MAPPING OF URBAN ABOVE-GROUND BIOMASS WITH HIGH RESOLUTION REMOTE SENSING DATA

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ABSTRACT: This paper reports on study carried out to determine and map the distributions and density of the urban total above-ground biomass (TAGB) content using high resolution satellite data of the SPOT-4 and Quickbird, with respective 10 and 4 meter spatial resolution for mapping two levels of urban biomass, Level I biomass derived at selected residential areas in Johor Bahru city urban landscape, and Level II biomass derived from SPOT-4 data in for the entire urban district (including the suburbs). The results of this study indicated that, Level I and Level II of biomass were derived at respective accuracy of $\pm 0.3 kgm^{-2}$ and $\pm 0.4 kgm^{-2}$, validated with in-situ verification.

1. INTRODUCTION

Biomass is one of the important biophysical parameter in determining the function of the environmental ecosystem. Biomass is also important the determination of the carbon budget because it directly represents the amount of carbon stored in living plant. The term used to describe all the organic matter, produced by photosynthesis that exists on the earth's surface, widely categorized into two, namely the above and below ground biomass. For simplicity of undertaking biomass studies, the below-ground biomass (BGB) often neglected, instead only total above-ground biomass (AGB) is adequate representation for the biomass of any particular area of interest with presumed proportion ratio of AGB to the entire total biomass in a given area. Hence, estimation of further parameters such carbon-related variables can be indirectly derived.

Estimation of above-ground biomass is used in studies of ecosystem productivity models for calculating and forecasting carbon budgets. In-situ methods for mapping AGB are resource intensive, often impractical due to remote access and are subject to inconsistencies due to destructive sampling techniques and elaborate laboratory procedures. On the other hand, advancement in remote sensing technology as a whole have facilitate the determination of total TAGB from satellite remote sensing data, and in recent years these information are more sought after as higher detailed information is possible with the present generation of high satellite remote sensing data. Biomass extraction from satellite remotely sensed data especially for forest to enable area can be traced back from as early 1980 within visible wavelength, and becoming more important with availability of synthetic aperture radar (SAR) after the 1990's (Le Toan et al (1992), Luckman et al 1998, Hashim et al 2002). Related biomass studies from remote sensing data from this point have been contributing into deriving further parameters such as related to carbon stock and carbon sequestration(Lucas et al 2006, Dong et al. 2002, Hashim et al 2005). Based on the previous studies on all the two approaches of biomass extraction from satellite remote sensing data were focused at small to medium resolution for forest-related area. Similar information extraction at large scale such biomass within urbanized area using high satellite resolution data have not much being reported, although such information is becoming very crucial for urban ecology studies. As more affluent living within large cities or metropolitan, environmentally-related parameters that require information on biomass is significantly crucial. Biomasses within urban areas have known direct influence on the environment and the flow of energy through reflection and absorption of solar radiation and evapotranspiration. Lack of urban forest has contributed to the increase of urban heat island, which is primarily due to the alteration of urban landscape, which changes the thermal response to solar radiation (Ozawa et al. 2004). Thus, it contributes to unstable urban ecosystem, namely the imbalance composition of oxygen and carbon dioxide that have direct impact to the air quality and human health.

The theoretical background that enables biomass extraction from remote sensing data relies on the attributes to spectral characterizations within vegetated matters. Once sample of spectral responses from known sites, which the total above-ground biomass can be conventional determined, usually by destructive sampling where the whole tree parts that make up the total biomass is dried and weigh. Relationship of the tree parts to whole biomass of the tree can then be established, i.e. the contributions of each tree parts such the trunk, stem, leave, and root to the total biomass of a tree. Models describing these relationships are known as allometry relationship (Bartelink 1996, Tufekcioglu et al 2003), and in large have focused on the tree parameters above the ground although below ground biomass also important. Allometry relationship is a relation that consists of measurement and study about the size of certain part for landscape species. This relation exists after the sample for in-situ data is collected where it involve empirical relationship between biophysical information of landscape species with remote sensing reflectance. Allometric relationships among tree parts originate from physical or physiological interrelations among stem dimensions, diameter at breast height (dbh), crown dimensions, foliage area, and biomass amounts. Destructive sampling of the trees was used to develop allometric equations based on height and dbh to estimate aboveground biomass. With regard to remote sensing satellite data, relationship with the above-ground biomass have been successfully established in visible and radar wavelength regions.

In this study, two sets of remote sensing data, namely SPOT-4 and Quickbird data are used to derive above-ground biomass information in urban forest in city of Johor Bahru, Malaysia. The urban forest in study referred to as the collection of woody and other vegetation that lies within an urban area. The urban forest includes trees along streets and other rights-of-way, trees in parks and residential yards, and in forested recreational areas near population centers. The same definition of urban forest is given in Rowntree (1984). The common trees species within the urban landscape in this study are mostly woody based trees made of *Filicium Decipiens*, *Pterocarpus Indicus*, *Tabebuia Pentaphylla* and *Eugenia Papilosa*.

2. MATERIAL AND METHOD

2.1 Study area

The study area is Johor Bahru district, southern most Malaysian city, with estimated area of 1817km^2 , among one of the biggest cities in Malaysia with approximate population of close to 1 million in the city, and 1.73 million in the greater metropolitan area. The city is an important industrial, tourism and commercial hub for southern Malaysia and is part of one Southeast Asia's most populous urban areas with 1km-away neighbouring island state Singapore. The population growth rate in Johor Bahru is among the highest in Malaysia, and has a highly developed industrial base which has made the city one of the biggest industrial centres of the country.

2. 2 Satellite and ancillary data

In this study, two sets of remote sensing data were used, Quickbird multispectral data and SPOT-4 multispectral data sets, acquired in March and October 2002, respectively. Both these data set has 4 spectral bands and technical specifications are tabulated in table 1.

2.3 In-situ measurement and Ancillary Data

A total set of ground control points (GCP) used for this study are acquired from GPS surveying. These GCP points were used in geometric correction of the both image sets.

Apart from GPS points, the samples of tree measurement later used to derive above ground biomass samples as input into generating correlation of spectral and biomass. The road map and building plan corresponding area obtained from the Planning and City Hall were also used for assisting planning for in-situ measurement.

(i) Filed measurement data

In this study, biophysical parameter of the landscape species within three residential areas is used. The most essential inventory as required in this study is the dbh (diameter at breast height) of the tree species, that is needed as input to calculate biomass content. The establishment of allometric equation is quite expensive for individual project because it involves the destructive sample for several landscape species. This means, several interested tree species need to be felled down, divided into particular components and their weights are measured (dry-oven weight). The complete inventory of the landscape species in this study is partially obtained from the Landscape Department. A total of 42 samples of landscape tree species were compiled in this study.

Figure 1(a) below shows the relationship of dbh and weight of the sample of acquired from in-situ tree measurements. With regression analysis, the relationship of dbh and weight is obtained, such that within urban trees in the study area is best represented by:

$$\text{Biomass} = 773.74*\text{dbh} - 418.72 \qquad \text{(equ. 1)}$$

where

Biomass is the dry weight (kgm^{-1}), and

Dbh is the diameter of tree at breast height in meter (m).

2.4 Data Processing

2.4.1 Image Preprocessing

Both the data sets are firstly preprocessed for geometric and radiometric corrections. Image masking was also performed to prepare the image set to cover only the area of interest. The GCPs obtained from in-situ measurement employing the DGPS survey were used in the geometric correction with the Image-to-map rectification approach. A total of 14 GCPs used with second degree polynomial transformation function. The grid resampling grid size for geometric corrected image is set to 4m and 10m for Quickbird and Spot4 image date set, respectively. The residual for each of the GCP in the transformation are ensured not allow residual more than $\pm$0.5 pixel, hence overall accuracy of RMSE of $\pm$0.5 pixel for the geometric correction of both image set are achieved.

2.4.2 Extraction of above-ground biomass

Five step procedures are carried out to obtain the TAGB from the satellite image sets, as follows:

(a) Identification of random tree samples within the urban landscape, where later the above-ground biomass for each samples were determined using built allometric relation in equation 1.
(b) Derivation of image variable for the image sets including the samples in (a), derived using three vegetation index selected in this study – the normalized vegetation index (NDVI), transformed NDVI (TNDVI), SR and VI). Table 2, list the mathematical algorithm of each of these index.
(c) Pixel-based sampling of TAGB, computed using equation 1, for all trees or vegetation at the grid equivalent of pixel size of both image sets.
(d) The relationship of the four vegetation index derived in (b) with corresponding TAGB derived in (c) were then examined using empirical analysis employing simplistic linear regression approach.
(e) The entire TAGB for the image set ere derived using the best model of the image variables with TAGB.

3. RESULTS & DISCUSSION

NDVI shows the best image variables among the 4 vegetation index examined for its correlated to TAGB. This is clearly depicted in Figure 1(b), the scatter plot of TAGB against NDVI derived both image set, with R^2=0.84 (P-value = 0.017). The final model best to derived TAGB at level I, for representing fine scale output at residential areas is best extracted from QuickBird image set, and level II to represent relatively large scale output adequate for at district level using Spot4 image set is given by equation 2 below. The final output of the TAGB for both level I and II is shown in Figure 2 and 3, respectively.

$$\text{TAGB} = 1459.4\,(a) - 28.903 \qquad (2)$$

where

TAGB is total above-ground biomass at pixel-of-interest in (kgm^{-2}),
a is the NDVI image.

Independent assessments of the TAGB derived from image were then verified by means of field visits at selected test sites. The root mean square error of the assessments were then determined, and found that RMSE of the level 1 TAGB is ±0.3kgm^{-2} , and ±0.4kgm^{-2} for level II derived with Quickbird and Spot4 image, respectively.

4. CONCLUSION

The study has demonstrated the best simplistic approach for deriving urban total above-ground biomass using high resolution satellite. The accuracy of Level I and Level II of urban biomass derived is given by RMSE of ±0.3kgm^{-2} and ±0.4kgm^{-2}, respectively. This is relatively very good accuracy for operational application and in fact the only non destructive method for determination of above-ground biomass over large area extent.

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Table 1: The specification of the data used in the study

Satellite	Quickbird (Multispectral Mode)	SPOT-4 (Multispectral Mode)
Spatial Resolution	2.4~2.8m resampled to 4m for this study	10m
Spectral Band	Band 1 (450-520nm) Band 2 (520-600nm) Band 3 (630-690nm) Band 4 (760-900nm)	500-590nm 610-680nm 780-890nm 1580-1750nm
Date of acquisition	March 2, 2002	October 19, 2002

Table 2: Image variables used in study

Variables	Index	Algorithm
Vegetation Indexes	NDVI	(NIR -RED)/(NIR + RED)
	TNDVI	SQRT((NIR-RED/NIR+RED)+0.5)
	SR	(NIR)/(RED)
	VI	NIR-RED

Source: (Jensen, 2000)

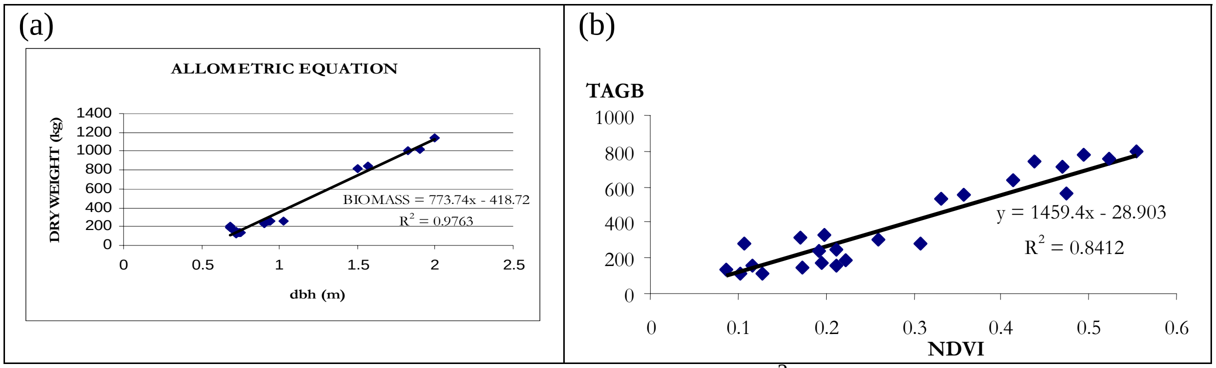

Figure 1: (a) Relationship of tree dbh and weight (n=42, R^2=0.9, Pvalue<0.005), and (b) TAGB plot against NDVI in urban above ground biomass (n=82, R^2=0.8, Pvalue<0.005)

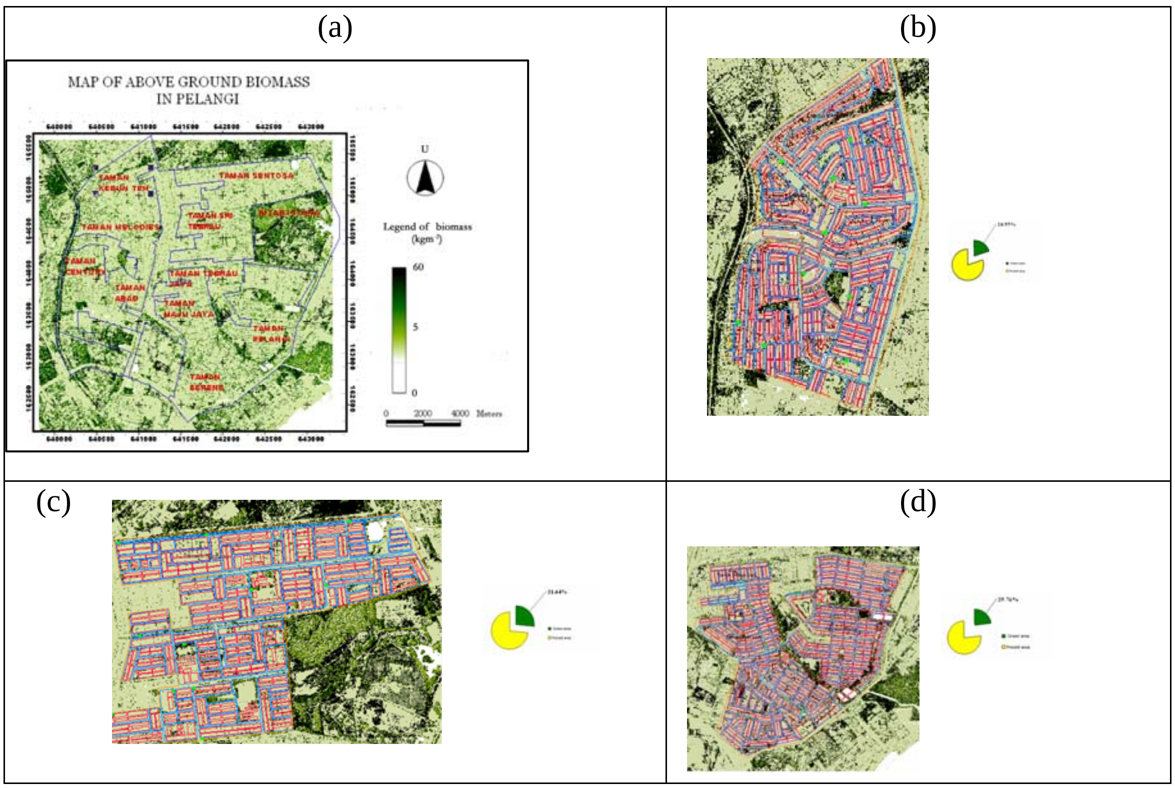

Figure 2: Derived output of the TAGB using QuickBird Image for (a) selected residential areas in Johor Bahru, and (b) through (d) are enlarged TAGB at three designated Taman Melodies, Taman Sentosa and Taman Pelangi respectively together with pie-chart of the TAGB in the area compared to non-vegetated area.

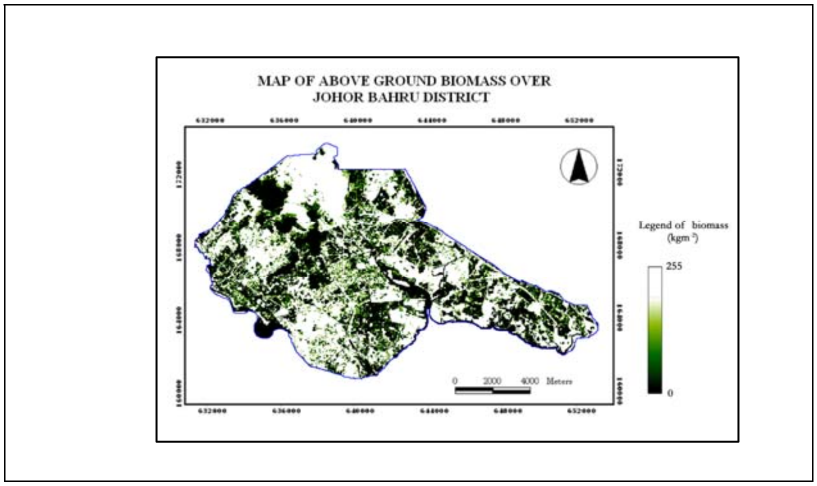

Figure 3: the final TAGB of the entire urban district of Johor Bahru derived from Spot4 image.