Remote sensing assessment of carbon storage by urban forest

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Remote sensing assessment of carbon storage by urban forest

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Abstract. Urban forests play a crucial role in mitigating global warming by absorbing excessive CO_2 emissions due to transportation, industry and house hold activities in the urban environment. In this study we have assessed the role of trees in an urban forest, (Mutiara Rini) located within the Iskandar Development region in south Johor, Malaysia. We first estimated the above ground biomass/carbon stock of the trees using allometric equations and biometric data (diameter at breast height of trees) collected in the field. We used remotely sensed vegetation indices (VI) to develop an empirical relationship between VI and carbon stock. We used five different VIs derived from a very high resolution World View-2 satellite data. Results show that model by [1] and Normalized Difference Vegetation Index are correlated well (R^2 =0.72) via a power model. We applied the model to the entire study area to obtain carbon stock of urban forest. The average carbon stock in the urban forest (mostly consisting of *Dipterocarp* species) is ~70 t C ha^{-1}. Results of this study can be used by the Iskandar Regional Development Authority to better manage vegetation in the urban environment to establish a low carbon city in this region.

1. Introduction

Globally, the average surface air temperature increased 0.5 ◦C in the 20th century and it is anticipated to increase further by 1.5–4.5 ◦C by the year 2100 [2]. Increasing levels of atmospheric CO_2 is the main reason for the increase in temperature [3] especially in the cities. The high population density, heavy industrialization and fossil fuel combustion in the cities will release higher concentrations of CO_2, and other greenhouse gasses (GHG) that will increase the temperature. By the year 2030, it is expected that more than 60% of the world's population will be living in towns and cities [4] which could amplify the effect of warming.

In order to mitigate the issue of carbon emission in cities, various actions such as green economy, green community and green environment can be implemented within the framework of low carbon cities [5]. Under the green environment, green infrastructure that includes the natural environmental components and green spaces that lie within and between the cities and towns [5] play a critical role as other infrastructures like roads or waste disposal. They provide a number of services which help to combat climate change [5]. Among the services provided by them include sequestrating and storing excessive CO_2 from the atmosphere (acting as a regional carbon sink), moderating high temperature in the cities and reducing GHG emissions by conserving energy used for space heating and cooling [5].

The net saves in carbon emission that can be achieved by urban trees planting can be up to 18 kg CO_2 year $^{-1}$ tree^{-1} and this benefit is corresponding to that provided by 3 to 5 forest trees of similar size and health [6]. Although the importance of tree planting and green spaces within urban areas is getting more noticeable in Malaysia [7,8], the effects of the trees on the city's environment improvement (i.e. carbon storage) has not been well studied. Consequently our understanding on the role of urban forests in carbon storage is limited and therefore their impact is rarely seriously taken into consideration in urban planning processes [9]. This study is an effort to explore the role of urban forest in storing atmospheric CO_2. In this study we have used WorldView-2 remote sensing data to estimate the carbon storage of urban forest in Iskandar Malaysia.

2. Study area

Iskandar Development Region (IDR) is located in the south of Peninsular Malaysia. This study is focused on an urban forest in the district of Skudai in flagship zone E of IDR (fig.1). It is located at 1°0'59.47" N latitudes and 103°3'52.96"E longitudes that is about 16 km from the metropolitan of Johor Bahru and covers a total area of 25 hectare and consisting of many tropical tree species that are commonly found in the a tropical forest.
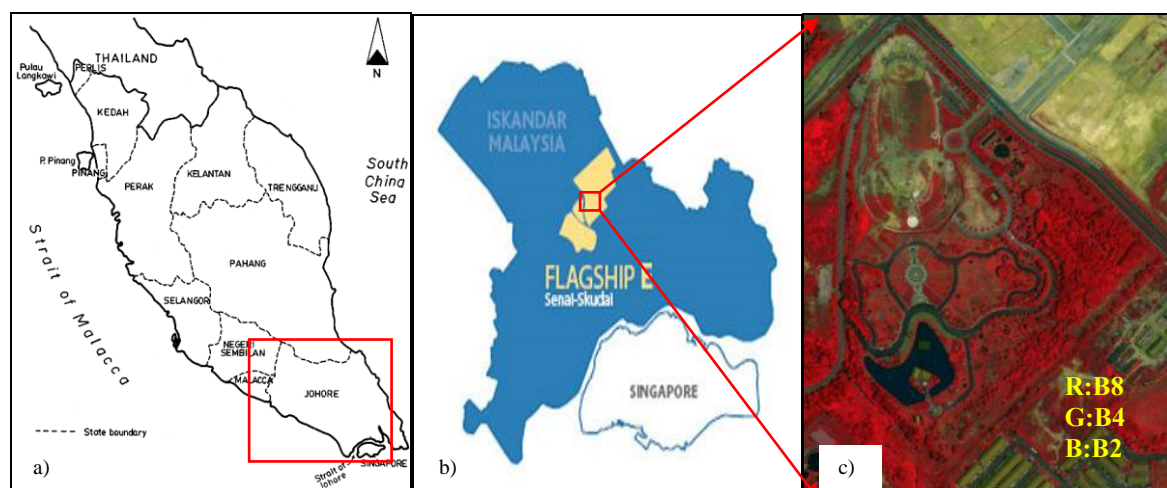

Figure 1. Study area, a) Johor state, Malaysia; b) Flagship Zone E (Senai-Skudai) of Iskandar Development Region; c) Johor Bahru Tengah Municipal Council Urban Forest (Mutiara Rini) shown by World View 2 satellite image (Red colour indicates vegetated area, green is open area and vacant lands while black colour represents water bodies).

3. Data and methodology

WorldView-2 satellite image with 2 meter spatial resolution and 8 spectral bands acquired on March 3rd, 2010 was used in this study. Field data such as Diameter at Breast Height (DBH), name of tree species and geographical coordinates of the trees were collected at Mutiara Rini urban forest. DBH measurement was taken at 1.3 m above the ground level. Random sampling technique was applied with 10 m x 10 m (0.01 hectare) sampling size for 35 sample plots. From the total samples, 30 were used for model development and the remaining 15 samples were used for model validation.

In this study, we used three allometric equations developed by [1,10,11] to estimate the above ground biomass (AGB). These equations were selected because they were developed specifically for tropical forests like in Sumatra, Kalimantan and Peninsular Malaysia [1,11,12] as follows:

$$42.69 - 12.8 * (DBH) + 1.242 * (DBH^2) \qquad [10]$$

$$0.066*(DBH^{2.59}) \qquad [11]$$

$$\ln(AGB) = (-1.498) + (2.234)\ln DBH \qquad [13]$$

The estimated AGB for the whole study area was converted into carbon by multiplying biomass with 0.5 [14-16]. World View 2 image was pre-processed (geometric correction, calibration) before computing various vegetation indices as shown in table 1.

Table 1. Various vegetation indices used to estimate the vegetation density in Mutiara Rini urban forest.

Normalized Difference Vegetation Index (NDVI)	$\dfrac{(NIR1 - RED)}{(NIR1 + RED)}$

Enhanced Vegetation Index (EVI)	$G\left(\dfrac{(NIR1 - RED)}{(NIR1 + C1 \times RED - C2 \times BLUE + L)}\right)$ G=2.5, C1=6, C2=7.5
Atmospherically Resistant Vegetation Index (ARVI)	$\dfrac{(NIR1 - 2 \times RED + BLUE)}{(NIR + 2 \times RED - BLUE)}$
Optimized Soil Adjusted Vegetation Index (OSAVI)	$\dfrac{(NIR1 - RED)}{(NIR1 + RED + Y)}$ Y=0.16
Modified Chlorophyll Absorption Ratio Index (MCARI)	$\left(\left((NIR1 - RED) - 0.2 * (NIR1 - RED)\right) * \left(\dfrac{NIR1}{RED}\right)\right)$

After computing the VI from WorldView-2 image and estimating the carbon at selected locations in the field, both of these parameters were correlated as to develop an empirical model to estimate carbon stock in the entire study area. Based on the relationship between VI and carbon stock estimated from the field, one empirical model with the highest R^2 and lowest root mean square error (RMSE) were selected to estimate AGB and carbon stock for the entire study area.

4. Results and discussions

Results of the study show that, NDVI correlated moderately well ($R^2 = 0.56$) with carbon stock estimated using the biomass model of [1]. The rest of the vegetation indices (EVI, ARVI, OSAVI and MCARI) yielded very low correlation coefficient (ranging between 0.11 and 0.43) with carbon stock estimated using Basuki model. Theoretically, different VIs may give different values based on different spectral bands and formula utilized. In another study estimating the carbon stock of mangrove forests in Malaysia [17] also found that NDVI yielded the highest correlation with carbon stock compared to other vegetation indices. This study shows that NDVI is a useful remotely sensed spectral vegetation index to detecting the biomass of urban forest that may not be as dense as tropical forests. Thus, the power model shown in fig. 2 was used to estimate the carbon stock in the Mutiara Rini urban forest.
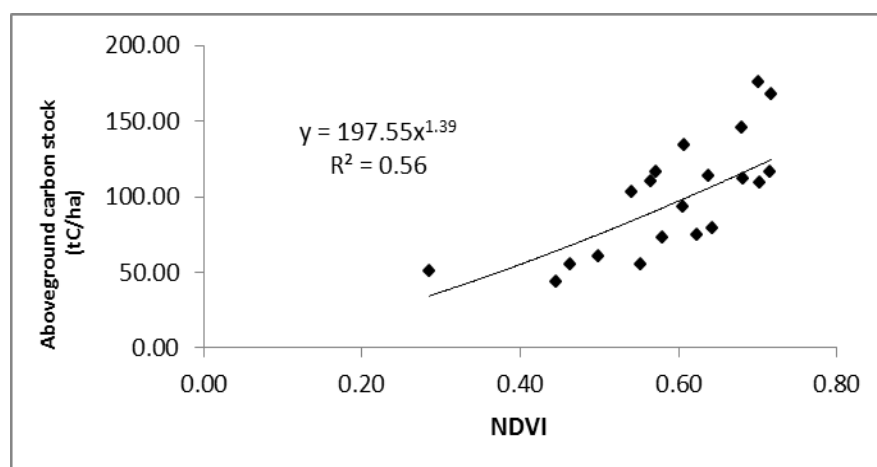

Figure 2. Relationship between the aboveground carbon stock and Normalized Difference Vegetation Index in Mutara Rini Urban forest.

We assessed the accuracy of the carbon stock estimated using the model (fig. 2) with carbon stock estimated in the field (independent samples that were not used in the empirical model development) show a moderate correlation with R^2 0.47 and a low RMSE of 24.48 t C ha^{-1}. Overall, this study

demonstrates that, carbon stock in Mutiara Rini urban forest is between 20 and 120 t C ha^{-1} (fig. 3). This amount is on average approximately 25% compared to the carbon stock of tropical *dipterocarp* forests in Malaysia [18-19]. However, it should be noted that their study were based on trees with DBH <15 cm compared to this study with DBH ranging between 10 and 35 cm. The average carbon sequestered by this forest is approximately 257 t CO_2e ha^{-1}.

Figure 3 depicts that, the amount of carbon stored by the urban forest is more in the middle of the forest (ranging between 80 to 120 t C ha^{-1}). The edge of forest area is covered mostly by small trees that were planted recently and shrubs or grasses which store comparatively less carbon (40-80 t C ha^{-1}). This is also shown in the pattern of vegetation density (i.e. NDVI- fig. 3b). Generally, large and healthy trees store more carbon than small trees [20]. In the middle of the urban forest *Dipterocarp* species such as *Dryobalanops Oblongifolia, Dryobalanops Aromatica, Manilloa Browneiodes* and *Shorea Spp* dominate. The *dipterocarp* forest usually contains a large variety of valueble tree species and most of the genera are *Hopea, Dryobalanops, Dipterocarpus, Shorea* and *Parashorea.* These species grow fast and therefore has high rate of carbon sequestration.
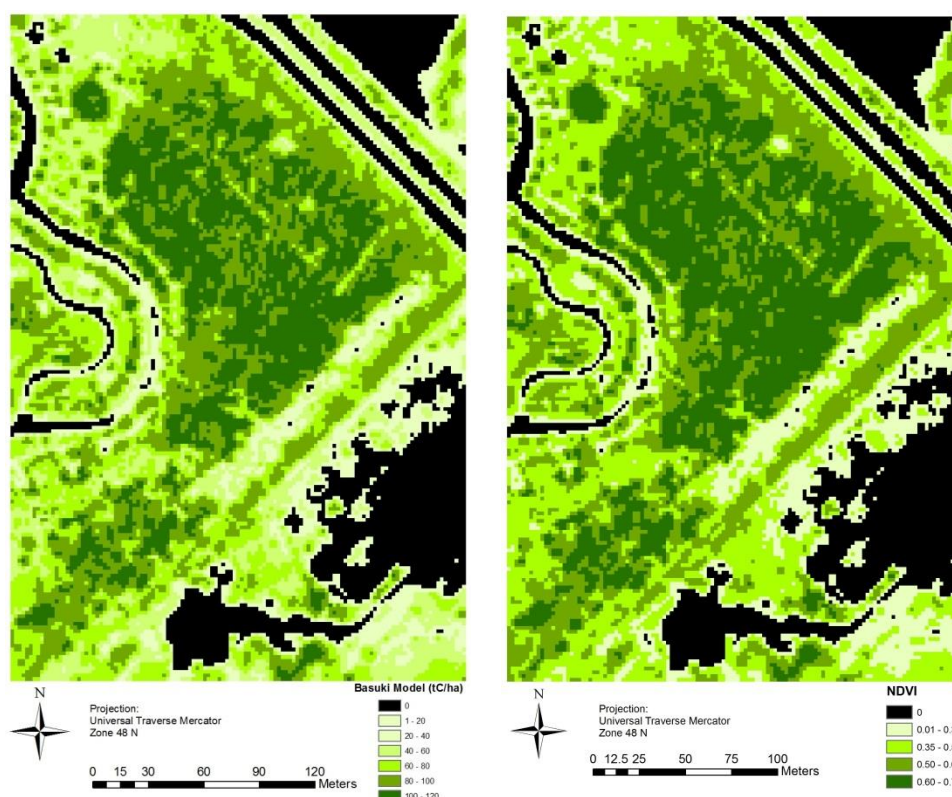

Figure 3. Map of carbon storage (left) (derived using allometric model of [1] and NDVI) and NDVI (right) of Johor Bahru Tengah Municipal Council Urban Forest (Mutiara Rini).

4. Conclusion
Quantification of carbon storage by urban forest is critical in assessing the role of the trees in reducing the concentration of CO_2 and moderating temperature in the urban area. Results of this study will provide insights into the carbon balance of urban ecosystem and the information can be used by urban planners and Iskandar Regional Development Authority to better manage vegetation in the urban environment to establish low carbon cities and subsequently to mitigate global warming and climate change.

References

[1]   Basuki T M, Van Laake P E, Skidmore A K and Husin Y A 2009 *Forest ecol manag* **257** 11
[2]   Houghton J T. Climate change 1995 : *The science of climate change. I P o C Change* (New York:Cambridge University Press) 572
[3]   Lashof D A and Ahuja D R 1990 *Nature* **344** 529-31
[4]   United Nation Environment Programme/GRID-Arendal 2007 National carbondioxide (co2) emissions per capita homepage http://maps.grida.no/go/graphic/national_carbon_dioxide_co2_ emissions_per_capita, Accessed 25/01/2012)
[5]   UTM-Low Carbon Research and Center *Low carbon society blueprint for iskandar malaysia 2025, summary of policymakers* (Malaysia:UTM-Low Carbon Research Center) 33
[6]   Ferrini F and Fini A 2011 *Jbes* **1** 1-20
[7]   Federal Department of Town and Country Planning Malaysia 2006 *National urbanization policy* (Kuala Lumpur Ministry of Housing and Local Government) 104-5.
[8]   Department of Statistics Malaysia 2009 Key statistics homepage http://www.statistics.gov.my/, Accessed: 25/1/ 2012.
[9]   Ho C S and Fong W K 2007 *IEEE Transaction* (Seoul: Korea) 314-23
[10]   Brown S, Schroeder P and Birdsey R 1997 *Forest ecol manag* **96** 37-47
[11]   Ketterings Q M, Coe R, van Noordwijk M, Ambagau Y and Palm C A 2001 *Forest ecol manag* **146** 199-209
[12]   Brown S, Gillepsie A J R and Lugo A E 1989 *Forest sci* **35** 881-902
[13]   Basuki T M, van Laake P E, Skidmore A K and Hussin Y A 2009 *Forest ecol manag* **257** 1684-94
[14]   Jain M, Garg V K and Kadirvelu K 2010 *J environ manage* **91** 949-57
[15]   Saatchi S, Marlier M, Chazdon R L, Clark D B and Russell A E 2011 *Remote sens environ* **115** 2836-49
[16]   Takeuchi K *Forest carbon stock in shifting cultivation of thailand and lao pdr. Apn science bulletin* (Asia-Pacific Network for Global Change Research (APN)) 142-4.
[17]   Hamdan O 2013 *J Trop Forest Scie (in press)*
[18]   Hikmat A 2005 *Media Konservasi* **10** 1-8.
[19]   Hertel D, Moser G, Culmsee H, Erasmi S, Horna V, Schuldt B and Leuschner C 2009 *Forest ecol manag* **258** 1904-12
[20]   Nowak D J 1993 *J environ manage* **37**