-Vegetated Land	807.47
2	Very Low Greenness	4,402.38
3	Low Greenness	3,454.17
4	Moderate Greenness	2,952.13
5	High Greenness	15,213.33
Total		26,829.48

Source: NDVI Analysis Results, 2025

The table above presents the area of each NDVI class in hectares (ha), derived from the reclassification of NDVI values into five vegetation categories. The total analyzed area covers 26,829.48 hectares, encompassing the entire administrative region of Kendari City. This value serves as the basis for assessing the ecological condition and sustainability of the city's green open spaces (GOS).

a. Non-Vegetated Land – 807.47 ha (±3.01%)

This category includes areas with NDVI values ranging from -1 to -0.03, generally representing surfaces without vegetation such as dense settlements, industrial zones, water bodies, open-pit mines, major roads, and heavily degraded lands. The total area of 807.47 hectares indicates that approximately 3% of Kendari City's territory consists of land entirely lacking vegetation cover. This reflects the pressure of anthropogenic activities and highlights the need for ecological rehabilitation or the development of artificial green open spaces (GOS) in densely urbanized areas.

b. Very Low Greenness – 4,402.38 ha (±16.41%)

The second category corresponds to NDVI values between -0.04 and 0.15, indicating areas with very sparse vegetation, such as open fields, low shrubs, fallow farmland, and transitional urban–rural zones undergoing development. Covering 4,402.38 hectares (about 16.4% of the total area), these regions show minimal vegetation presence. Without proper management, they could evolve into ecologically critical zones. Therefore, these areas are ideal targets for rapid tree planting, revegetation, or urban park development programs.

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

c. Low Greenness – 3,454.17 ha (±12.88%)

With NDVI values between 0.16 and 0.25, this class represents areas with low vegetation cover, including dry grasslands, mixed gardens, shrubs, or underproductive dryland agricultural areas. A total of 3,454.17 hectares or nearly 13% of Kendari City falls under this category. Although vegetation is limited, these zones still hold potential for recovery, either naturally or through community-based restoration interventions. Their presence also serves as ecological buffer zones whose ecosystem functions can be enhanced.

d. Moderate Greenness – 2,952.13 ha (±11.01%)

Areas with NDVI values ranging from 0.26 to 0.35 are classified as having moderate greenness. This category typically represents semi-permanent vegetation such as mixed gardens, urban park trees, riparian vegetation, and partially disturbed conservation zones. With an area of approximately 2,952.13 hectares (around 11% of the city), these areas are important to preserve and improve toward higher greenness levels. Efforts such as tree enrichment, landscape management, and community involvement in conservation can help sustain and enhance the ecological quality of these zones.

e. High Greenness – 15,213.33 ha (±56.7%)

The final category represents areas with NDVI values between 0.36 and 1.00, corresponding to dense, healthy, and lush vegetation. This includes urban forests, protected areas, tall shrublands, and intact natural vegetation. Covering more than 15,000 hectares or over half of Kendari City's total area this category demonstrates the city's significant ecological potential and its importance as a key asset for urban sustainability. These areas should be safeguarded from development pressures, designated as conservation zones or urban green sanctuaries, and integrated into ecosystem service–based GOS planning.

4. DISCUSSIONS

The availability of Green Open Spaces (GOS) was analyzed based on a Vegetation Density Map derived from the regression analysis between vegetation indices and field-measured vegetation density. A higher range of vegetation index values indicates a higher vegetation density, which in turn influences the classification and type of GOS [35]. The analysis of Green Open Space (GOS) sustainability in Kendari City, based on vegetation density data, reveals a relatively complex dynamic. The classification results of NDVI values derived from Sentinel-2 imagery indicate that Kendari City is predominantly covered by areas with high and moderate levels of greenness, accounting for approximately 56.7% and 11% of the total area of 26,829.48 hectares, respectively. This means that about 67.7% of the city's entire territory still possesses vegetation cover that functions as an ecological buffer. Such ecological potential plays a crucial role in promoting urban sustainability, particularly in regulating microclimate conditions, conserving groundwater, enhancing carbon sequestration, and supporting urban biodiversity habitats.

Nevertheless, the existence of Green Open Spaces (GOS) in Kendari City cannot be evaluated solely based on the quantitative aspect of greenness. In the context of spatial sustainability, the distribution, function, and quality of GOS are equally important indicators. The total area classified as "non-vegetated land" and "very low greenness" reaches nearly 5,210 hectares, or approximately 19.4% of the city's total area. These zones are predominantly located in the city center, development corridors, and densely populated residential areas. This condition indicates significant urbanization pressure on vegetation cover, posing a threat to GOS availability particularly in strategic and high-density zones. In fact, evenly distributed GOS within the urban area is essential to ensure public accessibility to green spaces, improve quality of life, and prevent ecological disparities among urban districts.

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

From a policy perspective, Kendari City is bound by Law No. 26 of 2007 on Spatial Planning, which mandates a minimum of 30% GOS coverage of the total city area comprising 20% public GOS and 10% private GOS. Based on NDVI classification data, the city appears to have quantitatively met or even exceeded this target. However, further examination is needed regarding the functional distribution and legal status of existing green zones. Not all areas with high NDVI values necessarily represent formal GOS, as some might still be undeveloped lands designated for non-ecological functions in the city's spatial planning (RTRW). Therefore, NDVI-based spatial analysis should be integrated with official spatial planning maps to ensure that areas with high vegetation density are preserved as legally protected GOS in the long term.

The sustainability of Kendari City's GOS also depends greatly on how the local government manages areas with low and very low vegetation density. These areas should be prioritized for urban greening programs, critical land restoration, neighborhood park development, and the establishment of green corridors that connect vegetated patches. Such initiatives not only expand the physical area of GOS but also strengthen ecological connectivity across regions, improve local air quality, and mitigate the urban heat island (UHI) effect. Furthermore, optimizing private GOS such as household yard greening, vertical gardens in office buildings, and rooftop gardens can contribute significantly to achieving the 10% non-governmental GOS requirement stipulated by national policy.

As a coastal city with varied topography, Kendari must also consider Green Open Space (GOS) sustainability within the context of disaster mitigation. Riparian zones, hilly areas, and coastal regions are particularly important to preserve, as maintaining vegetation in these areas helps reduce the risks of flooding, landslides, and coastal erosion. Moreover, in the era of climate change, GOS plays a strategic role as a carbon sink and as a provider of microhabitats for species affected by ecosystem shifts. Therefore, the GOS conservation strategy in Kendari City should not rely solely on technocratic approaches but must also incorporate ecological and social dimensions, involving active community participation in the management, maintenance, and monitoring of green spaces within local neighborhoods.

Overall, the sustainability analysis of Kendari City's GOS indicates that although the city's vegetation condition remains relatively well-preserved in quantitative terms, there are serious challenges concerning the spatial distribution, legal status, and long-term management of GOS particularly in areas experiencing high development pressure. The integration of NDVI data, spatial planning, and multi-stakeholder participation is essential to ensure the continued ecological functionality of urban green spaces amid the dynamics of urban growth. With a data-driven and well-structured strategy, Kendari City has great potential to evolve into a resilient and livable green city for all its residents.

This study contributes to the field of geospatial informatics by demonstrating a reproducible, cloud-based workflow that integrates Google Earth Engine (GEE) and QGIS for urban vegetation monitoring. The workflow enables automated data preprocessing, classification, and spatial policy evaluation using open-source platforms and globally available Sentinel-2 imagery. This integration not only enhances methodological transparency and scalability for annual vegetation assessments but also bridges the gap between remote sensing analytics and urban policy implementation. By promoting interoperability between cloud computation and desktop GIS environments, the study advances evidence-based urban planning systems and supports the broader development of sustainable geospatial informatics applications in developing cities.

5. CONCLUSION

The results of this study show that approximately 67.7% of Kendari City's total area exhibits *moderate to high vegetation density* based on Sentinel-2 NDVI analysis, while around 19% of the land is categorized as *low or non-vegetated*. These findings indicate that although vegetation still covers a

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

significant portion of the city, the spatial distribution remains uneven, with high vegetation concentrated in the northern and peripheral zones, while central urban areas are increasingly dominated by built-up land. When overlaid with the city's spatial plan (RTRW), only about 21% of the vegetated areas coincide with designated Green Open Space (GOS) zones, revealing a substantial gap between ecological potential and formal GOS allocation.

From a policy perspective, this research underscores the urgent need for restoration programs, the establishment of urban green corridors, and enhanced community participation to achieve the national target of 30% GOS coverage. The NDVI based evaluation framework provides quantitative evidence that can guide local governments in formulating adaptive urban greening strategies, ensuring that GOS planning aligns with spatial equity and ecological functionality. The integration of geospatial analysis into policy evaluation also reinforces the importance of data-driven decision-making in urban environmental governance.

Furthermore, this research advances the field of remote sensing informatics by developing an integrated Google Earth Engine (GEE) QGIS workflow for urban vegetation monitoring and policy assessment. The workflow demonstrates a reproducible, cloud-based, and open source approach that strengthens scalability, transparency, and interoperability within geospatial informatics. Future research should focus on extending this framework through multitemporal NDVI analysis (2015–2025), machine learning–based classification for improved accuracy, and web-GIS dashboard integration to support real-time public access and participatory environmental monitoring. Collectively, these advancements contribute to the development of evidence-based and sustainable urban planning systems in developing cities.

REFERENCES

[1] H. Hasddin, A. A. Muthalib, E. Ngii, and A. Putera, "The ability of green open spaces in greenhouse gas control to achieve green cities in Kendari City," *International Journal of Energy Economics and Policy,* vol. 12, no. 1, pp. 327-331, 2022, doi: https://doi.org/10.32479/ijeep.11980.

[2] W. I. R. Aulia, "The Concept of Urban Green Open Space Development with Green Infrastructure in Kendari City," 2020, doi: http://dx.doi.org/10.4108/eai.25-6-2019.2294309.

[3] I. Asmiwyati, I. W. D. GARGITA, and P. P. K. Wiguna, "ANALYSIS OF URBAN GREEN OPEN SPACE DEVELOPMENT IN NORTH DENPASAR DISTRICT, DENPASAR CITY, BALI, INDONESIA," *Geographia Technica,* vol. 20, no. 1, 2025, doi: http://dx.doi.org/10.21163/GT_2025.201.07.

[4] M. Priyanta and C. S. A. Zulkarnain, "Urban green open space in developing countries: Indonesia regulations, problems and alternative solutions," *Journal of Property, Planning and Environmental Law,* vol. 16, no. 2, pp. 134-151, 2024, doi: https://doi.org/10.1108/JPPEL-01-2024-0002.

[5] M. Luo and W. Zhang, "Fostering life hope in urban green spaces through brief online mindfulness: findings from four studies with park visitors," *Frontiers in Psychology,* vol. 16, p. 1642533, 2025, doi: https://doi.org/10.3389/fpsyg.2025.1642533.

[6] A. Agustiyara, D. Mutiarin, A. Nurmandi, A. N. Kasiwi, and M. F. Ikhwali, "Mapping Urban Green Spaces in Indonesian Cities Using Remote Sensing Analysis," *Urban Science,* vol. 9, no. 2, p. 23, 2025, doi: https://doi.org/10.3390/urbansci9020023.

[7] A. Rifai, H. Rakuasa, F. Tade, A. Purnama, A. Jufriansah, and A. Khusnani, "Spatial Analysis of Vegetation Index in Ambon City Center Area, Indonesia using Sentinel-2 Satellite Imagery in Google Earth Engine," *Frontiers in Sustainable Science and Technology,* vol. 2, no. 1, pp. 32-40, 2025, doi: https://doi.org/10.69930/fsst.v2i1.365.

[8] B. Alshehri, Z. Zhang, and X. Liu, "A Review of Google Earth Engine for Land Use and Land Cover Change Analysis: Trends, Applications, and Challenges," *ISPRS International Journal of Geo-Information,* vol. 14, no. 11, p. 416, 2025, doi: https://doi.org/10.3390/ijgi14110416.

[9] H. Wang and F.-Y. Gong, "Quantifying city-and street-scale urban tree phenology from Landsat-8, Sentinel-2, and PlanetScope images: a case study in downtown Beijing," *Remote sensing,* vol. 16, no. 13, p. 2351, 2024, doi: https://doi.org/10.3390/rs16132351.

[10] O. G. Narin *et al.*, "Integration of multi-temporal sentinel-1 and sentinel-2 data for paddy rice crop height estimation and uncertainty assessment using quantile regression forests," *Precision Agriculture,* vol. 26, no. 6, pp. 1-28, 2025, doi: https://doi.org/10.1007/s11119-025-10287-5.

[11] P. Oikonomou, V. Karathanassi, V. Andronis, and I. Papoutsis, "Assessing and Forecasting Natural Regeneration in Mediterranean Landscapes After Wildfires," *Remote Sensing,* vol. 17, no. 5, p. 897, 2025, doi: https://doi.org/10.3390/rs17050897.

[12] F. Ramdani, "A Very High-Resolution Urban Green Space from the Fusion of Microsatellite, SAR, and MSI Images," *Remote Sensing,* vol. 16, no. 8, p. 1366, 2024, doi: https://doi.org/10.3390/rs16081366.

[13] H. D. Nirwana, A. R. Saidy, G. M. Hatta, and A. Nugroho, "Design of Green City with Lower Carbon based on Vegetation in Banjarbaru using Sentinel-2," *Journal of Applied Data Sciences,* vol. 5, no. 2, pp. 583-599, 2024, doi: https://doi.org/10.47738/jads.v5i2.218.

[14] L. Moreschi, E. Gagliano, M. Gallo, and A. Del Borghi, "A framework for the environmental assessment of water-energy-food-climate nexus of crops: Development of a comprehensive decision support indicator," *Ecological Indicators,* vol. 158, p. 111574, 2024, doi: https://doi.org/10.1016/j.ecolind.2024.111574.

[15] X. Ren, X. Yu, and Y. Wang, "A spectral–spatial method for mapping fire severity using morphological attribute profiles," *Remote Sensing,* vol. 15, no. 3, p. 699, 2023, doi: https://doi.org/10.3390/rs15030699.

[16] M. A. Saadah, "Sustainable Urban Growth and Green Space Governance in Yogyakarta: Remote Sensing Insights and Lessons learned from Budapest (Integrating Remote Sensing into Urban Planning and Policy)," *Jurnal Studi Pemerintahan,* pp. 226-245, 2025, doi: https://doi.org/10.18196/jsp.v16i2.420.

[17] A. W. Hasyim, B. M. Sukojo, I. A. Anggraini, E. R. Fatahillah, and A. Isdianto, "Urban heat island effect and sustainable planning: Analysis of land surface temperature and vegetation in Malang City," *International Journal of Sustainable Development and Planning,* vol. 20, no. 2, pp. 683-697, 2025, doi: https://doi.org/10.18280/ijsdp.200218.

[18] D. A. Lestari, W. A. Arifin, N. S. Fitriasari, T. E. Ahmad, A. Rais, and D. R. Azhari, "Automatic Geographic Information System algorithm for temporal mangrove observation: A case study in Gopek Beach, North Banten," *Jurnal Pendidikan Geografi: Kajian, Teori, dan Praktek dalam Bidang Pendidikan dan Ilmu Geografi,* vol. 27, no. 2, p. 4, 2024, doi: http://dx.doi.org/10.17977/um017v27i22022p163-174.

[19] Y. Hu, A. Barberopoulou, and M. Koch, "Tracing the 2018 Sulawesi earthquake and tsunami's impact on Palu, Indonesia: a remote sensing analysis," *Journal of Marine Science and Engineering,* vol. 13, no. 1, p. 178, 2025, doi: https://doi.org/10.3390/jmse13010178.

[20] R. A. Pratomo, Z. Islamiah, and B. E. Bhaskara, "A pathway to urban resilience: investigating green open space priority areas to mitigate the urban heat island phenomenon in Samarinda City, Indonesia," *International Journal of Disaster Resilience in the Built Environment,* vol. 15, no. 4, pp. 591-616, 2024, doi: https://doi.org/10.1108/IJDRBE-02-2023-0047.

[21] J. Hang, L. An, Y. Zhao, Z. Wu, and J. Liao, "Comparative simulation of transpiration and cooling impacts by porous canopies of shrubs and trees," *Sustainable Cities and Society,* vol. 111, p. 105573, 2024, doi: https://doi.org/10.1016/j.scs.2024.105573.

[22] A. Onasis, H. Akib, R. Niswaty, and A. Kasmawati, "Evaluation of Green Open Space Policy in Supporting Sustainable Development," *Journal of Indonesian Scholars for Social Research,* vol. 5, no. 1, pp. 129-136, 2025, doi: https://doi.org/10.59065/jissr.v5i1.207.

[23] D. Moravec, J. Komárek, S. López-Cuervo Medina, and I. Molina, "Effect of atmospheric corrections on NDVI: Intercomparability of Landsat 8, Sentinel-2, and UAV sensors," *Remote Sensing,* vol. 13, no. 18, p. 3550, 2021, doi: https://doi.org/10.3390/rs13183550.

[24] F. Goroee and O. Bazrafshan, "Comparative Performance Analysis of Google Earth Engine and SNAP Platforms for Estimating Water Quality Parameters in Minab Dam Reservoir Using Multi-

Vol. 6, No. 6, December, 2025, Page. 5522-5538
https://jutif.if.unsoed.ac.id
DOI: https://doi.org/10.52436/1.jutif.2025.6.6.5409

Spectral Resolution Satellite Imagery," *Water and Soil Management and Modelling,* vol. 5, no. 3, pp. 104-122, 2025, doi: https://doi.org/10.22098/mmws.2025.16743.1557.

[25] T. L. Bui, Y. Mori, M. Maeda, and H. Somura, "Artificial macropores and water management effects on reduction of greenhouse gas emissions from rice paddy fields," *Environmental Challenges,* vol. 9, p. 100657, 2022, doi: https://doi.org/10.1016/j.envc.2022.100657.

[26] M. Drusch *et al.*, "Sentinel-2: ESA's optical high-resolution mission for GMES operational services," *Remote sensing of Environment,* vol. 120, pp. 25-36, 2012, doi: https://doi.org/10.1016/j.rse.2011.11.026.

[27] A. Nugroho, A. Jauhari, and M. Faisal, "Hasil Turnitin Urban Heat Island Spatial Model for Climate Village Program Planning," doi: https://repo-dosen.ulm.ac.id//handle/123456789/36499.

[28] D. Pangestu, M. Sunariya, and N. Anggani, "Utilization of NDVI analysis in fulfilling Green Open Space in Balaraja District, Tangerang Regency in 2023," in *IOP Conference Series: Earth and Environmental Science*, 2025, vol. 1438, no. 1: IOP Publishing, p. 012027, doi: https://doi.org/10.1088/1755-1315/1438/1/012027.

[29] M. Kelly-Fair *et al.*, "Analysis of land use and land cover changes through the lens of SDGs in Semarang, Indonesia," *Sustainability,* vol. 14, no. 13, p. 7592, 2022, doi: https://doi.org/10.3390/su14137592.

[30] A. Isdianto, A. W. Hasyim, B. M. Sukojo, I. Alimuddin, I. A. Anggraini, and E. R. Fatahillah, "Integrating Urban Design with Natural Dynamics: Enhancing Ecological Resilience in Malang City over a Decade," *International Journal of Sustainable Development & Planning,* vol. 20, no. 3, 2025, doi: https://doi.org/10.18280/ijsdp.200313.

[31] P. Tutuko, N. Aini, A. Safrilia, A. G. Sulaksono, and R. Wikantiyoso, "The Calculation of Green Open Space Patterns in The Cities in Indonesia Examining the Connectivity and NDVI of CBD and Residential Areas in the Colonial Cities of Malang and Bandung, Indonesia," *International Review for Spatial Planning and Sustainable Development,* vol. 13, no. 2, pp. 179-197, 2025, doi: https://doi.org/10.14246/irspsd.13.2_179.

[32] B. SUDARMANTO, S. SURANTO, S. SUNTORO, and J. SUTRISNO, "Measuring climate action readiness in maintaining ecological resilience using satellite imagery and field research in Garang Watershed, Central Java, Indonesia," *Biodiversitas: Journal of Biological Diversity,* vol. 24, no. 5, 2023, doi: https://doi.org/10.13057/biodiv/d240551.

[33] V. R. Parmono and Y. A. Singgalen, "Integrating Remote Sensing, Consumer Preferences, and Sustainable Marketing: A GWR Study of Urban Growth and Heat Island in BSD City, Indonesia," *International Journal of Sustainable Development & Planning,* vol. 20, no. 8, 2025, doi: https://doi.org/10.18280/ijsdp.200811.

[34] F. Gascon *et al.*, "Copernicus Sentinel-2A calibration and products validation status," *Remote Sensing,* vol. 9, no. 6, p. 584, 2017, doi: https://doi.org/10.3390/rs9060584.

[35] I. K. Putrajaya, "Analisis indeks Vegetasi Menggunakan Citra ALOS AVNIR-2 untuk Estimasi Kebutuhan Ruang Terbuka Hijau Berdasarkan Kebutuhan Oksigen Di Kota Denpasar, Provinsi Bali," *Jurnal Pendidikan Geografi: Kajian, Teori, dan Praktek dalam Bidang Pendidikan dan Ilmu Geografi,* vol. 22, no. 1, p. 6, 2024, doi: http://dx.doi.org/10.17977/um017v22i12017p049.