Mapping of mangrove coverage and canopy height using LiDAR data at Sangkulirang District, East Kutai, East Borneo

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Abstract. Light Detection and Ranging (LiDAR) is remote sensing technology using transmitted properties of scattered light to detect the intended target. This technology potentially used for spatial planning and management, including mangrove monitoring. The purpose of this research was to map the mangrove coverage and canopy height using airborne LiDAR data at mangrove areas of Sangkulirang district, East Kutai, East Borneo. The corrected point cloud LiDAR data inputed into 10 blocks boundary. This data is classified into 7 classes (ground, mangroves, non mangroves, water, vehicle, low point and isolated point). Ground class used as the data source for digital terrain model (DTM) while mangrove class used as the data source for digital surface model (DSM). The substraction from overlaying DTM - DSM will produce canopy height model (CHM) that represent the height of mangroves canopy from land. The result of this research showed that mangrove distribution had an area of 64.07 km^2. The height of mangrove canopy was dominated by 10-30 meters height while the maximum height reached 54.04 meters.

1. Introduction

Mangrove forest is one component of vital enviromental ecosystem in coastal area. Indonesia had the largest mangrove area (3,112,989 Ha or 22.6% from global mangrove distribution), even larger than mangrove area in Australia (7.1%) and Brazil (7.0%) [1]. Mangrove forest known as an unique and complex ecosystem, high ecological and economical value. Mangrove has ecological function as spawning grounds, nursery grounds, feeding grounds for marine biota and coastal protection from abration [2]. Losing this ecosystem as protector from abration can lead to unstable activity of abration and sedimentation in coastal area [3]. This condition led to the need of mangrove mapping and spatial planning to reach the suitable management of environment in coastal area.

The rapid development of remote sensing technology nowadays is so helpfull for the researcher to monitor mangrove forest. One of remote sensing technology that developed and proved to give high precision and high resolution data is Light Detection and Ranging (LiDAR) technology. LiDAR is an active remote sensing technology that emits intense-focused beams of light and measures the time it takes for the reflection to be detected by the sensor, using transmitted scattered light to measure range (height) and information from an object on the earth. The three-dimensional coordinates (x,y,z or latitude, longitude, and elevation) from an object on the earth computed using interval time information of transmitted pulse to reflected pulse [4].

LiDAR system consist of 3 components, namely global positioning system (GPS), Inertial Navigation System (INS) and laser scanner. These components work independently and integrated to produce LiDAR data. GPS component is used to define three-dimensional orientation of the acquisition vehicle. The positioning of the vehicle refers to the geodetic GPS mark on land used as a control point.

GPS and INS accuracy will determine the accuracy of the coordinate and elevation position that result in the accuracy of the targeted object [5].

LiDAR technology has the same principle with Radio Detecting and Ranging (RADAR) which uses active remote sensing sensor. The differences between these two technologies is the use of electromagnetic energy source. LiDAR uses infrared (IR) wave tansmission while RADAR uses microwave transmission. These two technologies are very often used to produce Digital Elevation Model (DEM). Mahmudi had analyzed the different accuracy of DEM using several data source, namely the Advanced Spaceborne Thermal and Reflection Radiometer (ASTER), Shuttle Radar Topography Mission (SRTM) and LiDAR. The result showed that LiDAR data had the highest DEM density accuracy ($\pm$ 0.3674 m) than SRTM ($\pm$ 8.0916 m) and ASTER ($\pm$ 9.8854 m) [6]. Vertical height accuracy was also performed on the control point. Lidar data had the smallest altitude difference with $\pm$ 0.078 m standard deviation than ASTER ($\pm$ 0.297 m) and SRTM ($\pm$ 0.422 m) [6].

LiDAR technology has great potential for spatial planning and management, including monitoring of mangrove ecosystem. The advantage of this technology is can be operated during day or night, operational cost is more effective than conventional survey method, can get elevation value with high accuracy and the ability to retrive large amount of data in short time. The height detection from LiDAR data can give accuracy up to 14 cm [7]. This technology is also capable of displaying three-dimensional (3D) vegetation data, measuring vegetation canopy height, canopy cover distribution, canopy volume, subcanopy topography, biomass, large tree density, trees diversity, foliage area index, and physiographic change [8].

Research on mangrove using LiDAR data is still rare in Indonesia, but has been widely practiced in other countries [9, 10, 11]. Development of study on mangrove ecosystem areas in Indonesia is still needed for suitable planning and management. Therefore, this study intends to map the mangrove canopy cover and canopy height in Sangkulirang District, East Kutai, East Borneo using the potential of airborne LiDAR data.

2. Methods

2.1. Time and resesarch location
LiDAR data processing was done on September 2016 to January 2017 at Earth and Toponymous Mapping Centre, Geospatial Information Agency and Laboratory of Mapping and Spatial Modeling, Faculty of Fisheries and Marine Science – Bogor Agricultural University. Area of interest in this study located in the mangrove area, sorrounding Tanjung Manis Village, Sangkulirang District.

2.2. Materials and tools
The tool used in this study is a set of computers equipped with software of spatial data processing, such as Microstation v8 + Terrasolid, ArcGIS 10.2.2 and GlobalMapper v15. The materials used in this study are *Airborne Laser Terrain Mapper* (ALTM) LiDAR data using infrared wavelength (IR) (λ=1,064 nm) that aquired on August 2016. Aerial imagery that acquired in the same time as the LiDAR data acquisition and land-use map from Ministry of Forestry and Environment (KLHK) are required in this study.

2.3. Data procesing procedure
2.3.1. Acquitition and pre-processing LiDAR data. The acquitition and pre-processing LiDAR data step were carry out by the company that colaborated with Geospatial Information Agency (BIG). At the acquitition step, LiDAR data is recorded using Optech Orion M200 ALTM instrument supported with Optech CS-10000 (80 MP) camera system on July to August 2016. All of these instrument integrated with airborne double engine fixed wing, *Cessna-402B*.

LiDAR acquisition conducted at an altitude of 700 m-800 m above sea level with a speed of 59.2 knots (30,192 m/s). The ffrequency of pulse rate used is 150.000 Hz with 40° viewing angle and 500 m-600 m sweep area. The use of ALTM Optech Orion M200 has the ability to detect up to 4 reflections with a density of 4 points per square meter with a vertical accuracy of 15 cm. The acquisition step

produce aerial imagery raw data, GPS / INS raw data, exterior orientation parameter data (EO) GPS and INS, LiDAR raw data and flight path data (trajectory) controlled according to BIG LiDAR acquisition procedure.

At the pre-processing step, raw data of GPS, INS and *laser scanner* are required to obtain dataset with good quality control. This step consist of sevral processes, including trajectory processing and LiDAR data matching. Trajectory processing used to correcting the LiDAR point cloud features along to the flight paths. Point clouds that overlayed between flight paths will be set aside (cut overlap). In addition, the outliers feature is also set aside. After this step was completed, the LiDAR data was ready for further processing step. Commonly, output from this step was *.las extention format.

2.3.2. Block boundaries. The block boundaries are conducted to minimize the scope of area to be studied. In addition, because of the LiDAR data big size, these block boundaries will make an ease data processing. Block boundaries in this study were made based on the delineation area of mangrove vegetation. The blocks size refers to BIG procedure. In Borneo index map, these block boundaries located on map with index number of 1916-63. Block boundaries creation adjust with large scale map format (1:10,000). The use of large scale map was in line with the increasing need for geospatial information in large scale map to support spatial planning and disaster management [12].

This process was done by making blocks in the study area that covered mangrove vegetation. Mangrove vegetation in the study area can be determined by visual interpretation of aerial imagery and KLHK land use map of the latest version, which is the 2012 version. This land use map is used to see the general description of mangrove location at the study area then followed by delineation of mangrove vegetation using aerial imagery reference.

After delineation of the mangrove area and the creation of boundary blocks, corrected LiDAR data is filled into each block that had been created. Furthermore, data processing will be done on each block to ease the processing data and improve the accuracy of data processing. In this study, 10 blocks were made in the study area using TerraSolid software (Tscan module). The number of blocks created depends on the ability of the computer to process the large-size of LiDAR data.

2.3.3. LiDAR data classification. LiDAR data classification was done using TerraSolid software (Tscan /Tphoto/Tmodel module). Classification using this software can be done automatically and manually method. In Tscan and Tmodel modules, the point features are classified using Macros (automatic) and Model Tool Box (manual). Additional data such as aerial imagery or high resolution satellite images are required in the LiDAR data classification process. The data is used as a reference to classify LiDAR point cloud in accordance with the appearance of the earth's surface. In this study, LiDAR point clouds are overlayed with aerial imagery (using Tphoto modules) so that they classified in line with visual interpretations of the earth appearance. Data flow diagram presented in figure 1.
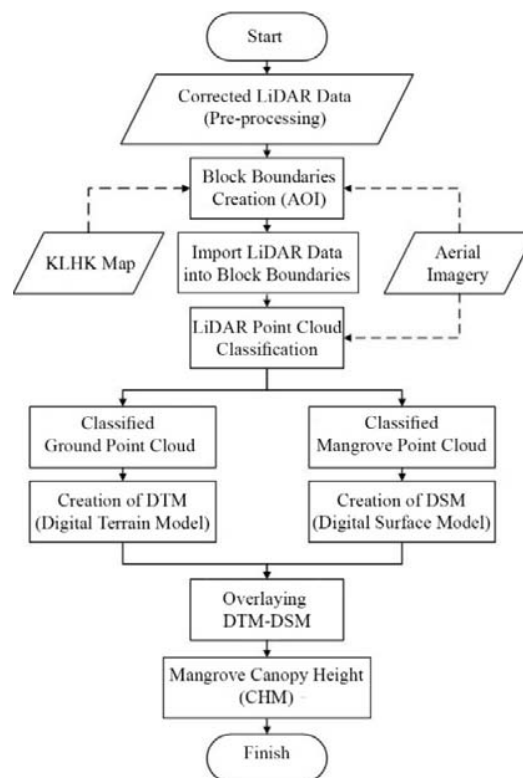
Figure 1. Flow chart of data processing.

LiDAR data classification was done to categorize the point cloud features in LiDAR data into a particular class. In this study, the points feature is categorized into 7 classes, consist of 2 main classes (ground class and mangrove class) and 5 supporting classes (non-mangrove class, waters, low point, isolated point, and vehicle). The classes are made according to the needs and appearance of the objects in the study site.

Generally, LiDAR point cloud classification was made into two classes (ground class and non ground class). In this study, the categorization of 7 classes consisting of main classes and support classes needs to be done because the classification of point cloud directly into the ground class and non ground class (mangrove class) still contain the noise features of the point cloud [13]. Therefore, additional classes for noise filtration are required in order to obtain good classification results in the main class. LiDAR data in ground class was required as a data source to produce digital terrain model (DTM) models that represent bare earth. LiDAR data of the mangrove class is needed as a data source to produce a mangrove surface model or digital surface model (DSM) that represents the surface shape of mangrove vegetation.

2.3.4. Digital Terrain Model (DTM). DTM is a model representation of bare-earth that obtained from ground class LiDAR data point cloud. Ground class LiDAR data that used to obtain DTM had to pass editing step to clear up point cloud that intersected with water area and corrected proportionally. The editing process of ground class was conducted by setting a minimum height of ground (0 meter) and filtering point cloud that intersected with water and vegetation. In addition, noise data such as low point (point cloud under minimum height of ground class) have to classify into other class in order to give good data source for DTM processing. This step was conducted in TerraSolid software (Tscan and Tmodel module) and the output in *.las extension format.

The result from TerraSolid was continued in GlobalMapper software. This sofware will determine data projection of LiDAR data that had been proceed (zone UTM 50 North). LiDAR data from ground class classification was needed as an input in order to conduct DTM. Elevation model from input data

was made by binning (minimum value - DTM) method. By this method, gridding of point cloud data will use minimum value (lowest height) to produce DTM.

2.3.5. Digital Surface Model (DSM). DSM is a model representation of object surface above the earth (mangrove canopy) that obtained from mangrove class LiDAR data point cloud. Vertical value from this model was computed from mean sea level. Mangrove class LiDAR data that used to obtain DSM had to pass editing step. The editing process of mangrove class was conducted by filtering point cloud that intersected with water and ground. In addition, noise data such as isolated point (point cloud that have extremely height of mangrove class) have to classify into other class in order to give good data source for DTM processing. This step was conducted in TerraSolid software (Tscan and Tmodel module) and the output in *.las extension format.

The result from TerraSolid was continued in GlobalMapper software. This sofware will determine data projection of LiDAR data that had been proceed (zone UTM 50 North). LiDAR data from ground class classification was needed as an input in order to conduct DSM. Elevation model from input data was made by binning (maximum value - DSM) method. By this method, gridding of point cloud data will use maximum value (highest height) to produce Digital Surface Model (DSM). The differences between DTM and DSM was illustrated in figure 2.
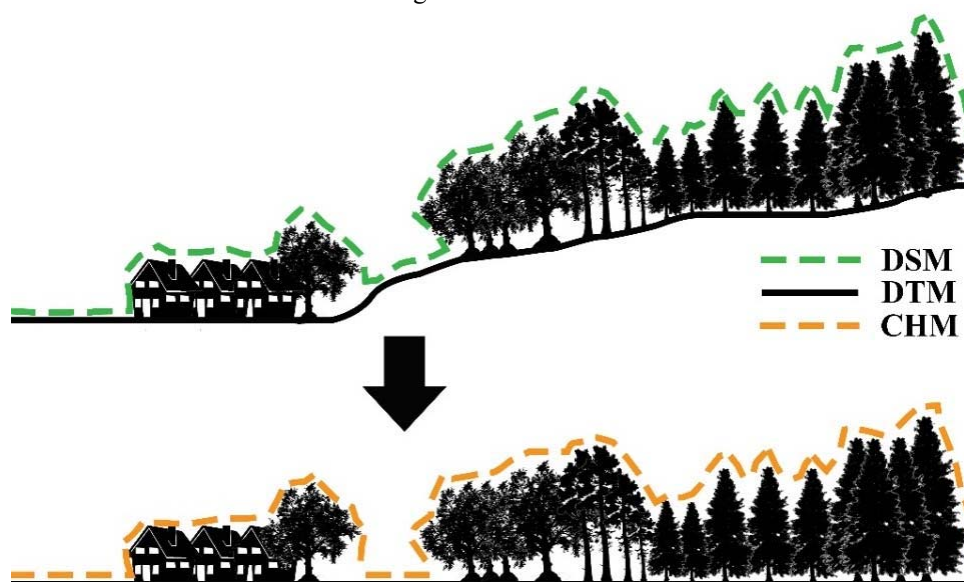

Figure 2. Canopy Height Model/ CHM (orange) conducted by substracting DTM (black) and DSM (green).

2.3.6. Canopy Height Model (CHM). Digital Surface Model (DSM) still not represent the real height of mangrove because the mangrove height was conducted from mean sea level (geoid). So, it is necessary to obtain Canopy Height Model (CHM) that represent the real mangrove canopy conducted from the ground (figure 2). CHM was proceed and produced in GlobalMapper software. DTM and DSM grid data that had been obtained are the source to proceed this model. Substraction analysis of DTM and DSM was done to observe the vertical differences from the ground to mangrove canopy.

3. Results and discussion

3.1. Block boundary
The blocks boundary that created adjusted to the ability of the computer processing large-size LiDAR data. The total area covering the block is 213.90 Km^2. Figure 3 shows the result of block boundaries.
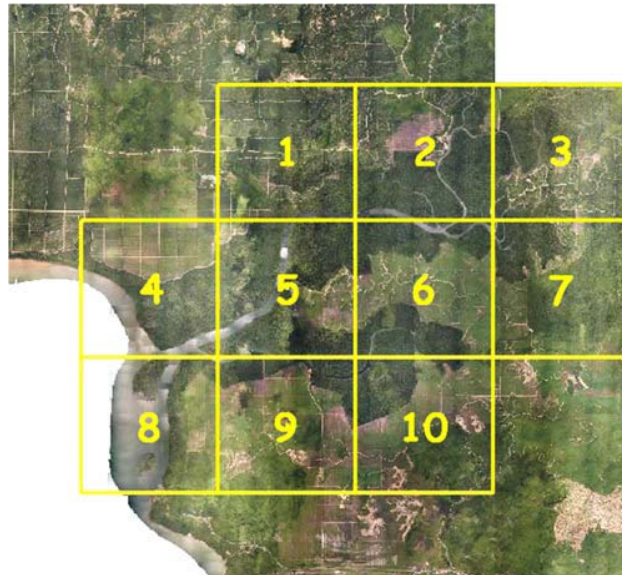
Figure 3. Block boundary in study area.

The total amount of cloud points that filled the entire block boundary was 535,044,728 point clouds. The block that has the fewest number of point cloud was block number 8 with the amount of 30,815,485 points (figure 4). Block number 8 had the fewest point cloud distribution because it contain large water body area inside the block. LiDAR acquisition using ALTM is sensitive to water area. ALTM using scattered light with $\lambda=1,064$ nm (Near Infrared/ NIR). This wavelength had high reflectance to vegetation and ground but this wavelength had low reflectance to water area. Because of this condition, LiDAR acquition using this instrument will not well-detected area of water [4].

3.2. Point cloud LiDAR classification
In this study, point cloud LiDAR classified into 7 classes that consist of 2 main class (ground class and mangrove class) and 5 supporting class (non-mangrove class, water, low point, isolated point, and vehicle). Point cloud distribution in each block boundary shown in figure 4.

Supporting class was made for unnecessary point cloud (noise) so it was not included as the main class that could distract the process of DTM and DSM. Direct classification of point cloud into ground points still produce noise point cloud while classification into several class could minimize noise point cloud in ground class (main class) [13]. It is necessary to produce good quality of DTM and DSM in order to give better result.
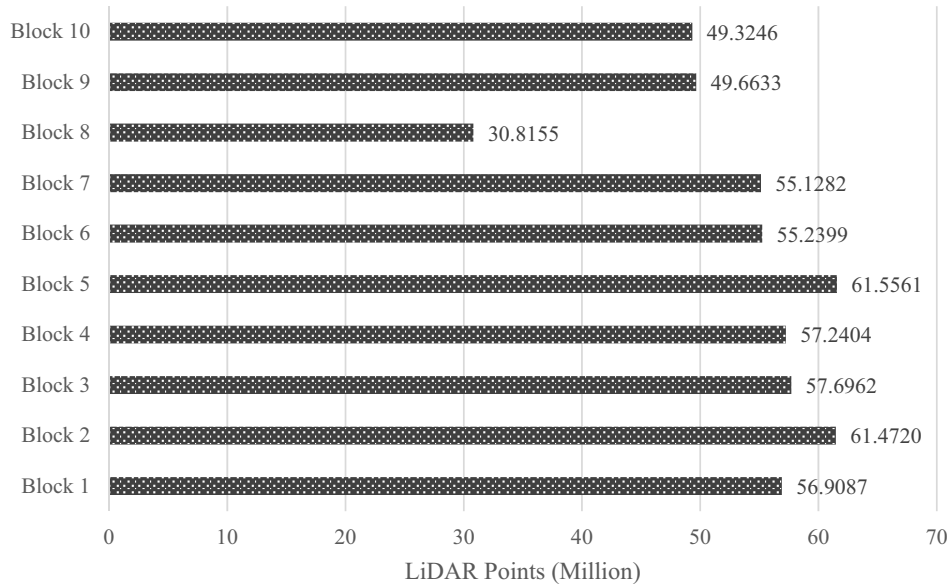
Figure 4. Point cloud distribution in each block boundary.

Generally, non-mangrove class had the most amount of point cloud distribution. It is because non-mangrove class in this study define as all point feature in vegetation area that not belong to mangrove vegetation. In this study, non-mangrove had an area about 70% of all block boundary and that condition made this class had the most amount of point cloud (figure 5).
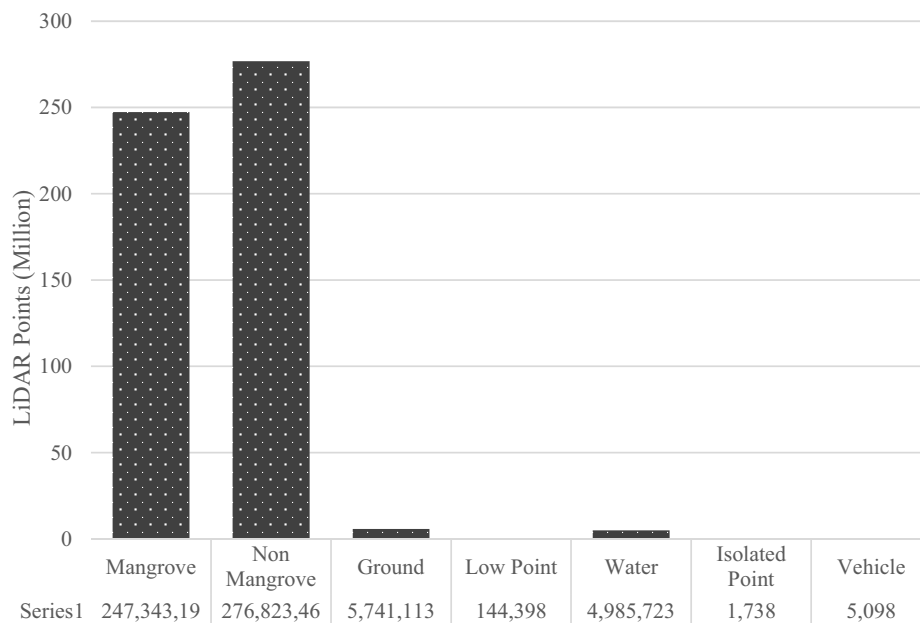

	Mangrove	Non Mangrove	Ground	Low Point	Water	Isolated Point	Vehicle
Series1	247,343,19	276,823,46	5,741,113	144,398	4,985,723	1,738	5,098

Figure 5. Point cloud distribution in each class.

Based on the main class clasification, point cloud distribution in mangrove class had more point cloud than ground class. Generally, there are two kind of reflectantion of LiDAR data, last reflectance and others reflectance (first reflectance). The last reflectance is the reflectance from ground while the the first reflectance is the reflectance of vegetation canopy [14]. ALTM LiDAR has an advantage to detect up to 4th reflectance in single transmisson of scattered light. So, point cloud from first to third reflectance are reflectance from object above the ground, including mangrove vegetation. This situation caused mangrove class had more point cloud distribution than ground class.

3.3. Digital Terrestrial Model (DTM)

DTM consist of point cloud that classified in order to represent bare earth of the ground [15]. In the result of grid interpolation from ground class, elevation of ground had a height of 0 meter to 39.76 meter, dominated by blue colour that indicated domination of 0 meter to 2 meter height. This condition show that the ground topography in studied area is located at coastal area that adjoin with water area. It is in line with visualisation of earth from aerial imagery that show the river body, estuary, and open water area. The result of DTM that proceed with GlobalMapper shown in figure 6.
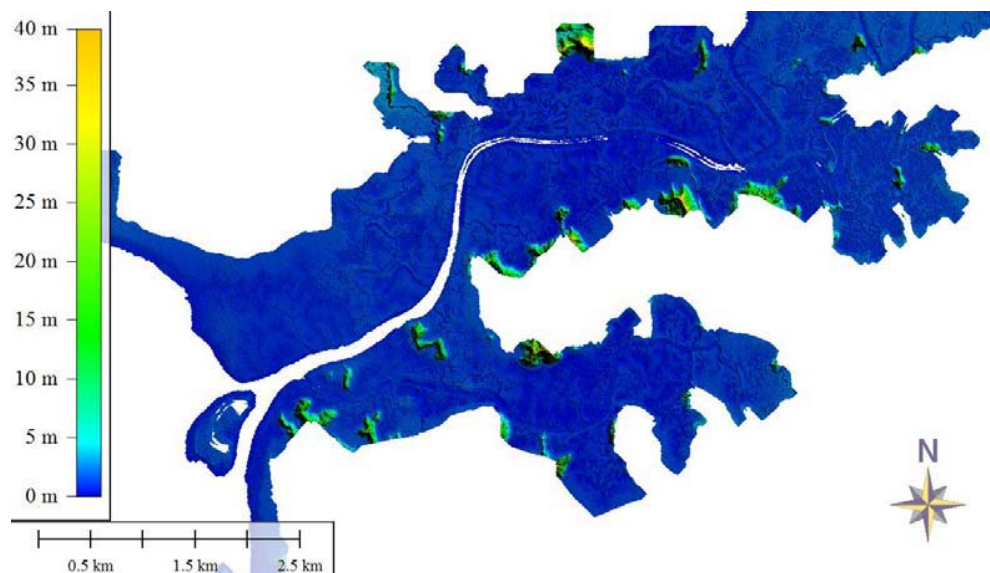

Figure 6. Digital terrain model (DTM) in study area.

3.4. Digital Surface Model (DSM)

DSM can be generally defined than DTM, DSM is a model production that represent surface (ground surface, building surface, or canopy surface) [4]. In the result of grid interpolation from mangrove class, the elevation of mangrove canopy had a height up to 68.09 meter. Mangrove canopy dominated by green colour that indicated height of 10-30 meter. The result of DSM that proceed with GlobalMapper shown in figure 7.

DSM using LiDAR data is very relevant for telecommunication management, vegetation management, air traffic safety, and 3D model simulation [16]. Elevation of surface can be used to produce canopy height model (CHM). DSM value can not directly used to represent the height of canopy from the earth because the height of LiDAR data corrected by geoid layer (SRGI 2013 datum) that assumed as the mean sea level. So, DSM valu*e* had to corrected by DTM value to produce the height value that count from the ground.
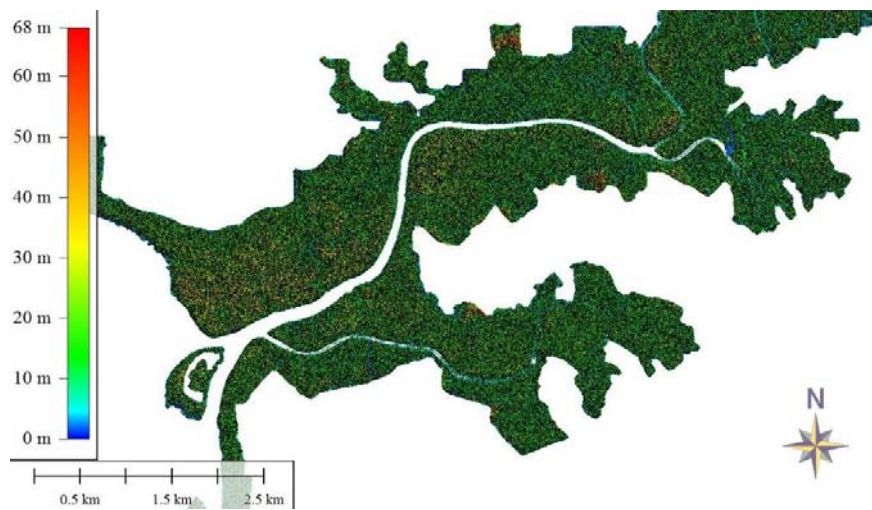
Figure 7. Digital surface model (DSM) in study area.

3.5. Canopy Height Model (CHM)
Generally, CHM is a representation of vegetation canopy [17]. CHM produced by point cloud DSM and point cloud DTM [9]. CHM can be applied to map the important caracteristic of vegetation such as biomass for understanding carbon contentin vegetation [18].

The result of CHM that proceed with GlobalMapper shown in figure 8. CHM show the vegetation height that dominated by green colour. That colour indicated a heoght of 10 – 30 meter. The maximum height of mangrove canopy reach a height of 54.04 meter. From this model, we can get the mangrove coverage in study area had an area of 64.07 km^2.
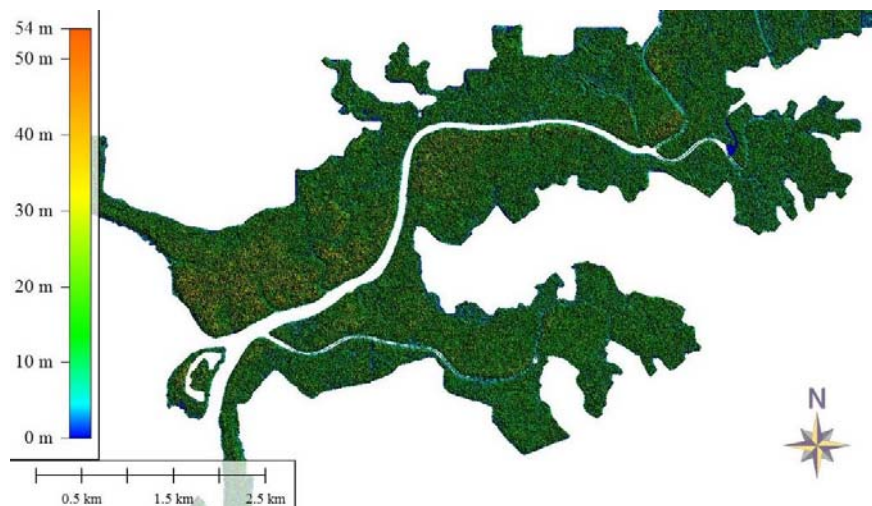

Figure 8. Canopy Height Model (CHM) in study area.

Indonesia has the largest mangrove area distribution (22.6%) and has many unexplored area that not affected by human activity (such as Papua amd Borneo). These condition had a potential for mangrove vegetation to growth naturally and optimally. Similiar study of mangrove height at the area of Mimika, Papua using SRTM elevation data. Mangrove canopy height in that area reach up to 40 meter height [19]. Borneo island known as the island that have a lot of river and estuary at coastal area. A lot of estuary that protected from strong oceanography dinamics, especially at Sangkulirang Bay, provide well natural condition for mangrove vegetation to grow optimally. It is proved by 54.04 meter height of mangrove canopy gained in this study area.

The main natural parameters that affected mangrove growth are fresh and salinity water supply, nutrient, and substrate stability [20]. Mangrove vegetation in study area lived around Sangkulirang Bay, at Kerayan River estuary. This estuary is protected the mangrove habitat because the Northern area has peninsula at Berau District and Southern area has peninsula at Kaliorang Sub-district. These peninsulas will slow down current water flow from Makassar Strait into the estuary. Moreover, the estuary also protected by Hantu Island. Geographic position of this island caused low penetration of current waterflow into mangrove habitat so that the fresh water and salinity supply stability are controlled. Geographic condition and mangrove existing will get the stability of subtrat condition. Unique mangrove root system will slowing down the fresh water supply and banding particle of sediment so that particle with high orgic level will precipitate rapidly and form sediment layers [20]. These condition show that Sangkulirang District has good suitability environment parameters for optimally mangrove growth.

4. Conclusions

Point cloud LiDAR can be used to produce canopy height model that can be applied to analyse other important caracteristic of vegetation. The area that covered all of studied area was 213.90 km^2. In this study area, mangrove coverage at Sangkulirang District, East Kutai, East Borneo has an area of 64.07 km^2 mangrove distribution. Mangrove vegetation dominated by the height of 10 – 30 meter. The maximum height of mangrove in this area reached 54.04 meter. LiDAR data is potentially used as the data source of mangrove canopy mapping.

Acknowledgments

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