Residential Population Estimation in Small-Area using LiDAR and Aerial Photograph Data

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Abstract. Population data has an important role in various aspects, such as policy determination, urban planning, and disaster mitigation. But, the most accurate population data in Indonesia is obtained once every 10 years. In this research, population estimation is conducted by applying the Object-Based Image Analysis (OBIA) classification method to detect the residential area. The OBIA classification utilizes aerial photogrammetry data and DSM & DTM of LiDAR. Then the population estimation is generated by the calculation of mathematical demographics and linear regression. Based on the results, OBIA classification produces a high accuracy land use / land cover map, assigned from the accuracy assessment using confusion matrix with kappa coefficient of 0.929 and overall accuracy of 95.24%. While, the habitable surface area classification achieves a high accuracy map with kappa coefficient of 0.86 and overall accuracy of 92.86%. The population estimation results, reveal that the linear regression method has a smaller error than the mathematical demographic method. The MAE, MAPE, RMSE, and RRMSE in Wisma Menanggal values are 40, 21%, 45, dan 0.25, while the ones of Gayungsari Timur are 23, 18%, 34, dan 0.278. In addition to the small error value, the MAE, MAPE, RMSE, and RRMSE values indicate that the population estimation produced by the linear regression model is most optimal.

Keywords : DSM, DTM, OBIA, Population Estimation

1. Introduction
Population data is useful for a variety of purposes, such as research, urban planning, and disaster mitigation management. In disaster mitigation management, population data is useful for estimating how many people are affected and could reach the disaster safe area [1]. In Indonesia, the most reliable population data is available every 10 years with the smallest scope at village administration level [2].

Developments of spatial technology occur quickly, such as very high-resolution imagery, LiDAR, etc. Research on population estimation has been going on since 2 decades ago. [3]. Lately, research on population estimation based on spatial has begun to utilize volume approach and Object-Based Image Analysis (OBIA) classification for land use / land cover interpretation. The volumetric and OBIA approaches can be used to differentiate heterogeneous types of dwellings. Research on population estimation using very high-resolution imagery can produce an increasingly detailed population [4]. So that in this research, aerial photo data that has a very high resolution and DSM DTM derived from LiDAR used to perform residential classification with the OBIA method.

In this research, the population will be estimated in Surabaya, especially in the Menanggal Village, using LiDAR and aerial photograph data. Menanggal Urban Village is considered because it has quite diverse housing conditions such as flats and several dense areas of settlements. However, the dense area in the Menanggal Village in this study was not examined, the area that going to be researched is in the western area of Menanggal Village.
This research aims to classify using the OBIA method which is used to estimate the population. In addition, this research also finds out the results of the population estimation along with the accuracy value of the reference data used.

2. Data and Method
2.1. Study Area
The location used as a case study in this research is in Menanggal Village, Gayungan District, Surabaya City. Menanggal Village has various types of dwellings such as single-family housing and flat. However, the eastern area of Menanggal Village has an irregular area when it is used as a study location. The area taken is the western side of Menanggal Village, which is Wisma Menanggal housing with reference population estimation of 1248 people and East Gayungsari housing with reference population estimation of 366 people.

![Figure 1. Case Study Location](image)

2.2. Data and Tools
The data used in this study are aerial photograph data and DSM-DTM derived from LiDAR of Surabaya City. Aerial photograph and LiDAR was taken in Augustus 2016, it sourced from Office of Human Settlements and Spatial Planning, Surabaya City. Also, the primary data used population sample data of one block in each housing unit. For the accuracy assessment of classification, 175 ground-truth points data were used to validate the results of classification. In addition, the reference population data sourced from the office of Menanggal Village are used as validation results of population estimation.

As for the hardware used in this study, namely laptop for processing the data, smartphones for ground truth documentation, and survey forms to collect the population sample data. While the
software used is Microsoft Office software to process numbers and spatial data processing software to perform the OBIA classification and GIS.

2.3. Data Processing
2.3.1. nDSM Calculation
The height of the building can be conducted by calculating nDSM. The nDSM calculation is performed using DTM and DSM data. The nDSM data is the height of an object above ground level, so building height can be obtained. To obtain the value of nDSM, it could be calculated by the following formula [5]:

\[ n_{DSM} = DSM - DTM \]  

(1)

2.3.2. OBIA Classification
OBIA classification process consists of two stages, namely segmentation and classification. The first thing that needs to be done in OBIA classification is segmentation. Segmentation is grouping pixels of raster data input in the OBIA process based on homogeneity criteria determined by user. The result of segmentation is called image-object. In this research, the segmentation process is performed by utilizing the multiresolution segmentation algorithm. This algorithm requires the parameter values of scale, shape, and compactness obtained from trial and error process. The image-object then is classified using rule-based of OBIA which utilizing features and threshold values of each class.

There are three levels of classification that need to be done in this study, each level is performed by using the rule-based of OBIA method. The first step is classification of land use with 3 classes, namely building, ground surface and road, and vegetation. The second step is land cover classification in the building class. Building class will be divided into 3 classes, namely residential buildings, commercial buildings, and public facilities buildings. And then the last step, the residential buildings will be classified into habitable surface area. Habitable surface area is an area of residential buildings that can be inhabited. Population estimation by volumetric approach can be conducted by using method that is displayed in figure 2. Figure 2 will provide an illustration of the habitable surface area.

![Figure 2. Illustration of Habitable Surface Area [6]](image)

2.3.3. OBIA Result Accuracy Assessment
The results of the OBIA classification will be tested using matrix confusion that compares the results of OBIA classification with ground truth data. From the results, overall accuracy and kappa coefficient of matrix confusion will be calculated. If the overall accuracy and kappa coefficients are less than 85%, then it will be reclassified. However, if the overall accuracy and kappa coefficients are more than 85%, the results of the OBIA classification can be used to calculate population estimates. There are two accuracy assessments that need to done, namely land cover classification (level 1) and habitable surface area classification (level 3). It is because that two steps using a threshold value.
2.3.4. Residential Population Estimation
There are two methods used in this research to estimate the residential population. The first method will be called mathematical demographics method. In this method, it is necessary to calculate the population density first to do the estimation. The calculation formula of the mathematical demographic method will be explained in equations 2 and 3 [6].

\[
P_D = \frac{P_P}{R_A} \quad (2)
\]

\[
ERP = HS \times PD \quad (3)
\]

Where PD is population density, PPP is population, RA is residential area, ERP is population estimation, and HS is habitable surface area.

The second method is using simple regression linear model. Two variables will be used, namely the area of residential building and population in it. The equation of simple regression method will be explained in equation 4 [3].

\[
Y = \beta_0 + \beta_1 X + \epsilon \quad (4)
\]

Where \( Y \) is the population estimate, \( \beta_0 \) is the value of the intercept constant, \( \beta_1 \) is the direction coefficient value, \( X \) is the habitable surface area and \( \epsilon \) is a random error.

2.3.5. Validation of Population Estimates
After the population estimation results are obtained, a comparison is made between the value of the population estimation and the population reference. It aims to see how much error value is generated in the estimated population that has been conducted.

3. Result and Analysis
3.1. nDSM Result
From the results of nDSM processing, the average value of nDSM is 4.620 meters with a standard deviation of 3.547 meters. The value range for nDSM is between 0.001 meters to 27.136 meters. In Figure 3, it can be seen that the distribution of the highest nDSM values is at 0.001 meters to 3.63 meters with a total of more than 35,000 pixels. Another high value that dominates in the research area is around 3.655 meters to about 11.596 meters.

![Figure 3. nDSM Value at Case Study Location](image)

3.2. OBIA Classification Result
3.2.1. Segmentation
There are 4 parameters required to run the OBIA image segmentation, the value of 4 parameters obtained by using trial and error method. In this research, the multiresolution segmentation algorithm
has been used. This algorithm requires several parameters, namely scale parameter, shape parameter, compactness parameter, and weighting of each raster data that used as an input. The parameter values used are as follows:

| Parameters          | Value |
|---------------------|-------|
| Scale               | 50    |
| Shape               | 0.2   |
| Compactness         | 0.5   |
| RGB and nDSM weights| 1,1,1.5 |

The result of segmentation could create objects that separate buildings with vegetation as well as buildings with roads and ground surfaces. In addition, the resulting objects also managed to separate the vegetation from the road and the ground surface.

3.2.2. Land Cover Classification (Level 1)

The level 1 of OBIA classification process is conducted using the rule-based method. To perform the OBIA rule-based, threshold value is needed. Threshold values for each classification class are obtained by interpreting features based on hue, color, shape, and size.

Figure 4 explains the ruleset used to classification the land cover. In the process of land cover classification, road and ground surface class is performed first. Road and Ground surface classifications use interpretations of size because roads and land surfaces tend to have a low height. The height feature of the nDSM data is utilized with a value of $\leq 2.75$.

Furthermore, vegetation classification is carried out using the interpretation of color and size. The green index feature is used because vegetation has a dominant green color. The green index value used in this research is $\geq 0.76$. The next feature used is a slope with value of $\geq 22$. The slope feature is used because vegetation tends to be steeper than other classes.

Classification of buildings class is interpreted through hue, color, and size. There are several features used, the first is the RBSI (Red Blue Spectral Index) with value of $\geq 0.15$ which is used for classification of buildings with brick red roofs. Furthermore, building classification utilized brightness features with value of $\geq 156$ on the object to classify buildings that have white color. the reason for using brightness in building classifications is because there are buildings with white roofs in the research area. In addition to the white roof, there is also a building with a green roof. The feature that distinguishes a green roof from vegetation is the brightness value of vegetation which tends to be smaller, which means darker. So by using a combination of the green index value $\geq 0.8$ and brightness $\geq 126$ we could classify several green building roofs.

Value of the threshold used will be validated at the OBIA classification accuracy assessment. So that it can be determined how accurate of the used threshold.
The result of OBIA land cover classification is shown in figure 5. The area generated in the building class dominates in the research location with 92,380.43 m$^2$. On the road and land surface classes, an area of 48,013.476 m$^2$ and 62,517.146 m$^2$ is generated in the vegetation class.
3.2.3. Building Land Use Classification (Level 2)
The classification of building land use in this research uses vector data support. The use of vector data is because it is difficult to distinguish between residential buildings and other building land uses if it only based on visual appearance of aerial photographs and building height values. Vector data used is digitation generated by field surveys. From the digitation vector data, there are two classes of land cover for buildings, namely commercial buildings and public facility buildings. Thus, the final result of OBIA level two classification is three classes of land cover for buildings, namely residential buildings, commercial buildings, and public facilities buildings. Figure 5 shows the ruleset used for building land use classification. If the building class from land cover classification is located inside the polygon of vector data, then it will be classified as the same as the polygon attributes, such as commercial and public facilities.

![Figure 6. Building Land Use Classification Ruleset](image)

![Figure 7. Building Land Use OBIA Classification Result](image)
3.2.4. Habitable Surface Area Classification

According to SNI 03-1733-2004 concerning Procedures for Housing Environmental Planning in Urban Area, the minimum ceiling height of residential buildings is 2.5 m. However, the nDSM data is the top view data so that the height obtained is the height up to the roof of the building. For this reason, interpretation is made with aerial photographic data and nDSM to determine the appropriate value of the minimum residential building height, where the value obtained is 3 meters. This minimum building height will be classified as non-habitable class.

Residential buildings in the study area only have a maximum of 2 floors. Thus, the threshold value between one floor and two floors residential building is needed. The threshold value between buildings that have floors 1 and 2 is obtained from the manual digitization process of the sample building, then the mean zonal statistics is performed. The digitization process is based on the number of floors, so that if there are residential buildings with two floors that only a portion of its whole house will have 2 or more polygons inside.

From the results of zonal statistics process, the threshold value between 1 floor and 2 floors is 6.1 meters. Where a value of < 6.1 meters is a 1-story settlement and a value of ≥ 6.1 meters is a 2-stories settlement. The ruleset used for habitable surface classification as follows:

![Habitable Surface Area Classification Ruleset](image1)

![Habitable Surface Area OBIA Classification Result](image2)
3.3. OBIA Result Accuracy Assessment

The first accuracy assessment is the accuracy of land cover classification. Because the results of the classification of land cover are used for further processes which if the classification results are less precise it will have an impact on the next process.

The results of the accuracy assessment of land cover classification show that the classification is done well so that the threshold value used in land cover classification is correct. Misclassification occurs in building classes and road and land classes. In the building class, there are two test points that are classified as vegetation, while in the road and soil classes there are three test points that are also classified as vegetation. In addition, the overall accuracy and kappa coefficients produced are quite high with 95.24% and 0.929. Table 2 will explain the accuracy assessment that has been done for land cover.

The second is the accuracy assessment of the habitable area classification results. This is done because the results of this classification will be used as an estimate of the population so that it requires precise results.

There was an error in the classification of one-story settlements with three test points and twostories settlements with two test points. From the results of the calculation of the accuracy test, the overall accuracy and kappa coefficient values were 92.86% and 0.86, respectively. The value is that the results of the classification of habitable surface areas meet the minimum accuracy and threshold test requirements used quite precisely. Thus, the results of classification could be used to calculate population estimates. Table 3 shows the calculation of the habitable surface area accuracy test.

| Table 2. Land Cover Classification Accuracy Assessment |
|-------------------------------------------------------|
| Class | V | RG | B | Total | User Accuracy |
|-------|---|----|---|-------|--------------|
| V     | 35| 3  | 2 | 40    | 87.50%       |
| RG    | 0 | 32 | 0 | 32    | 100.00%      |
| B     | 0 | 0  | 33| 33    | 100.00%      |
| Total | 35| 35 | 35| 105   |              |
| Producer Accuracy | 100.00% | 91.43% | 94.29% |

| Reference | V | RG |

| Table 3. Land Cover Classification Accuracy Assessment |
|-------------------------------------------------------|
| Class | Reference | L1 | L2 | Total | User Accuracy |
|-------|-----------|----|----|-------|--------------|
| L1    | 32        | 2  | 35 | 94.12% |
| L2    | 3         | 33 | 36 | 91.67% |
| Total | 35        | 35 | 70 |        |
| Producer Accuracy | 91.43% | 94.29% |

Information:

V : Vegetation; RG : Road and Ground Surfaces; B : Building; L1 : one-story Settlement; L2 : two-stories settlements
3.4. Residential Population Estimate
Calculation of population estimation will be conducted using two methods, namely the mathematical demographic and the linear regression model. The calculation of these two methods, samples of unoccupied houses are still included, because not all houses in the study area are inhabited and it is expected to provide a good adjustment.

1. Mathematical Demographic Method:
In this method, it is necessary to calculate population density in advance using equation (2). In Gayungsari Timur housing, a population density of 0.007 person/m² with a sample area of 3541.504 m² was obtained. Whereas in the Wisma Menanggal, it is obtained population density of 0.012 person/m² with an area of 3852.365 m².

2. Linear Regression Method:
The linear regression model utilizes the area of each house in the sample area and the population of each house. In Gayungsari Timur housing, the regression equation of $Y = 0.006x + 0.109$ was obtained. While in Wisma Menanggal housing, a regression equation of $Y = 0.016x - 0.845$ is obtained.

![Figure 10. Linear Regression Gayungsari Timur Population Estimation Model](image1)

![Figure 11. Linear Regression Wisma Menanggal Population Estimation Model](image2)

The coefficient of determination in each housing is 0.0709 for Gayungsari Timur housing and 0.2234 for Wisma Menanggal housing. While the correlation coefficient values for each sample are 0.27 for East Gayungsari housing and 0.47 for Wisma Menanggal housing. Based on the table 4, the correlation value between the population variables with the area of housing in Gayungsari Timur housing has a low relation, while Wisma Menanggal housing has a moderate relation.

After the population density values in the first method and the regression equation in the second method have been obtained, then the population estimation is then calculated. Table 5 and table 6 shown the result of population estimation.

| Table 4. Coefficient Correlation Interpretation [7] |
|--------------------------------------------------|
| Interval Coefficient | Relation Level |
|----------------------|----------------|
| 0.00 - 0.199         | Very Low       |
| 0.20 - 0.399         | Low            |
| 0.40 - 0.599         | Moderate       |
| 0.60 - 0.799         | High           |
| 0.80 - 1.000         | Very High      |
To test the significance of the relationship in the regression model obtained, a partial T test will be conducted at each research location with a significance level of 5%.

The hypothesis in the T test in this research are as follows:

H₀ = There is no significant effect between the area of the house and the population.

Hₐ = There is a significant influence between the area of the house and the population.

If T table < T value, H₀ is rejected and Hₐ is accepted. Meanwhile, if T table > T value, H₀ is accepted and Hₐ is rejected.

In the Gayungsari Timur housing, a T value of 0.87364 was obtained. Meanwhile, T table obtained at 8 degrees of freedom with α of 5% is 2.22213. This shows that T table > T value, so H₀ is accepted which means there is no significant effect between the area of the house and the population in East Gayungsari housing.

At Wisma Menanggal housing, the t value is 2.14555. While the value of the T table with α of 5% and 16 degrees of freedom is 2.1199. This shows that T table < T value, so H₀ is rejected, which means there is a significant influence between the area of the house and the population in Wisma Menanggal housing.

Table 5. Gayungsari Timur Population Estimate

| Neighbourhood | Reference Data | Total Area (m²) | Mathematical Demographic Estimate | Linear Regression Estimate |
|---------------|----------------|----------------|----------------------------------|---------------------------|
| 1             | 124            | 17648.98       | 125                              | 118                       |
| 2             | 106            | 16816.351      | 119                              | 113                       |
| 3             | 136            | 28946.611      | 204                              | 194                       |
| Total         | 366            |                | 448                              | 425                       |

Table 6. Wisma Menanggal Population Estimate

| Neighbourhood | Reference Data | Total Area (m²) | Mathematical Demographic Estimate | Linear Regression Estimate |
|---------------|----------------|----------------|----------------------------------|---------------------------|
| 1             | 172            | 7724.814       | 100                              | 130                       |
| 2             | 255            | 11802.982      | 153                              | 199                       |
| 3             | 132            | 7372.067       | 96                               | 124                       |
| 4             | 160            | 7035.66        | 91                               | 118                       |
| 5             | 116            | 7747.488       | 101                              | 130                       |
| 6             | 201            | 9048.872       | 117                              | 152                       |
| 7             | 212            | 8598.839       | 112                              | 144                       |
| Total         | 1248           |                | 770                              | 997                       |

In table 5 total population estimation at Gayungsari Timur Housing is 448 persons on mathematical demographic method and 425 persons on linear regression method. Meanwhile in table 6, population estimation at Wisma Menanggal Housing with total 770 persons on mathematical demographic method and 997 persons on linear regression method.
3.5. Validation of Population Estimates
The estimation results were analyzed by reference data. The results of the analysis are expected to
determine which model is better.

From table 7 and table 8, population estimation using linear regression method has more optimal
results. This can be seen from the smaller difference value. Besides MAE, MAPE, RMSE, and
RRMSE also have smaller values, where the smaller the value, the better the results could be.

In Gayungsari Timur housing, the estimated value exceeds the reference data with a difference of
59 to 82 people. It is seen in the table 5, the over-estimation value occurs in neighbourhood of 03.
Whereas in Wisma Menanggal housing, there is under-estimation with a large enough difference,
namely 251 to 478 people. In table 6, the largest under-estimated value is caused by neighbourhood
of 02 and 07.

The occurrence of under-estimation and over-estimation can be caused by various factors. The
first is the number of samples taken only one block in each housing. Second, there is only one variable
that is used to estimate the population. Variable area of settlement at the study site has a low and
medium level of relationship. Also based on the T test, there is no significance arising from the
variable area of settlement in Gayungsari Timur housing. And third, the reference data used is sourced
from the population registration data which is the Family Card (KK) data. The use of reference data
is because the population census data for 2019 or 2020 are not yet available.

| Table 7. Gayungsari Timur Population Estimate Comparative with Reference Data |
|-----------------------------------------------|
| **Comparative analysis of Gayungsari Timur’s estimated results** |
| Calculation | Mathematical Demographic | Linear Regression |
| Total Estimation | 448 | 425 |
| Difference | 82 | 59 |
| Error | 22% | 16% |
| MAE | 27 | 23 |
| MAPE | 21% | 18% |
| RMSE | 40 | 34 |
| RRMSE | 0.328 | 0.278 |

| Table 8. Wisma Menanggal Population Estimate Comparative with Reference Data |
|-----------------------------------------------|
| **Comparative analysis of Gayungsari Timur’s estimated results** |
| Calculation | Mathematical Demographic | Linear Regression |
| Total Estimation | 770 | 997 |
| Difference | -478 | -251 |
| Error | 38% | 20% |
| MAE | 68 | 40 |
| MAPE | 36% | 21% |
| RMSE | 74 | 45 |
| RRMSE | 0.418 | 0.250 |
To find out whether the population estimation results in this study can be used for further research, a chi square test ($\chi^2$) is performed with 5% of significance level. Chi square test was performed to determine whether the standard deviations obtained were met or not. The hypotheses in this test are as follows:

Ho: There is no significant difference between population estimates and population references.

Ha: There is a significant difference between population estimates and population references.

If $\chi^2$ value > $\chi^2$ table, then Ho is rejected and Ha is accepted. Meanwhile, if $\chi^2$ value < $\chi^2$ table, the opposite applies.

Chi square test for each housing with both methods is rejected, which mean there is a significant difference between the estimated population and the population reference. Thus, Data taken on population samples provide a lack of optimal estimating result when compared with population reference data. So that the sampling data of population one block in a housing is not recommended for further research.

4. Conclusion
In the OBIA classification, segmentation is carried out using multi-resolution segmentation algorithm with a scale parameter value of 50, shape parameter of 0.2, compactness parameter of 0.5, and layers weight of the RGB-nDSM layer of 1,1,1,5. OBIA classification is carried out using a rule-based method by utilizing the features of pixel value, height, green index, slope, RBSI, brightness, and the relationship between classes. The results of the OBIA classification obtained a kappa coefficient of 0.929 and overall accuracy of 95.24% for land cover classification. While the habitable surface area classification has an overall accuracy and kappa coefficient of 92.86% and 0.86, respectively.

The results of population estimation in Gayungsari Timur housing with the mathematical demographic method obtained 448 people and the linear regression method obtained 425 people. Meanwhile, in Wisma Menanggal housing, the mathematical demographic method results obtained 770 people and the linear regression method obtained 997 people.

The accuracy of population estimation with the linear regression method is most optimal in this research area. It is characterized by smaller MAPE, MAE, RSME, and RRMSE values. The MAPE, MAE, RMSE, and RRMSE values in Gayungsari Timur housing with the linear regression method were 23, 18%, 34 people, and 0.278 respectively. Meanwhile, the MAPE, MAE, RMSE, and RRMSE values in the Wisma Menanggal housing complex were 40, 21%, 45 people, and 0.250. However, the linear regression model in Gayungsari Timur housing is quite inferior, it can be seen at the poor significance of T-test and low coefficient of determination. In addition, the use of a one-block population sample in the study area is not recommended for further research.

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