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Land Use/Land Cover and Forest Canopy Density Monitoring of Wafi-Golpu Project Area, Papua New Guinea

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Abstract

This study aims to examine the use of Remote Sensing and Geographical Information System (GIS) technology in land use/land cover mapping to aide sustainable planning and development in the Wafi-Golpu project area. At the same time, this study examines an existing method of Forest Canopy Density (FCD) model to estimate forest canopy density of the proposed deforestation site, which is known as the Advanced Exploration Feasibility Study Activities (AEFSA) area within the Wafi-Golpu Project site. The FCD model calculates the forest canopy density using the three (3) indices of vegetation, soil and shadow from the Landsat-8 Operational Land Imager (OLI) satellite image of year 2013. In this study an attempt has been made to monitor the forest loss or degradation during deforestation in a natural forest stand of the Wafi-Golpu project area using forest FCD mapping and monitoring model and the findings of the study will assist the project planners and developers with their work on forest rehabilitation and reforestation for the purposes of sustainable forest management. The result of the work shows that a considerable amount of forest loss will be undertaken during the AEFSA deforestation exercise and also the findings show that a reliable land use/land cover map will greatly assist sustainable development in a resource project development period.

Keywords

Remote Sensing, GIS, FCD Model, Land Use/Land Cover, Forest Land Management

1. Introduction

The modern day activities and trend for economic and social development includes activities such as urbaniza-

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tion, mining, industrialization, farming, etc. Vast amount of land and forest areas are being used for the purposes of development, resulting in an ever increasing decline of especially forest areas through the process of deforestation. Forest areas, forest density and greenness of an area are major issues for ecosystem, biodiversity, etc. [1]. In forest management and decision making, there is a continuous need for high quality information on forest and the state of forest resources can be monitored by a form of map. Forest maps are effective tool for identifying the state of forest resources and monitoring ongoing spatial process in forested landscapes. One of the most important forest properties is the canopy cover and it provides habitats for many animal species [2] and is essential to environmental and economic health, providing additional cooling, increasing property values, improving air/ water quality, and contributing to a more beautiful, friendlier and livable community [3]. Monitoring of forest canopy cover is an essential tool for sustainable management of natural resources. Forest canopy density mapping is one of the most useful parameter to consider in the planning and implementation of afforestation and reforestation programs [4]. Assessment of forest density and its evaluation is one of the important aspects of management and long term monitoring of protected area for meaningful biodiversity conservation. It is also helpful in planning and implementation of forest rehabilitation programs [5].

Forest canopy can be used to understand and measure the forest condition efficiently from satellite images [6]. Satellite remote sensing has proven to be the most cost effective means of mapping and monitoring environmental changes in terms of forests, vegetation and other ecological issues [7]. It provides a more efficient and fast option for estimating the density of forests, then the conventional way of ground monitoring which can be tedious and time-consuming [8]. One of the methods to assess the forest health and status through remote sensing application is through the use of the Forest Canopy Density (FCD) model. This model has been used widely to assess forest conditions and status through the mapping of forest canopy density. Forest Canopy Density model is based on the growth phenomenon of forests and it can indicate the degree of degradation. Dense canopies represent healthy forest while sparse or no canopies indicate the reverse [8] [9]. FCD model is one of the useful methods to detect and estimate the canopy density over large area in a time and cost effective manner [10].

The knowledge of land use and land cover [11] is important for many planning and management activities as it is considered as an essential element for modeling and understanding the earth feature system. Land use is defined as any human activity or economical related function associated with a specific piece of land, while the term land cover relates to the type of feature present on the surface of the earth [12]. Remote sensing has the capability to acquire data timely at regular interval and becomes useful data source for land use monitoring [13] [14]. In addition, GIS that has the capabilities to manipulate and analyze spatial and temporal data can be used to map, monitor and identify driving forces and measure the intensity of land use/land cover transformation [14] [15]. Both will provide the understanding on the dynamic process of not just urban but rural land use/land cover transformation and plan towards an effective sustainable development.

Without accurate synoptic overview [12] of the whole area of study, poor planning for sustainable development is inevitable. When a project developer is guided by a social responsibility and social licensing to deliver long term sustainable development projects into its local and impacted communities, it requires sufficient information to understand the dynamics of its environment to make well informed decisions when it comes to planning for long term sustainable developments. Confidently understanding the land use and land cover dynamics of the Wafi-Golpu (WG) project area is currently a major gap in planning for sustainable development within the project footprint and this study aims to close in this gap by producing as much as possible an accurate land use/land cover map of the Wafi-Golpu (WG) project area that could empower project developers and planners in making well informed decisions and better planning for long term sustainable development and in turn maintaining its social responsibility. With the rising global concern of greenhouse effect and global warming, societies are urged to be more proactive in our attempts to manage our natural and especially forest resources in a more sustainable way. The Wafi-Golpu (WG) project, again guided by a social responsibility and social licensing to carry out its operations in a more sustainable manner, has an obligation to ensure a sustainable management of its natural resources including forests. As plans for mine infrastructure developments are underway, activities such as deforestation are inevitable. This therefore requires proper planning for forest rehabilitation and reforestation for sustainable forest management. However, without proper quantification or estimate of possible forest loss, there will be a lack in reasonable judgment and planning for rehabilitation, reforestation or re-vegetation.

Remote Sensing research focusing on image classification in land use/land cover mapping has attracted the attention of many researchers [16] and a number of studies have been conducted using different classification algorithms. It should be noted that valuable surface information extraction and analysis is also well performed using image classification. Image classification is the process of assigning pixels of continuous raster image to predefined land cover classes (Samanta *et al*., 2012). The invent of Remote Sensing and GIS techniques in land use/land cover mapping has given a useful and detailed way to improve the selection of areas designed to agricultural, urban or industrial areas of a region [17].

One of the purposes of this study is to assess the forest canopy density of the Wafi-Goplu project area during pre-deforestation and mining using the FCD model. The estimate loss of forest cover from mine planning activities and mine infrastructure development can be used by concerned authorities to plan for reforestation and rehabilitation programs for sustainable forest management. Apart from forest canopy density mapping, another purpose of this study is to undertake a Land Use/Land Cover (LULC) mapping of the project area to get a general overview of the project area to assist project developers and their stakeholders in making informed planning and management decisions in sustainable development within the project footprint communities. Understanding the general land use/land cover phenomenon of the Wafi-Golpu project area is of great importance to the project developers and decision makers in terms of planning for sustainable development especially in a rural context and especially where a project developer is guided by existing national legislations to deliver sustainable developments to its impacted communities.

2. Study Location and Its Description

The Wafi-Golpu project is located in the Morobe Province of Papua New Guinea. It is approximately 65 kilometers south-west of the port city of Lae, PNG's industrial hub and second largest city. The project site is accessed by sealed road from Lae to Demakwa and then via a 38 km dirt base track to the project site. The site is situated in moderately mountainous terrain, 4 km from the broad Watut and Markham valley plains (**Figure 1**) of the Markham River which reaches the ocean near Lae. The area is dominated by primary forests, rugged mountains with steep slopes [18].

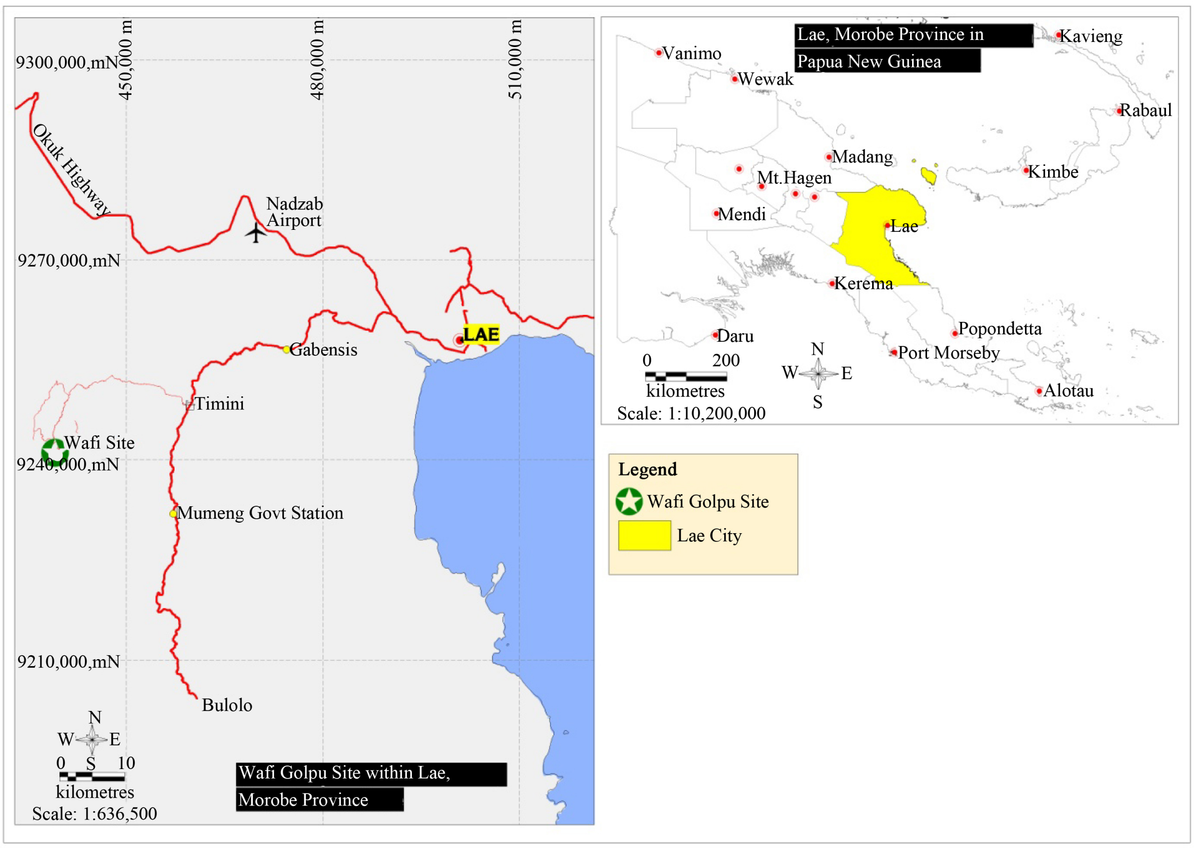

Figure 1. Locality map of the Wafi Golpu project site in the Morobe of Papua New Guinea.

The Golpu Project which is part of the broader Wafi-Golpu Project is owned by the Wafi-Golpu Joint Venture (WGJV) and operated by Wafi-Golpu Services Limited of the Morobe Mining Joint Ventures. In November 2014, a Pre-Feasibility Optimization Study was completed to determine a technically feasible and economically viable method of mining and processing the Golpu deposit. It is anticipated the project will involve the staged development of an underground gold and copper mine, associated processing facilities and various support services and infrastructure. The 2014 pre-feasibility optimization study recommended an early works Programme involving advanced exploration and feasibility support activities (AEFSA) comprising the expedited construction of some project components in parallel with a Feasibility Study. The AEFSA include construction of underground infrastructure; surface infrastructure and industrial area; hard rock borrow pit and river gravel extraction sites; northern access road; and construction of the Phase 1 of the Watut accommodation camp. Currently, the Morobe Mining WGJV is doing some forward planning to clear some forest areas in the AEFSA areas prior to early works. At this stage, a forest resource inventory is necessary in the marked areas for the WGJV Project AEFSA. The forest types in the Wafi-Golpu area is a mixture of low altitude forest, lower montane and secondary forest which can be identified from the forest base map. **Figure 2** and **Figure 3** shows the proposed mine infrastructure designs/plans highlighted in white and the AEFSA (proposed deforestation area) highlighted in magenta.

3. Materials and Methodology

Geospatial technologies, including remote sensing, GIS and Global Positioning Systems (GPS), provide factual data and information on quality and forest canopy density status of forest area [19]. International and domestic

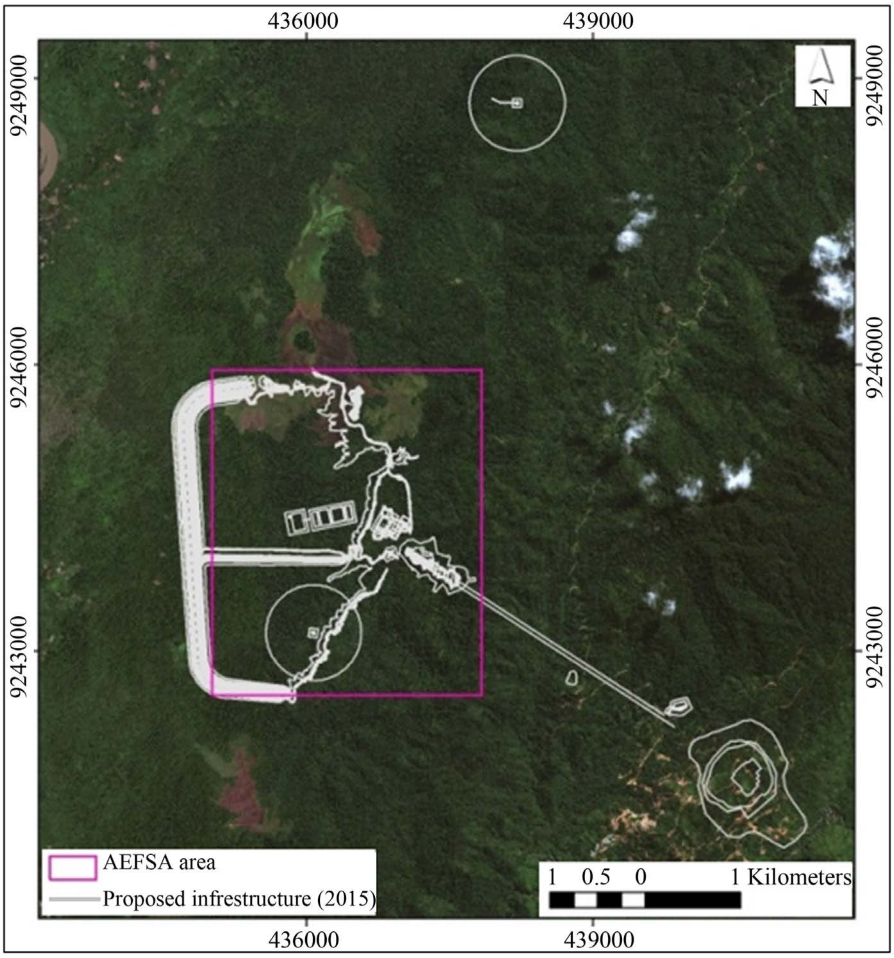

Figure 2. The Wafi Golpu AEFSA location.

Figure 3. A photo taken at the top of Mt Golpu with the watut plains at the foreground.

forestry applications where remote sensing can be utilized are biomass and carbon stock [20], diverse and include sustainable development, biodiversity, land title and tenure (cadastre), monitoring deforestation, reforestation monitoring and managing, commercial logging operations, shoreline and watershed protection, biophysical monitoring (wildlife habitat assessment), and other environmental concerns [21]. Both the satellite remote sensing and the GIS technology used as the main tool for data acquisition for the purpose of the forest canopy density (FCD) mapping and the land use land cover (LULC) mapping respectively. Different type of data sets, like Landsat-8 OLI imagery of 2013, GeoEye Satellite image of 2010, forest information management systems (FIMS) database of 2009, Wafi-Golpu proposed mine infrastructure designs/plans & area marked for deforestation, topographic data (digital elevation model), existing forest survey reports of the study area and national administrative boundaries data sets were used in this study. Different tools and softwares, including handheld GPS, Erdas Imagine 8.5, ArcGIS 10 and MapInfo 8.5 were use to complete this research work.

All data used in this study was re-projected to the UTM projection system of AMG66, Zone55 using Nearest Neighbor resampling technique. This is because AMG66, Zone 55 is the projection system used in the Wafi-Golpu Project Area. An AOI (Area of Interest) and sub-setting operation was done on the Landsat-8 imagery using Erdas Imagine to obtain areas of interest (study areas) for both the LULC mapping and the FCD mapping. All spatial datasets were converted from their respective formats (Mapinfo tab, dxf CAD, gpx, etc) to ESRI shp format since ArcGIS and Erdas Imagine were the main softwares used for data/image processing and output mapping in this study. Different image enhancement techniques were applied on to the Landsat-8 imagery to aide visual interpretation of features on the image [22]. Different radiometric and spatial enhancement techniques utilizing methods like brightness/contrast stretch, convolution low pass filtering, noise reduction, brightness inversion techniques were applied. The brightness contrast stretch was used to improve the visible contrast and brightness of the image whilst convolution filtering was used to average small sets of pixel across the image [15]. Noise reduction is an important precursor in most image enhancement for without this, the image interpreter is left with the prospect of analyzing enhanced noise. The interpretation key used here is based on the relationship between ground features and image elements like texture, tone, shape, location and pattern as well as elevation, date of imagery and resolution.

Based on the priori knowledge and ground truth information of the study area a classification scheme was developed to indentify different land use/land cover classes. The USGS Level 1 classification system was adapted to develop the classification scheme. Supervised training classification technique was used for classification in this study. After the classification ground truth verification and accuracy assessment was performed using stratified random sampling method to assess the accuracy of the classified output. An overall classification accuracy of 88% and overall Kappa statistics of 0.83 was achieved from the accuracy assessment.

The proposed deforestation study area was further clipped from the bigger study area subset image (Landsat-8

OLI) was used for FCD model, which was clipped using area of interest (AOI) layer in ArcGIS software. This model utilizes forest canopy density as an essential parameter for characterization of forest conditions and involves bio-spectral phenomenon modeling and analysis. The model calculates forest canopy density using the three (3) indices of Bare Soil Index (BI), Shadow Index (SI) and Advanced Vegetation Index (AVI). According to [10], the FCD method is one of the useful methods and estimates the canopy density in a time and cost effective manner. Using the three (3) indices, the Canopy Density was calculated in percentage [5].

Vegetation Index responds to all vegetation items such as the forest and the grassland. Advanced Vegetation Index (AVI) reacts sensitively for the vegetation quantity compared to NDVI. Shadow Index increases as the forest density increases. Black colored soil area shows a high temperature thus Bare Soil Index increases as the bare soil exposure degrees of ground increases.

These index values are calculated for every pixel. Details NDVI is unable to identify subtle differences in canopy density [5]. For a more reliable estimation of the forest status and using the power degree of the infra-red response, the Advanced Vegetation Index (AVI) is calculated for use in the FCD model. AVI is noted to be more sensitive to forest density and physiognomic vegetation classes. The bare soil areas and fallow lands are enhanced using the Bare Soil Index (BI). This index helps to give a sure understanding of the vegetation from the surrounding environment. Similar to the concept of AVI, the Bare Soil Index is formulated with medium infra-red information. The crown arrangement in the forest stand leads to shadow pattern affecting the spectral responses. The young even aged stands have low canopy shadow index (SI) compared to the mature natural forest stands. The later forest stands show flat and low spectral axis in comparison with open area [10]. An existing FCD model equation used for the Landsat-8 (OLI) data was adapted in this study [23]. **Table 1** shows the combination characteristics of the three indices categories.

Following equations (Equations (1) to (5)) are applied on the satellite image to generate different vegetation index.

$$\mathrm{AVI} = \left[(\mathrm{B5}\ +1)(65536-\mathrm{B4})(\mathrm{B5}-\mathrm{B4})\right]^{1/3} \tag{1}$$

where B refers to Band number, AVI = 0 If B5 < B4 after normalization

$$\mathrm{BI} = \mathrm{BIO} * 100 + 100 \tag{2}$$

$$\mathrm{BIO} = \left[(\mathrm{B6}+\ \mathrm{B4}) - (\mathrm{B5}+\mathrm{B2}) / (\mathrm{B6}+\mathrm{B4}) + (\mathrm{B5}+\mathrm{B2})\right] \tag{3}$$

$$\mathrm{SI} = \left[(65536-\mathrm{B2}) * (65536-\mathrm{B3}) * (65536-\mathrm{B4})\right]^{1/3} \tag{4}$$

where, SI refers to Canopy Shadow Index

Vegetation Index is obtained through Principal Component Analysis (PCA 1) between AVI and BI and then scaled from 0 to 100 to form Scaled Vegetation Index (SVD). Scaled shadow index (SSI) was calculated using a linear transformation function from normalized SI. Maximum SSI (100%) represents the highest possible shadow whilst minimum represents the opposite.

$$\mathrm{FCD} = \left((\mathrm{SVD} * \mathrm{SSI}) + 1\right)^{1/2} - 1 \tag{5}$$

All data extraction through the existing respective equations was computed in the ArcGIS v10 software. All of the above equations were completed using the ArcGIS Raster Calculator to compute respective values. It must be highlighted here that the Bare Soil Index (BI) obtained for this study area turned out to be zero (0) as the area was heavily forested and there was no bare soil coverage. Vegetation density (VD) was obtained through a principal component analysis (PCA1) between AVI and BI and then scaled from 0 to 100 to form scaled vegetation density (SVD). SSI was obtained using a linear transformation of SI. Fuzzy Membership transforms the input raster into a 0 - 1 scale indicating the strength of a membership in a set, based on a specified

Table 1. Combination characteristics between the three indices.

	High FCD	Medium FCD	Low FCD
AVI	High	High	Mid
BI	Low	Low	Low
SI	High	High	Mid

fuzzification algorithm. Linear membership option calculates membership based on the linear transformation of the input raster and assigns a membership value of 0 at the minimum and a membership of 1 at the maximum. **Figure 4** explains the methodological flow chat that was adapted in this study.

4. Result and Discussion

The produced pixel by pixel land use/land cover (LULC) map [24] showed the greater part of the study area especially in the higher lands as forested areas whilst the lower lands has a mixed land cover of mainly forested land and grassland coupled with a small portion of wetland or swamp land areas and water bodies (**Figure 5**). Given that the study area is in a rural setting, built-up land is a minor class in the classification. Built-up (land use) features depicted on this LULC map does not represent the actual and current built-up areas on the ground because the image data used for the classification is a 2013 data and there has been an increase in the land use activities since 2013 due to the different development stages of the advanced exploration project in the past two years. Some of the present domineering land use built-up features not captured in the LULC map include rural settlements as people move closer in to settle in the vicinity of the project footprint. The areas (ha) of the different LULC classes were obtained (**Table 2**), so that they can be used as a reference to monitor how the different land covers would change over time during the different stages of the advanced exploration and eventually the mining project.

With the provision of the LULC map and further studies and investigations into the different LULC classes, the Wafi-Golpu project developers and decision makers can now be able to make informed and accurate decisions in planning for rural sustainable development within the project footprint locale. Viable socio and economic development plans for sustainable and infrastructure developments and programs within the study area

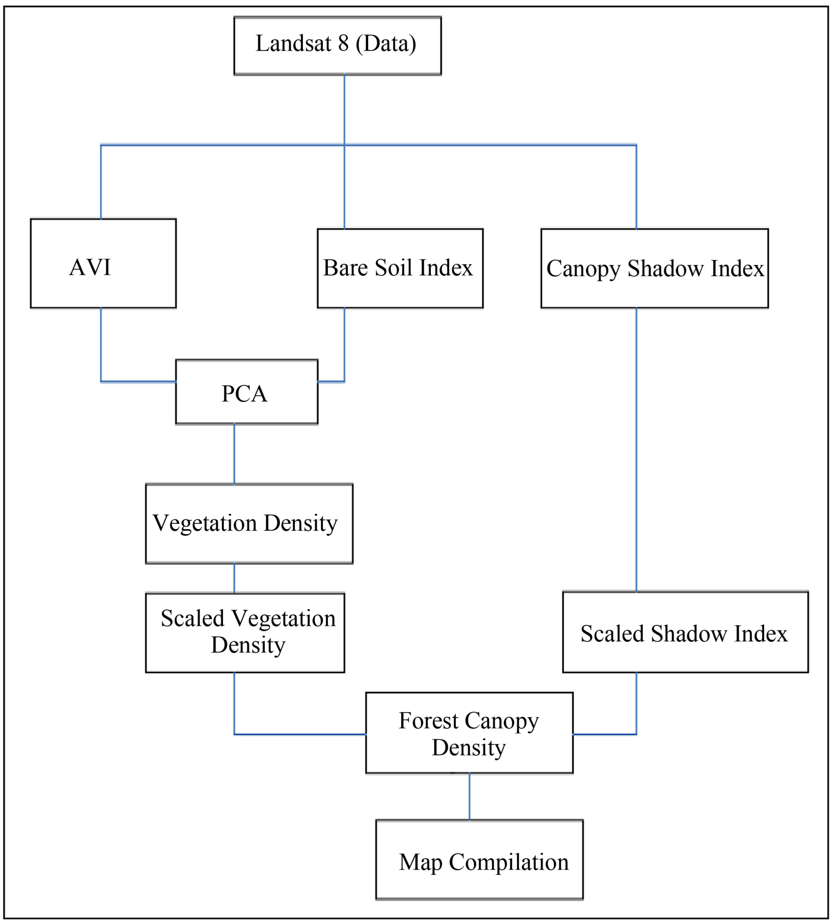

Figure 4. Methodological flow chart of forest canopy density mapping.

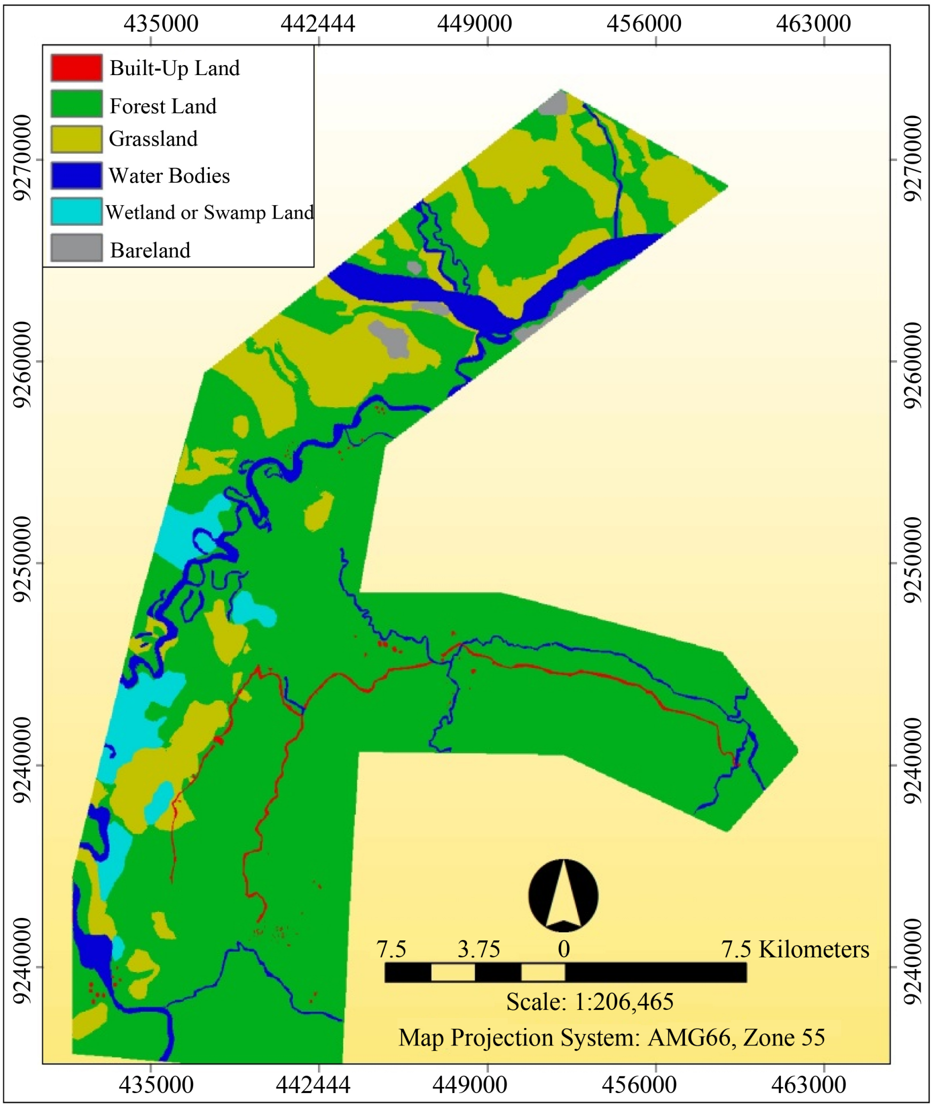

Figure 5. Land use/land cover classified map of the study area.

Table 2. Land use/land cover categories for the study area.

Code	Land use/land cover	Areas (Ha)
1	Built-up Land	476.73
2	Forest Land	352,179.26
3	Grassland	7892.37
4	Water Bodies	3557.34
5	Wetland or Swamp Land	1801.26
6	Bare-land	439.02
	Total	**366,345.98**

can now be embarked on with a synoptic land use land cover overview of the project locality. For instance, planning for agricultural cash crop farming for the local communities along the main water bodies in the lower lands will require careful assessment of the different land cover conditions. As part of the sustainable development and its social licensing, the Wafi-Golpu Project has an obligation to maintain its social responsibility when dealing with relocation of the local communities within the mining lease (License) areas. This prepared LULC map will again enable the project planners to see at a glance suitable areas for relocation purposes and to initiate the relocation plan. For instance, local communities living along the corridor of the proposed access road will have to be relocated somewhere feasible where sustainable developments plans is also feasible and this LULC map will assist project planners in making practical decisions (**Figure 6**).

The original FCD output data was smoothed using a low pass edge enhancement to produce a smoothing effect on the data (**Figure 7**). One or two small patches of cloud cover may have altered the output slightly however, as highlighted in the image above, five (5) class values were produced from the original FCD data. The original five (5) classes obtained from the FCD were then re-classed into three (3) classes of the different forest categories of High, Medium and Low forest classes according to the pixel distribution on the raster image. That is classes 1, 2 and 3 were grouped together as one class (Class 1) whilst class 4 and 5 were grouped individually as separate classes of (Class 2) and (Class 3) respectively (**Figure 8**).

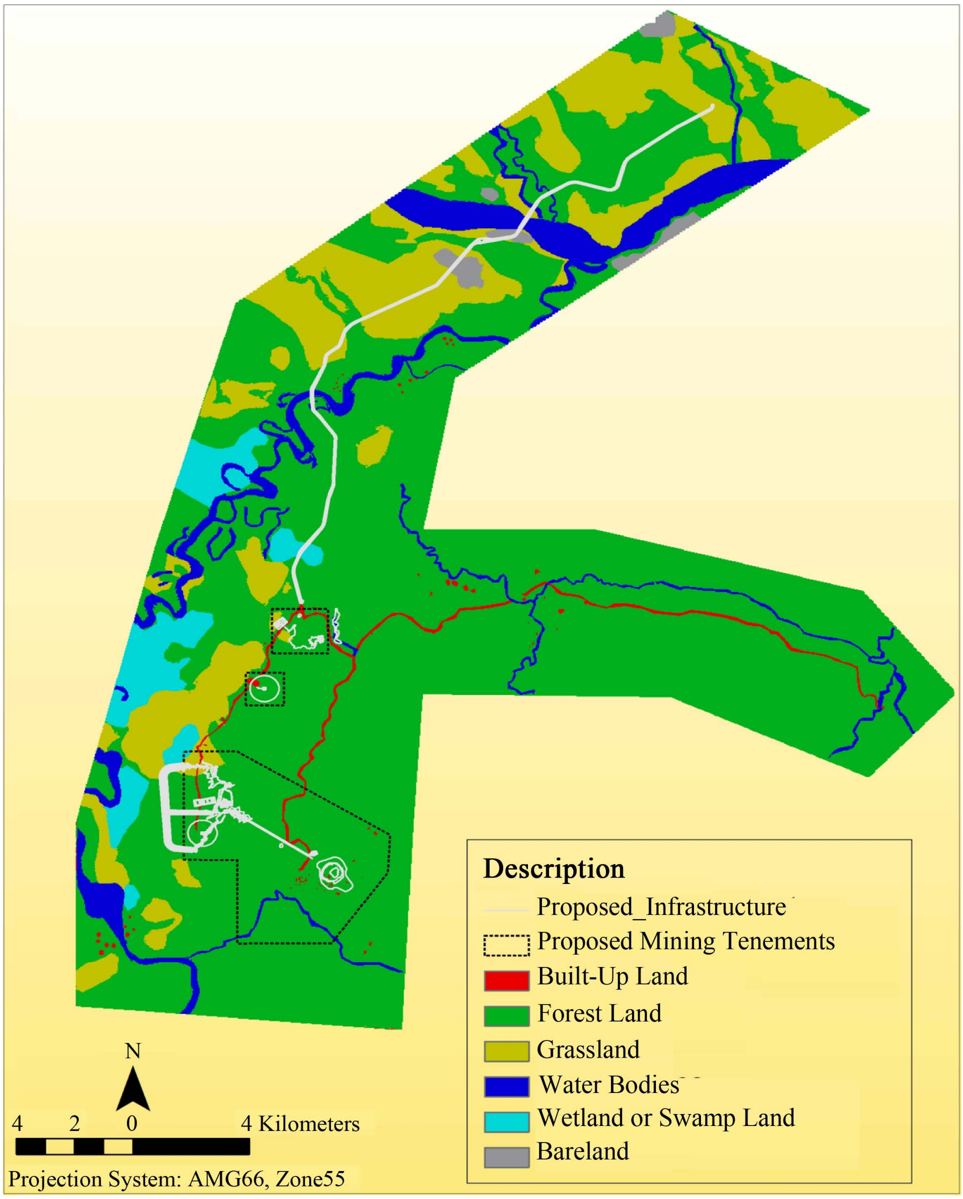

Figure 6. The LULC map with proposed infrastructure designs (in white outline).

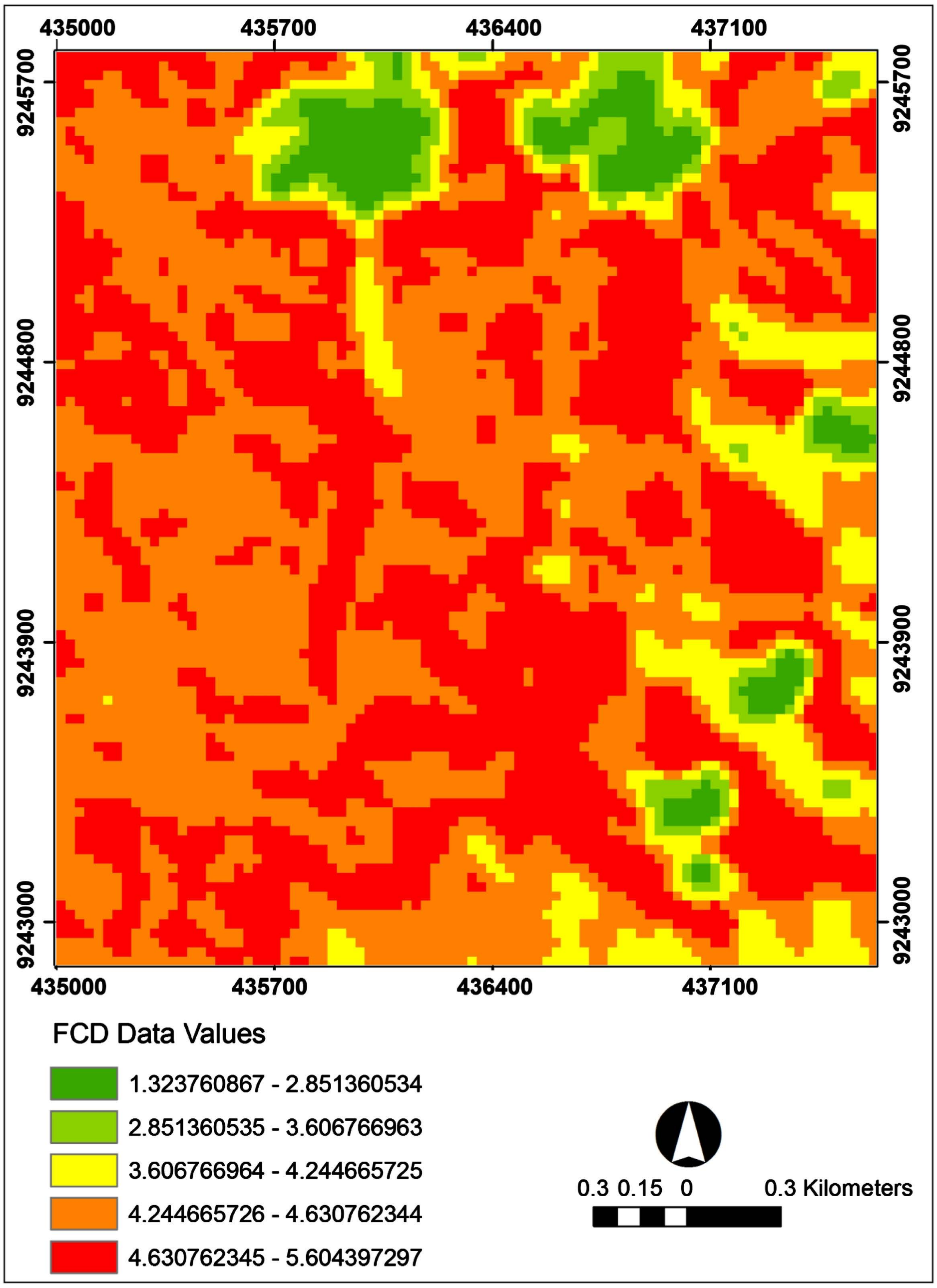

Figure 7. AEFSA FCD obtained through the FCD model.

Table 3 shows the values for both the original FCD data and the re-classed data together with values in percentage of the re-classed data. The outcome of the forest density mapping using the FCD model shows that the proposed Wafi-Golpu AEFSA area for deforestation will face a huge loss of primary forest. The result indicates that even the low forest is still intact or untouched given the long/high stretch of the quantification (0% - 71%) and thus the result can be concluded that the AEFSA area marked for deforestation is a dense forested area. A supervised classification was carried out to be used as a guideline and for general overview purposes of the forest classes within the AEFSA area. The classification was carried out using the Landsat-8 OLI satellite image applying the interpretation keys of tone and texture for forest class interpretation (**Figure 9**). The comparison depicted the FCD data showing a more detailed output of the low forested area than the supervised classification output.

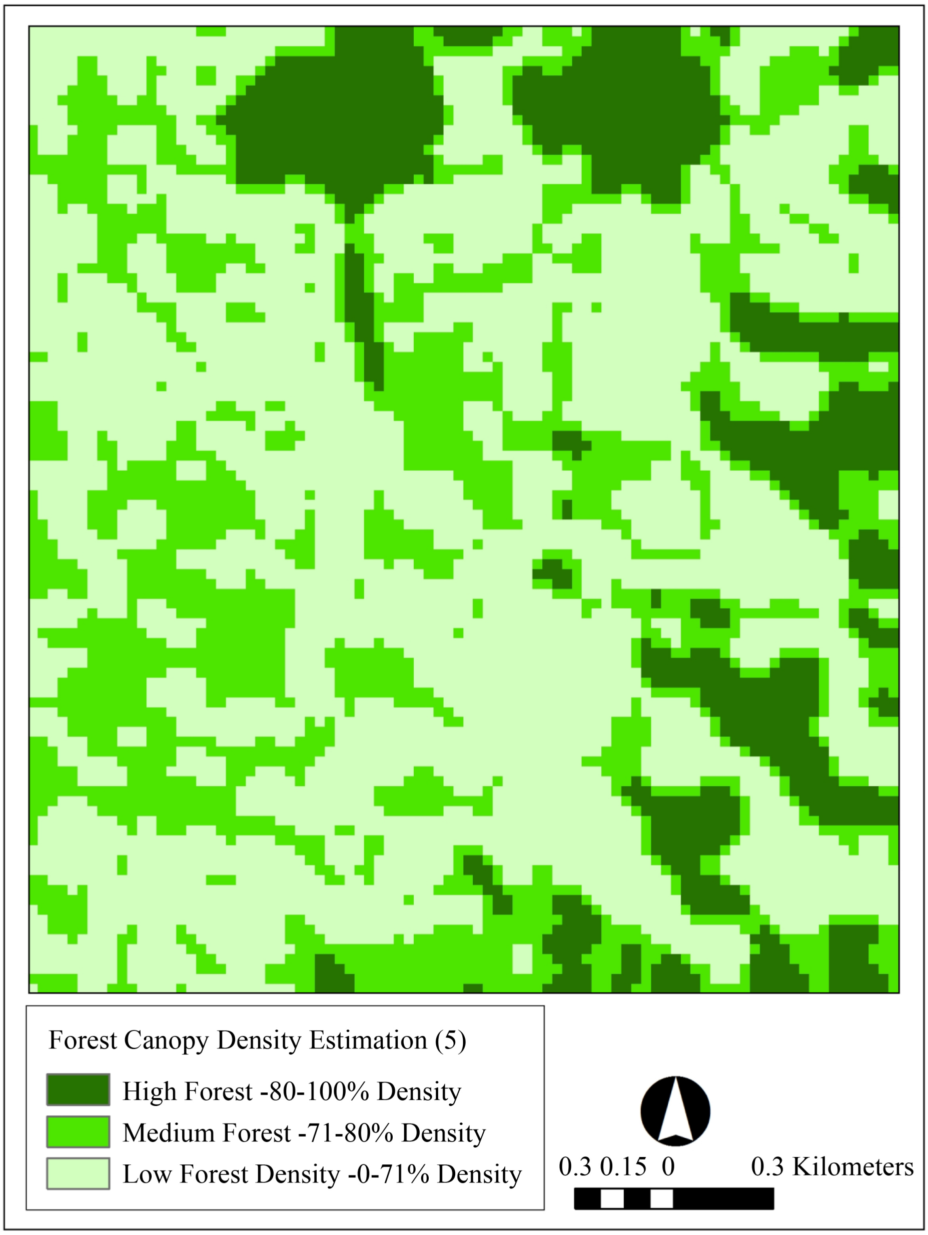

Figure 8. Classified FCD in percentage based on the FCD model.

5. Conclusions and Recommendations

This study using the Remote Sensing and GIS techniques to establish a land use/land cover map to aide sustainable development planning and development has been noted to be a useful study as the output LULC map gives a synoptic overview of the general land use and land cover phenomenon of the study area in terms of planning for sustainable development. Given the current advanced exploration and pre-mining stage of the Wafi-Golpu project, project planners and developers will truly appreciate the LULC map that can be used as a base map to aide planning for mine infrastructure development as well as planning for sustainable development within the surrounding local communities. A recommendation to be noted in this LULC study is for the Wafi-Golpu project to embrace the use of the Remote Sensing and GIS technology in terms of remote sensing data acquisition and remote sensing software so that updating of the LULC map over time and during the different project stages will be possible so as to use the technology to continue to support project planning and development

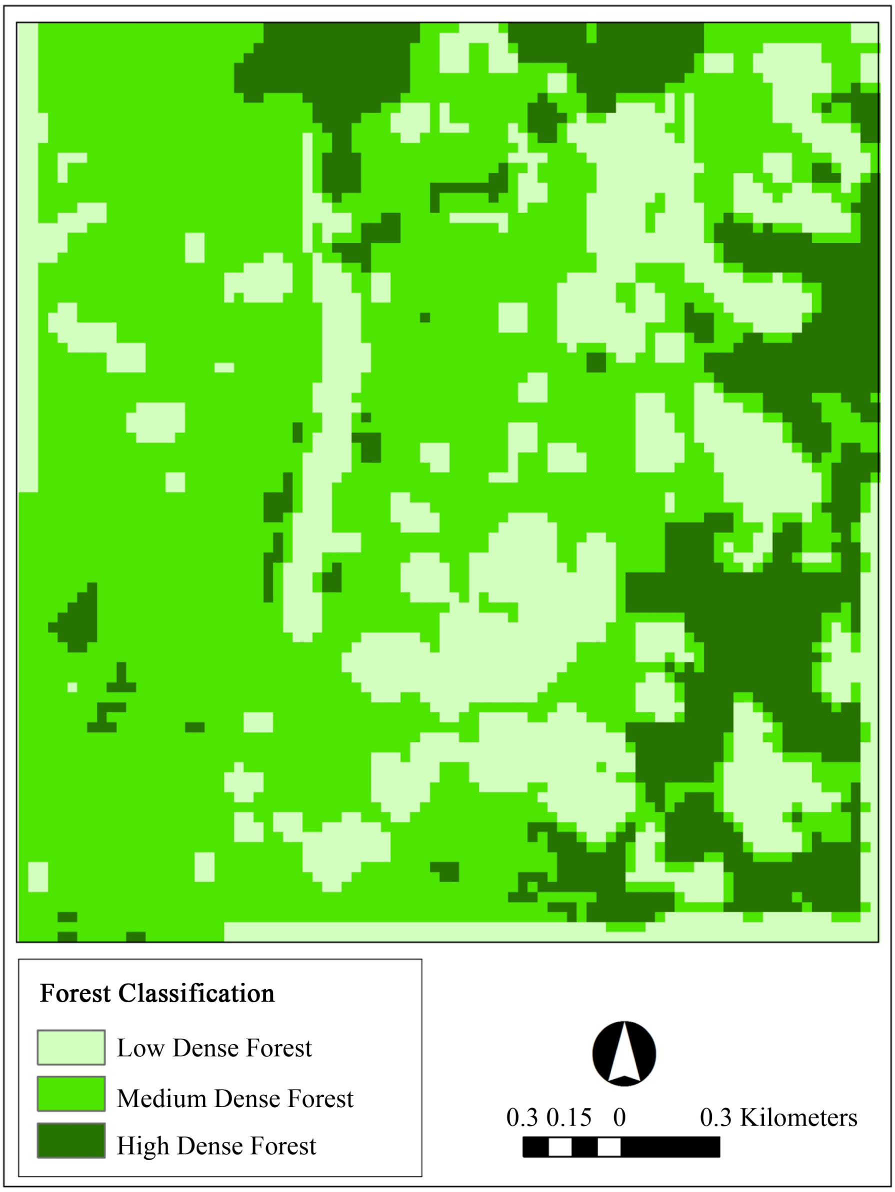

Figure 9. The Wafi Golpu AEFSA forest classification map obtained through supervised classification.

Table 3. FCD and Re-classed FCD data in percentage.

Initial FCD class	Values	Re-class	Forest Density	Density in %
1	0 - 2.571412449			
2	2.57141245 - 3.466814999	1	High	More than 80
3	3.466815 - 4.20150427			
4	4.201504271 - 4.660685064	2	Medium	71 - 80
5	4.660685065 - 5.85455513	3	Low	Less than 71

and further more to provide support in maintaining the project's social licensing and social responsibilities.

The FCD model using the Remote Sensing and GIS technologies to estimate forest loss in this study has been noted to be a time and cost effective method. Once reliable accuracy check is carried out, the forest loss estimation from this study can be captured in the forest inventory for forest management purposes. This data can also be used as a guideline to plan for forest rehabilitation and reforestation programs post deforestation. Cloud cover issue poses a major challenge in this study of forest loss estimation using the FCD model. Thoughtful considerations and advance planning on ways to address cloud issues is important in this FCD model for forest estimation. This study of forest density estimation has been observed to be a valuable study as it gives the planners and developers of the Wafi-Golpu project not just an overview but an estimate of the possible forest loss within the proposed deforestation area. The obtained information can be incorporated into the planning for reforestation and forest rehabilitation.

Given Papua New Guinea's vast natural forested areas and our pursuit to maintain sustainable forest management in the midst of growing natural resources extraction and development, the use of the FCD model to assess, estimate and quantify forest is recommended for use in forest management activities as it has proven to be a time and cost effective method. It is also recommended that this model be used again to estimate forest canopy density and possible forest loss in the other proposed deforestation areas in the Wafi-Golpu project.

Conflict of Interest

The authors declare that there is no conflict of interest for the publication of this article.

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