Biomass estimates from urban green space in Bekasi City using Sentinel imageries

R D Putra¹, I P A Shidiq*, and Rokhmatuloh¹
¹Department of Geography, Faculty of Mathematics and Natural Sciences, University of Indonesia, 16424, Jawa Barat, Indonesia

* iqbalputut@sci.ui.ac.id

Abstract. The establishment of urban green spaces is essential for reducing climate change and global warming impacts in the urban ecosystem. Rapid expansion from the Jakarta’s megalopolitan is influencing Bekasi City and further leads to the massive conversion of urban green space into built-up areas. The land cover changes are affecting biomass and carbon sequestration capability of urban green space towards emissions from anthropogenic activities. Monitoring efforts through biomass estimation is important for a better understanding of the benefits of urban green spaces. Therefore, the goals of this study are to examine the best vegetation index used for interpreting urban green space, and analyze the spatial distribution of biomass. This study used Sentinel-2B satellite imageries acquired in 2020, and further employ them to generate four vegetation indices, NDVI, GNDVI, SAVI, and OSAVI. The calculation of stand tree biomass was carried out by field measurements and allometric equations developed by the United States Department of Agriculture (USDA). Biomass estimation models developed from the relation between vegetation index and the observed biomass value. The results of this study was that the best vegetation index was OSAVI with an accuracy rate of 99%. The biomass produced in this study was 0.10149 tons/grid or 101.49 kg/grid to 1.913 tons/grid or 1913.99 kg. Bekasi dominated the low biomass value, while the value of biomass was more dominant in the Bekasi City Forest area. This research is expected to be an input for the local government, and the findings will become base information for maintaining urban green space in the city.

Keywords: Biomass estimation, allometric equation, Sentinel-2B, urban green space

1. Introduction

Bekasi which is one of the buffer areas of DKI Jakarta Capital. Its position is very strategic in the east of DKI Jakarta, as well as passed by the national vital transportation route namely Jakarta-Cikampek Toll Road. In addition, the flat physical condition of the land with an area of 210.49 km² is very supportive to be developed into industrial, residential and trade areas. This led to a change in land use in Bekasi. Land use changes are phenomena caused by human activity as spatially-temporal impacts that are in line with human dynamic growth. With the rapid expansion of the city will result in the conversion of land from vegetation to built land that can cause damage to urban ecosystems. As a result, some environmental issues arise in terms of land, use and greenhouse gas emissions, especially about the release of CO₂ into the atmosphere. This has prompted the government to provide land use policy, especially in urban centers with the Law of the Republic of Indonesia No. 26 of 2007 on Spatial Arrangement. This requires each city to provide and utilize urban green space of at least 30% of the total area divided into public Urban Green Space (UGS) of at least 20% and Private UGS of at least 10% [1]. While the area of Green Open Space Bekasi only amounts to 14.55 km² or 6.91% of the total area of Bekasi.

Vegetation in the form of Green Open Space, plays an important role in addressing climate change and global warming in urban areas. Green Open Space has an important role in stabilizing urban ecosystems such as reducing air pollution caused by carbon dioxide (CO₂) [2]. Bekasi’s rapid expansion led to the conversion of green areas into urban use. This triggered changes in land cover
that influenced the amount of biomass content in reducing carbon emissions. Biomass content estimation is important for understanding the benefits of vegetation in urban areas.

Remote sensing can capture features of the Earth's surface especially the characteristics of vegetation [3]. Vegetation index is a commonly used method for environmental issues using remote sensing. Such as the NDVI (Normalized Difference Vegetation Index) and some spectral variables are also used to develop rubber tree upright age models using remote sensing data to determine the biomass in rubber trees in Kedah, Malaysia [4]. In addition, vegetation indexes can be used to estimate above-surface biomass. In Indonesia, the estimation of biomass, especially in urban areas, has been carried out by Siwi [5] to estimate carbon dioxide (CO\textsubscript{2}) absorbed in Depok city and by Pitriya [6] estimating the value of biomass, the amount of CO\textsubscript{2} stored by the vegetation and explaining the spatial distribution of biomass in South Tangerang City.

Therefore, this research aims to find the best vegetation index used for urban RTH, as well as explain the spatial distribution of biomass in Bekasi. This study used Sentinel-2B satellite imagery data in 2020 to conduct vegetation index formulas in the form of NDVI, GNDVI, SAVI, OSAVI. Above-surface biomass calculations are performed by field measurements using allometric equations developed by the United States Department of Agriculture (USDA) and vegetation index formulas to develop biomass estimation models. This research is expected to be input for Bekasi city government as the basis of information in the maintenance of Urban Green Open Space in Bekasi.

2. Methods

2.1. Study Area

Geographically, Bekasi is located at 106°48'28" – 107°27'29" East Longitude and 6°10'6" – 6°30'6" South Latitude which is precisely located in West Java Province, to the north and east border bekasi regency, the south bordering the south of Bogor regency and Depok City, and to the west bordering DKI Jakarta Province (Figure 1). Bekasi has an area of approximately 210.49 km\textsuperscript{2} with a population of 2448.830 and a population growth rate of 1.3% [7]. The Green Open Space of Bekasi city has an area of 14.55 km\textsuperscript{2} or 6.91% of the total area of Bekasi City. The Green Open Space consists of UGS Green Line, UGS City Park, UGS Taman Kecamatan, UGS Taman Kelurahan, River Border, SUTET lines, Railway Road Boarder, UGS Recreation, Setu / Lake Border. RTH in Bekasi city is dominated by Swietenia mahagoni, Terminalia catappa, Musa x paradisiaca, Nauclea orientalis, Mangifera, Arecaceae, and Cinnamomum camphora. Based on the Spatial Plan of Bekasi City Area in 2011-2031, UGS development to reach a proportion of 30% of the city area is approximately 6.70 Ha, consisting of Public UGS of approximately 4.21 Ha (20%) and Private UGS covering approximately 2.105 Ha (10%). In addition, the area will be mostly allocated for an industrial area of 1.24 Ha or about 5.87%, a residential area of 11.32 Ha or about 53.78%, a trading and services area of 6.94 Ha or about 32.98%, and others about 7.37% which includes the provision of UGS [8].
2.2. Research Framework

This research aims to find the best vegetation index and measure the above-surface biomass content in Urban Green Space areas. In terms of achieving that goal, for the best vegetation index index of the regression model between field result biomass and vegetation index is carried out integration to produce biomass estimation model. This researched came from the idea of the need for green space that should sustain human activity and in the absence of some environmental issues arise in terms of land, used and greenhouse gas emissions, especially about the released of CO$_2$ into the atmosphere. The variables used in this studied were NDVI, GNDVI, SAVI AND OSAVI to create biomass models based on the association between in-situ biomass done by measuring the diameter of the trunk as high as the chest, tree height, tree typed, and wood density obtained from ICRAF and USDA wood density. Green opened space data was obtained from Bekasi City Spatial Office. The result of this studied was the amount of biomass content in bekasi city produced from biomass estimation model using the best vegetation index

2.3. Data collection and processing

2.3.1. Data Collection

The data in this studied was primary data and secondary data. Primary data was obtained directly in the field and secondary data was obtained from certain sources and related agencies to be processed before being done in field measurements. The primary data in this studied was the diameter of the tree, the height of the tree and the typed of tree. While the secondary data used was Sentinel-2B satellite imagery data in 2020 from the United States Geological Survey (USGS) obtained on the earthexplorer.usgs.gov website, RBI map published by the Geospatial Information Agency (BIG) in 2020 with a scale of 1: 25000 for bekasi city administrative boundary, and green opened space obtained from Bekasi City Spatial Office.

2.3.2. Remote Sensing Data and Processing

In this study, to determine the number of plots used for field biomass measurement using slovin method (Equation 1).

$$n = \frac{N}{1 + (N \times e^2)}$$ (1)

Based on the similarity of the method, N is the population and e is the margin of error set. The total sample field is in the form of a square / grid that amounts to 94 grids with random selection of samples and uses a 10% trust level. With a plot size of 100x100 meters each or equal to 10x10 pixels.
To calculate the amount of biomass above the surface is done with field measurements and allometric equations developed by the United States Department of Agriculture (USDA) using biophysical parameters such as chest-high diameter (dbh), tree height (m), and tree type. To get the value of biomass is done based on the group of trees namely conifer (Equation 2), broad-leaved tree (Equation 3), and palm (Equation 4).

\[ V_{\text{conifer}} = 0.0000426 \times D^{2.24358} \times H^{0.64956} \]  
\[ V_{\text{broadleaf tree}} = 0.0001967 \times D^{1.951853} \times H^{0.664255} \]  
\[ DW_{\text{palms}} = (6 \times H + 0.8) + (0.8 \times H + 0.9) \]

Based on these equations (Equation 2 and Equation 3), V is a volume in kilograms, D is a Diameter at Breast Height in cm or equivalent to 1.3 meters, H is high in meters (m), and for palm vegetation types do not use volume equations but use DW or dry weight biomass values (Equation 4). To convert the volume to DW biomass, the volume is multiplied by the density factor of DW [9,10]. However, for DW biomass there is no need to be multiplied by the wood density factor of DW.

For remote sensing data processing, use Sentinel 2B satellite imagery with image recording on March 10, 2020 and cloud cover of <10% obtained from USGS. For image processing, geometric correction and atmospheric correction using Sentinel 2B band bands are changed from digital numbers (DN) to reflectance values. Vegetation index values are obtained from the NDVI/Normalized Difference Vegetation Index (Equation 5), GNDVI/Green Normalized Difference Vegetation Index (Equation 6), SAVI/Soil Adjusted Vegetation Index (Equation 7), and OSAVI/Optimized Soil Adjusted Vegetation Index (Equation 8) with values in the range of -1 to 1.

\[ NDVI = \frac{(NIR-RED)}{(NIR+RED)} \]  
\[ GNDVI = \frac{(NIR-GREEN)}{(NIR+GREEN)} \]  
\[ SAVI = \frac{(NIR-RED)}{(NIR+RED+L)} \times (1 + L) \]  
\[ OSAVI = \frac{(NIR-RED)}{(NIR+RED+0.16)} \]

The Vegetation Index is extracted from sentinel 2B imagery with red band range from 0.650 μm - 0.680 μm, green band of 0.543 μm - 0.578 μm, blue band from 0.458 μm - 0.523 μm and near infrared band of 0.758 μm - 0.900 μm. For validation of biomass models produced using Normalized Mean Absolute Error (NMAE) (Equation 9) is considered a parameter that fits between estimation and measurement data. Xest shows the estimated image processing value and Xmeans indicates the measurement value in the field.

\[ NMAE (%) = \frac{1}{N} \sum \left| \frac{X_{\text{est}} - X_{\text{means}}}{X_{\text{means}}} \right| \times 100 \]

3. Results and Discussion

3.1. Vegetation Indices

The highest NDVI value in Bekasi is 0.79 and the smallest value is -0.37. The highest GNDVI value is 0.86 and the smallest value is -0.29. The highest OSAVI value is 0.58 and the smallest value is -0.18. While the highest SAVI value in Bekasi city is 0.57 and the smallest value is -0.20 (Figure 2 and Table 1).
3.2. Open Green Spaces

Based on data from Dinas Tata Ruang Kota Bekasi, the area of Green Open Space in Bekasi City is only 14.55 km² or 6.91% of the total area of Bekasi City (Figure 3).

Table 2. Urban Green Space Area

| UGS / Urban Green Space       | Total (Km²) |
|-------------------------------|-------------|
| UGS Green Line                | 1.13        |
| UGS City Park                 | 2.61        |
| UGS Taman Kecamatan           | 1.18        |
| UGS Taman Kelurahan           | 0.67        |
| River Border                  | 4.96        |
| SUTET lines                   | 1.87        |
| Railway Road Border           | 0.31        |
| UGS Recreation                | 0.03        |
| Setu / Lake border            | 0.11        |
| **Total (Km²)**               | **12.90**   |
| **Total Bekasi (%)**          | **6.91**    |

Source: Bekasi City Spatial Planning Office
From the table (Table 2), UGS Bekasi city is only 14.55 km² or 6.91% of the area of Bekasi City. The UGS consists of UGS Green Line, UGS City Park, UGS Taman Kecamatan, River Border, SUTET lines, Railway Road Border, UGS Recreation, Setu / Lake border. UGS has the largest area in River Border at 4.96 km².

3.3. Biomass

Table 3. Correlation and error biomass estimation using each vegetation index formula

| Pearson Correlation (%) | Biomass Estimation Model | NMAE (%) |
|-------------------------|--------------------------|----------|
| NDVI 75.2               | Y = 286.875 + 764.266X – 1704.342X² + 3077.836X³ | 1.46     |
| GNDVI 54.9              | Y = 215.311 + 1886.251X – 6826.312X² + 7358.224X³ | 1.81     |
| SAVI 75.2               | Y = 270.274 + 1826.675X – 7688.818X² + 20309.721X³ | 1.22     |
| OSAVI 75.3              | Y = 283.189 + 1026.358X – 647.377X² + 4215.225X³ | 1.00     |

Source: Data Processing, 2020

Figure 3. (a) Biomass (ton) and (b) Biomass (kg/grid) distribution map in Bekasi City

In the research area there are several types of trees that are found during field surveys. Among them are *Swietenia Mahagoni*, *Terminalia catappa*, *Musa x paradisiaca*, *Nauclea orientalis*, *Mangifera, Areceaceae*, and *Cinnamomum camphora*. The amount of regression analysis for biomass estimation modeling using Sentinel 2B satellite imagery can be referenced in Table 3. In the table, it shows that OSAVI has a better Pearson Correlation of 75.3% to biomass value with NMAE of 1.00%. In contrast GNDVI had the lowest correlation of 54.9% with the highest number of errors around 1.81%. In addition, SAVI also shows a considerable correlation percentage value of approximately 75.2% with an error of approximately 1.22%. Furthermore, NDVI has a fairly good correlation percentage value of about 75.2% with a total error of about 1.46%. In each vegetation index, the best model is taken in cubic regression to obtain a biomass estimation model using field sample data. Thus, the best vegetation index found in OSAVI was chosen as the best predictor because it has the highest correlation with biomass of about 75.3% with a low error value of about 1.00%. Cubic regression is used to build biomass models namely Y = 283.189 + 1026.358X – 647.377X² + 4215.225X³ where Y is biomass, and X is the pixel value of SAVI. The result of the regression coefficient shows a positive value which means that every increase in the value of OSAVI then the value of biomass will increase.
The overall test result of biomass guessing has an error value of 1.00%. The value indicates that the model built has an accuracy rate of 99%.

Figure 3a shows a map of biomass distribution in Bekasi city that is integrated using a model of biomass estimation field measurement with SAVI. The biomass value produced from the model ranges from 0.10149 tons/grid or 101.49 kg/grid to 1.913 tons/grid or 1913.99 kg/grid. In Figure 3b, the biomass value is classified into three classifications namely low biomass value of 101.49 – 705.65 kg/grid, medium of 705.66 – 1309.82 kg/grid and height of 1309.82 -1913.99 kg/grid. Low grade biomass dominates in Bekasi City. Due to Bekasi, the plant species has low biomass namely Musa x paradisiaca, Mangifera, and Arecaceae. For medium and high biomass there is in the central part of Bekasi City which is precisely in the Green Open Space of Bekasi City because many plants with high biomass are Swietenia Mahagoni, Terminalia catappa, Nauclea orientalis and Cinnamomum camphora.

4. Conclusion
It can be concluded that the best vegetation index in this study is OSAVI. OSAVI provides better service than SAVI, NDVI and GNDVI. The biomass produced in this study was 0.10149 tons/grid or 101.49 kg/grid to 1.913 tons/grid or 1913.99 kg/grid. Bekasi City dominates the low biomass value, while the biomass value is more dominant in the Bekasi City Forest section.

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