Multi-sensor satellite data for carbon storage mapping of green space in a fast growing development corridor in Malaysia

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ABSTRACT: Disturbances such as deforestation and land use change on natural vegetation have caused carbon dioxide (CO_2) emission to the atmosphere which contributes to global warming and climate change. Malaysia has started to take necessary steps to mitigate the potential impact of increased CO_2 and integrating the green infrastructure into urban planning is a way to go. Green space in urban environment provides a variety of benefits to the community by sequestrating carbon, absorbing urban emissions and producing oxygen. In this study we quantified the carbon storage capacity of various green spaces, namely forests, mangroves and urban parks by biometric measurements and remote sensing techniques at a rapidly developing economy region in Iskandar Malaysia (IM) in the southern Peninsular Malaysia that covers an area of 2,217 km^2. Satellite imageries such as RapidEye and Advanced Land Observing Satellite phased Array type L-band Synthetic Aperture Radar) were used for mapping the carbon content of different vegetation in IM. The spatial distribution of carbon storage shows that mangroves contribute the largest amount of carbon storage in IM with 0.437M t C and this is mainly due to their vast area (8382 ha). This is followed by tropical forest (0.185M t C). However, tropical forest has the highest carbon density with 161.7 tC ha^{-1} compared to mangroves (52.1 tC ha^{-1}). In general, trees in urban parks have lower carbon storage (ranging between 32.63 tC ha^{-1} to 48.81 tC ha^{-1}) compared to forests and mangrove. In total, these vegetation types in IM remove ~2.29 M tCO^2eq. Green space in IM was found to remove about 3% of carbon emitted to the air in IM. These results suggest that the government must make firm policies to increase more green cover in the urban areas and to preserve the existing green space for improving environmental quality for people and supporting biodiversity conservation.

1. INTRODUCTION

Rapid urban development without considering the environmental effects has led to various problems in cities such as increased air/surface temperature, air and noise pollutions, improper disposal of sewage etc. Urban areas emit more than three quarter of global CO_2 emissions as a consequent of land cover change (Seto et al., 2012). It is projected that more than a million km^2 of land will be altered to urban surface by 2030 which is expected to release large amount of CO2 stored in natural vegetation (Seto et al., 2012). Thus, natural vegetation must be conserved in cities to improve the environmental quality. Moreover, green infrastructure must be integrated into the planning and development of new cities. Green infrastructure includes the natural environmental components and green spaces that lie within and between cities (Community Forests Northwest for the Northwest Climate Change Partnership, 2011).

In the 15th Conference of the Parties (COP), Malaysia has committed voluntarily to reducing CO_2 emission to 40% in 2020 compared to its level in 2005 and under the 10th Malaysia plan (2011-2015), the government has taken various efforts to reduce CO_2 emission. Quantifying carbon storage by urban vegetation can provide some data needed for carbon accounting of the nation. Malaysia is currently developing into an urbanised nation, with an expected urban population of 78% by 2030 (United Nation Habitat, 2011). The country also aspires to become a "Garden Nation" by 2020 to achieve a balance in economic development and natural resources conservation. Hence urban green areas must be increased in line with the increase in population to enable urban residents live in an healthy environment. However, studies on urban green spaces and their effect of climate change are not so widespread in Malaysia (Kanniah et al., 2014; Misni et al., 2015). Worldwide several studies have been carried out to assess the potential of urban green space to store and sequester carbon (Nowak and Crane, 2002; Nowak et al., 2013; Churkina, 2010; Strohbach and Haase, 2012; Davies et al. 2011; Liu and Li, 2012; Wang et al. 2013; Velasco et al. 2013). All these studies found significant contribution of urban vegetation in absorbing CO_2 from the atmosphere.

In general, assessing the carbon storage capacity of vegetation can be done by measuring the dry weight of carbon stored in aboveground components like trunk, leaves, etc. and in the belowground (roots). Estimating the aboveground biomass by harvesting method is destructive and may not be practical for the areas where trees are not allowed to be destroyed especially in the cities and forest reserve. Alternatively, this leads to the use of allometric equation, which is a non-destructive method that often used in forestry to relate the measurable biophysical parameters like age, diameter at breast height, tree height, etc. to the biomass. The estimated biomass was then converted to carbon content. Estimating biomass at a regional scale can be done by remote sensing, which is an effective tool for carbon studies that can provide repetitive observations over a large area. Spectral information, such as radiance, reflectance and vegetation indices have been widely used for biomass studies (Lu, 2006). In most cases, models are developed by establishing empirical relationships between vegetation indices, and the biophysical characteristics such as leaf area index, canopy density, height of trunk, species, etc. (Lu, 2006). In this study we quantified the aboveground carbon storage capacity of various green spaces in a fast growing economic region in south of peninsular Malaysia using biometric measurements and remote sensing data.

2. STUDY AREA

Iskandar Malaysia (IM) is a new economic and infrastructure development region in the southern part of Peninsular Malaysia (Figure 1). IM was established in November 2006 and the project is administered by Iskandar Regional Development Authority (IRDA). The development region encompasses an area of 2,217 km^2 and urban developments within IM are carried out at five flagship zones, A, B, C, D and E covering five local government authorities (Figure 1).

Currently natural environment (forest, mangrove, rivers and water bodies) covers ~ 15% or 32,777.33 hectares (ha) of total IM land area. Some 15.35% of the total natural environment area has been developed as residential, commercial, industrial, institution/community facilities, infrastructure and utilities. The remaining 84.65% of the total area is occupied by agricultural land (35.3%), vacant land/shrubs (8.48%). These green spaces have an important function to Southern Johor Economic Region (SJER) as it not only acts as a watershed area, habitat and biodiversity protection, but it is also important for recreation, tourism, research and education. In this study we assessed the carbon storage of the natural forest (forest and mangroves) and four urban parks.

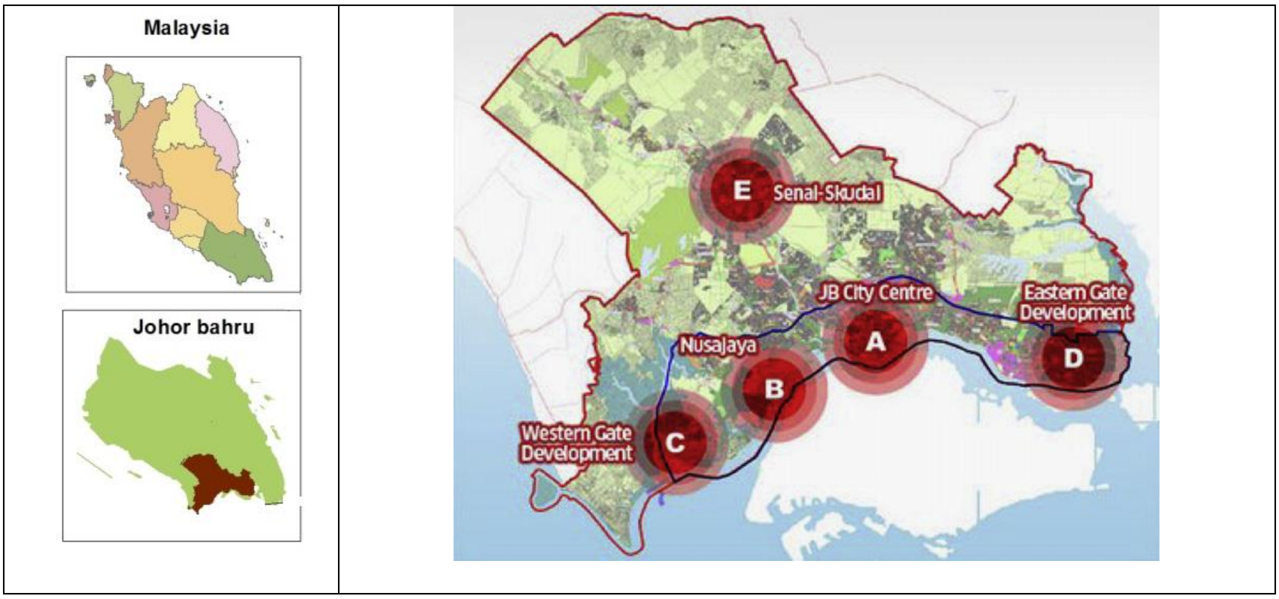

Figure 1: The location of Iskandar Malaysia within Peninsular Malaysia and the five flagship zones within Iskandar Malaysia development region (Source: Low Carbon Society, 2013)

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3. DATA AND METHODOLOGY

3.1 Biometric data

Biometric data including tree species and their diameter at breast height (DBH) at 1.3 m above the ground were collected at various locations in IM. The Global Positioning System (GPS) locations of the trees were also recorded. We collected these data at four urban parks in IM, Tanjung Piai National Park for mangroves. We used a random sampling technique to collect biometric data from 35 plots from the urban parks (each plot with 10 × 10 m or 0.01 ha size). Tanjung Piai National Park with 526 ha is located at the southernmost tip of the mainland Asia (Figure 2).

Biometric data from a total of 40 random sampling plots with 0.01 ha were collected. For forest, we obtained 36 random sampling plots from Forestry Research Institute Malaysia. DBH data was collected from dipterocarp forests in the states of Selangor, Pahang, Negeri Sembilan and Terengganu (the locations are not shown in figure 2).

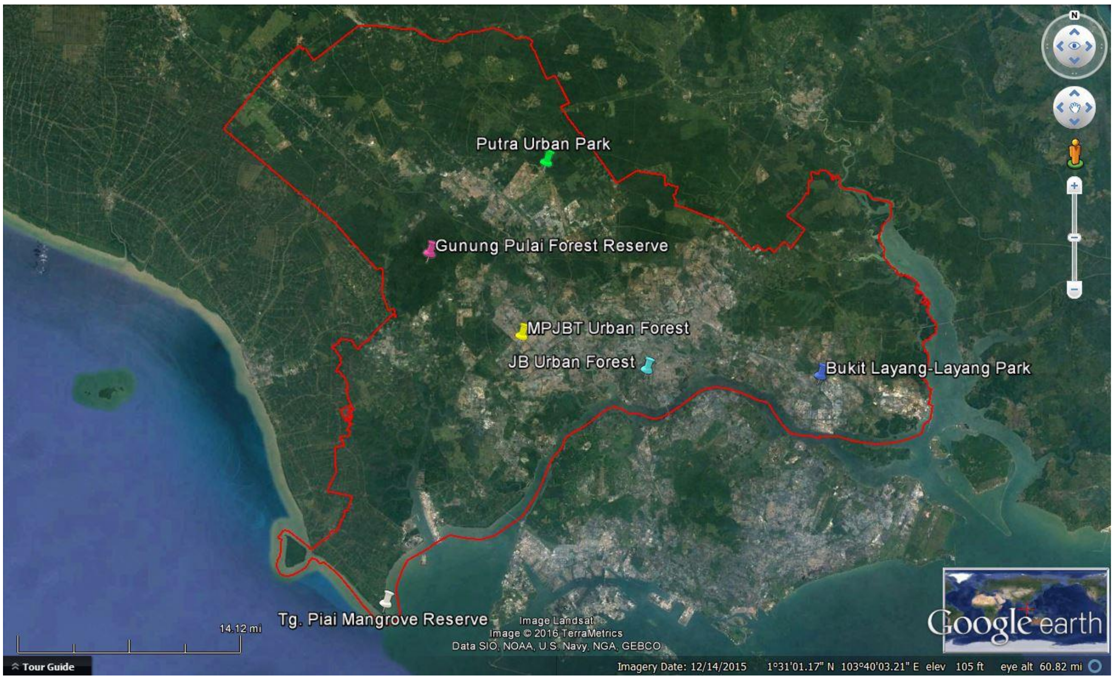


Figure 2: Locations of field data collection. The boundary of Iskandar Malaysia is outlined in red colour.

3.2 Satellite data

Rapideye and Advanced Land Observing Satellite phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) satellite imageries were used for mapping the carbon storage of different vegetation in Iskandar Malaysia (Table 1) based on their availability for the study sites, cloud cover and their different needs (for example high resolution data for urban parks). Details of the satellite data used in this study are described in Table 1.

Table 1: Specifications of the remote sensing data used in this study

Satellite Data	Data level	Spatial resolution	Bands	Date	Purpose
Rapid Eye	Level 3A	5.0 × 5.0 m	Blue: 440 – 510 nm Green: 520 – 590 nm Red: 630 – 685 nm Red Edge: 690 – 730 nm NIR: 760 – 850 nm	2 February to 26 October 2013	Urban parks carbon mapping
ALOS PALSAR	Level 1.5	12.5 × 12.5 m	HH, HV polarizations	1 October 2010	Forests and mangroves carbon mapping

A total of 12 scenes of multi-temporal RapidEye (Level 3A) data dated from 2 February to 26 October 2013 were mosaicked to cover the IM region. In addition, ALOS PALSAR was used for forest and mangrove carbon mapping in IM. The data was acquired on 1 October 2010. The digital numbers of ALOS PALSAR HH and HV polarizations were calibrated to backscatter coefficient or sigma nought σ° (dB) based on the following equation (Eq 1):

$$\sigma° \text{ (dB)} = 10 \times \text{Log}_{10}(DN^2) + CF \qquad \text{Eq (1)}$$

Where *DN* is digital number, and *CF* is the conversion factor, set at -83 (Shimada et al., 2009).

3.3 Estimating carbon storage of urban parks, oil palm, forest, and mangrove in Iskandar Malaysia

Urban Parks

The aboveground biomass (AGB) was calculated using allometric equation developed by Basuki et al. (2009) (Eq 2):

$$\ln(AGB) = (2.234)\ln DBH - 1.498 \quad \text{Eq (2)}$$

where *AGB* (kg tree^{-1}) is aboveground biomass, DBH (cm) is diameter at breast height

The AGB was then converted to carbon content by multiplying with a scale factor of 0.5 as the carbon content is approximately 50% of the AGB (Brown et al. 1997). An empirical relationship between the carbon content with Normalized Difference Vegetation Index (NDVI) calculated from RapidEye data was developed to estimate carbon storage of all the four urban forest.

Forest

ALOS PALSAR data was used to delineate forest pixels in Peninsular Malaysia by applying the threshold of 3.5 < (HH-HV) < 6.5, -15 < HV < -7, and 0.3 < (HH/HV) < 0.7 (Dong et al., 2014). We used the allometric equation of Kato et al., (1978) (Eq 3-6) for estimating AGB.

$$AGB = M_S + M_b + M_l \quad \text{Eq(3)}$$

Where,

AGB (kg tree^{-1}) is aboveground biomass
M_S (dry mass of stem, kg) = $0.0313 \times (DBH^2h)^{0.9733}$ Eq (4)
M_b (dry mass of branches, kg) = $0.136 \times (W_S)^{1.070}$ Eq (5)
$1/M_l$ (dry mass of leaves, kg) = $1/(0.124M_S^{0.794}) + 1/125$ Eq(6)
DBH = diameter at breast height (cm)
h= height of trees (m)

Forest biomass was converted to carbon content by multiplying by 0.5 as the carbon content is approximately 50% of the forest biomass (Brown, 1997). We correlated the estimated carbon content from the equation of Kato et al., (1978) with ALOS PALSAR radar backscattering coefficient values to establish an empirical equation to estimate AGB based on radar signals.

Mangrove

The AGB of mangrove within the sampling plots were calculated based on Komiyama et al. (2005) (Eq 7).

$$AGB = 0.251\rho(DBH)^{2.46} \quad \text{Eq (7)}$$

where *AGB* (kg tree^{-1}) is aboveground biomass, *DBH* is diameter at breast height (cm) and ρ refers to wood density and it is set as 0.506 g cm^{-3}.

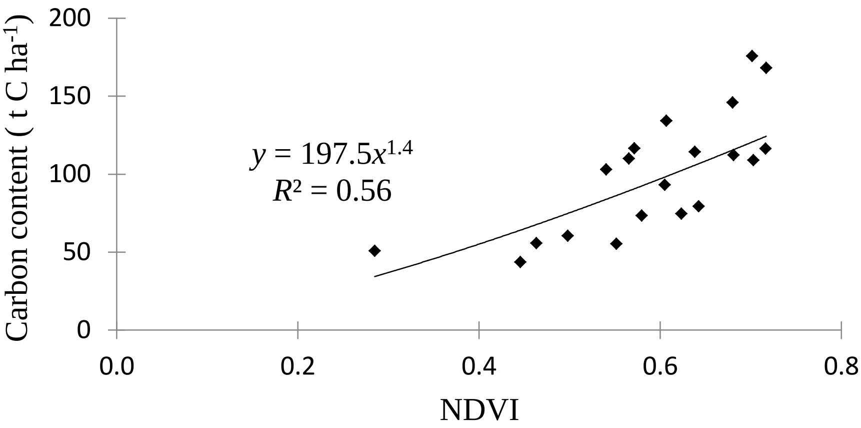
Mangrove biomass was converted to carbon content by multiplying with 0.5 as the carbon content is approximately 50% of the biomass (Brown, 1997). The carbon content at plots was correlated with radar backscattering coefficient values to establish an empirical equation to estimate AGB based on radar signals.

4. RESULTS AND ANALYSIS

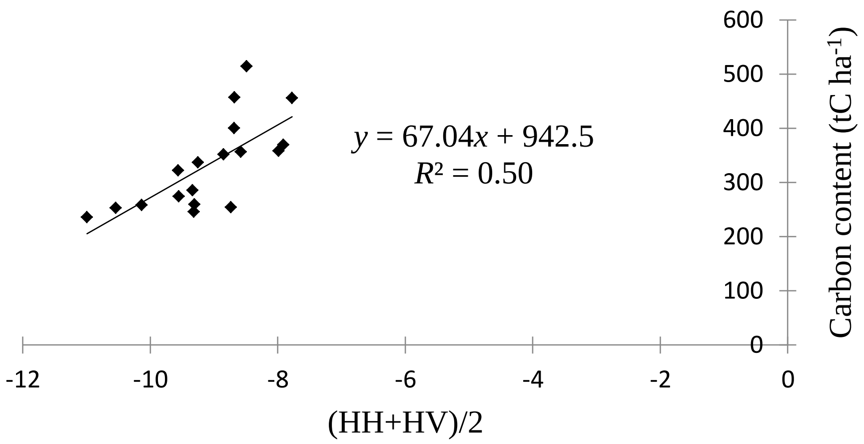
4.1 Empirical models for correlating the carbon content of urban parks, forest and mangrove with remotely sensed data

Based on 20 sample plots used in the regression analysis. The correlation between NDVI and carbon storage yielded a moderately good relationship with R^2=0.56 (Figure 3a). The Root Mean Square Error (RMSE) calculated based on the remaining 15 sampling plots is 24.48 $tCha^{-1}$. The equation formed from this regression ($y = 197.5x^{1.391}$) was then applied to the four urban parks to calculate their carbon content. After all the carbon content were computed, a reduction of 20% was considered based on the suggestion by Nowak et al. (2013), as urban forest carbon content was found 20% lower than that of natural forests.

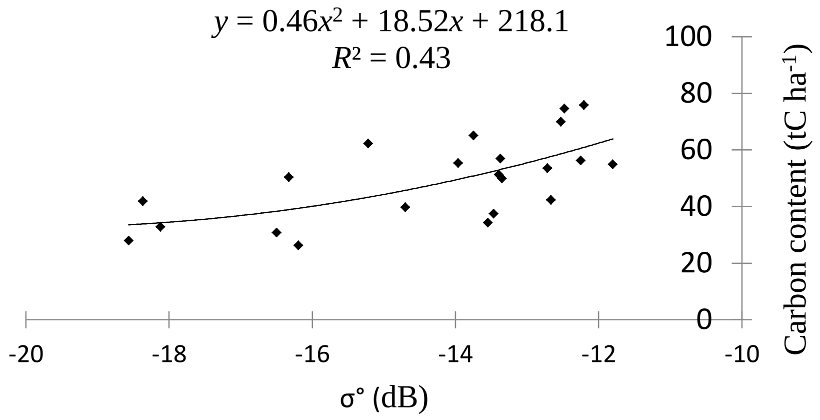
For forest, the correlation analysis between AGB and radar backscatter (HH+HV)/2 ($y = 942.54 + 67.05 \times (HH+HV)/2$) yielded the best R^2 (0.50) using biometric data collected at 18 plots (Figure 3b). We validated the regression model by another 50% of the remaining sampling plots (another 18 plots) and it was found to have R^2 (0.45) and RMSE (190.11 $tCha^{-1}$). Meanwhile, a regression analysis established between carbon storage and radar backscattering values with 22 out of the 40 sampling plots in the mangrove forest yielded a moderately good relationship ($y = 0.462x^2 + 18.52x + 218.1$, $R^2 = 0.43$) (Figure 3c). Another set of 18 sampling plots were used to validate the model output and it yielded RMSE 28.22 tC ha^{-1}.



(a)



(b)



(c)

Figure 3: Regression analysis and empirical models between carbon storage and remotely sensed data for (a) urban parks, (b) forest and (c) mangrove

4.2 Estimated carbon and CO_2eq for various vegetation in Iskandar Malaysia

Results of total area (ha), mean total carbon per hectare (tC ha^{-1}) and CO_2 equivalent per hectare (tCO_2eq ha^{-1}) estimated in this study are shown in Table 3. Of these vegetation, mangroves contribute the largest amount of carbon storage in IM with 0.437M t C and this is mainly due to their vast area (8382 ha). This is followed by tropical forest (0.185M t C). However, tropical forest has the highest carbon density with 161.7 tC ha^{-1} compared to mangroves (52.1 tC ha^{-1}). In general, trees in urban parks have lower carbon storage (ranging between 32.63 tC ha^{-1} to 48.81 tC ha^{-1}) compared to forests and mangrove. In total, these vegetation types in IM remove ~2.29 M tCO^2eq. We compared results obtained in this study with the results produced by Gomi (Low Carbon Society, 2013) and found that they both match with percentage difference ranging between 2.4 and -43% in which the largest disparity was found in urban forest.

Table 3: Estimated carbon and CO_2eq for various vegetation in Iskandar Malaysia

Land use	Total Area (ha)	Mean tC ha^{-1}	tCO^2eq ha^{-1} (this study)
Forest	1,144	161.7	0.68M
Mangrove	8,382	52.1	1.60M
MPJBT Urban Forest	26.16	34.03	3264.76
Bukit Layang-Layang Park	44.69	32.63	5346.46
JB Urban Forest	15.17	43.06	653.23
Putra Urban Forest	17.47	48.81	3126.65

We compared the carbon values in Table 3 with other previous aboveground carbon storage studies conducted in Malaysia by Hikmat (2005). Overall, the carbon value of different forest (lowland dipterocarp and hill dipterocarp) in Peninsular Malaysia ranges between 100.3 – 287 t ha^{-1} (mean 204.07 t ha^{-1}). Bukit Rengit in Krau has recorded the highest carbon (287 t ha^{-1}). The mean carbon values of mangroves and urban forest in this study are generally lower than the forests. The result shows that lowland dipterocarp forest is an important resource in storing carbon for mitigating climate change. The carbon value of mangrove (52.1 t ha^{-1}) is at least about 50% lower than dipterocarp forest. However, conservation of mangrove including Ramsar sites is important because mangrove is not only an important source of carbon sequestration but also habitats to many biodiversity. The mean carbon of urban forests in Iskandar Malaysia (Putra Urban Forest, JB Urban Forest, MPJBT Urban Forest and Bukit Layang-Layang Park) is 39.63 t ha^{-1}. Urban forest is very important in sequestering CO_2 in the long run and it can reduce the urban heat. A modeling study by Gomi (Low Carbon Society, 2013) shows that green space (forest, mangrove, oil palm and urban parks) in IM was found to remove about 3% of total carbon emitted to the air.

5.0 CONCLUSION

In this study the preliminary results of carbon storage calculated using satellite data for forest, mangrove and urban forest are presented. The results demonstrate that these vegetation types in IM are potential to remove ~2.29 M tCO^2eq with mangroves contribute the largest amount of CO2eq. Therefore it is vital to protect the mangrove resources from further destruction in IM (Kanniah et al., 2015). Since urban parks are also an important source of carbon storage, their areas should be further increased (Rasli et al., 2016). These results suggest that the government must make firm policies to increase more green cover in the urban areas and to preserve the existing green space for improving environmental quality for people and supporting biodiversity conservation.

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References

Basuki, T. M., Van Laake, P. E., Skidmore, A. K., & Hussin, Y. A. 2009. Allometric Equations for Estimating the Above-Ground Biomass in Tropical Lowland Dipterocarp Forests. Forest Ecology and Management, 257(8), pp.1684-1694.

Brown, S., Schroeder, P., and Birdsey, R. 1997. Aboveground Biomass Distribution of US Eastern Hardwood Forests and the Use Of Large Trees As An Indicator Of Forest Development. Forest Ecology and Management, 96(1), pp.37-47

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer, Rome, FAO.

Churkina, G., Brown, D. G., and Keoleian, G. 2010. Carbon stored in human settlements: the conterminous United States. Global Change Biology, 16(1), 135-143.

Community Forests Northwest for the Northwest Climate Change Partnership. 2011. Green Infrastructure to Combat Climate Change A Framework for Action in Cheshire, Cumbria, Greater Manchester, Lancashire, and Merseyside. Retrieved March 8, 2012, from http://www.greeninfrastructurenw.co.uk/climatech

Davies, Z. G., Edmondson, J. L., Heinemeyer, A., Leake, J. R., and Gaston, K. J. 2011. Mapping an Urban Ecosystem Service: Quantifying Above-Ground Carbon Storage at a City-Wide Scale. Journal of Applied Ecology. 48(5), pp.1125-1134.

Dong, J. W., Xiao, X. M., Sheldon, S., Biradar, C., Zhang, G. L., Duong, N. D., Hazarika, M., Wikantika, K.,

Kanniah K D, Muhamad N and Kang C S. 2014. Remote sensing assessment of carbon storage by urban forest, International Symposium on Digital Earth, 26-29 August 2013, Kuching, Sarawak, Malaysia. IOP Conf. Series: Earth and Environmental Science 18,p. 012151.

Kanniah, K. D., Sheikhi, A., Cracknell, A. P., Goh, H. C., Tan, K. P., Ho, C. S., and Rasli, F. N. 2015. Satellite Images for Monitoring Mangrove Cover Changes in a Fast Growing Economic Region in Southern Peninsular Malaysia. Remote Sensing, 7(11), pp. 14360-14385.

Kato R, Tadaki Y, and Ogawa H .1978. Plant Biomass And Growth Increment Studies in Pasoh Forest Reserve. Malay Nat J 30, pp.211–224

Komiyama, A., Poungparn, S., and Kato, S. 2005. Common Allometric Equations for Estimating the Tree Weight of Mangroves. Journal of Tropical Ecology, 21(04), pp.471-477

Liu, C., and Li, X. 2012. Carbon storage and sequestration by urban forests in Shenyang, China. Urban Forestry & Urban Greening, 11(2), 121-128.

Low Carbon Society, 2013, Development of Low Carbon Society Scenarios for Asian Region: Full Report: Low Carbon Society Blueprint for Iskandar Malaysia 2025 (Nov 2013) pp.253.

Lu D. 2006. The potential and challenge of remote sensing - based biomass estimation. International journal of remote sensing, 27(7), 1297-1328.

Misni, A., Jamaluddin, S., & Kamaruddin, S. M.2015. Green Criteria Used in Estimating the Carbon Sequestered in Pasir Gudang, Johor Malaysia. Proceedings of the 2nd International Conference on Research Methodology for Built Environment and Engineering Shah Alam,Malaysia,

Nowak, D.J., Greenfield, E.J., Hoehn, R.E., and Lapoint, E. 2013. Carbon Storage and Sequestration by Trees in Urban and Community Areas of the United States. Environmental Pollution, 178, pp. 229-236.

Nowak, D. J., and Crane, D. E. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental pollution, 116(3), 381-389.
Rasli, F. N., Kanniah, K.D., Muthuveerappan, C and Ho C. S. 2016.An Integrated Approach of Analytical Hierarchy Process and GIS for Site Selection of Urban Parks in Iskandar Malaysia,International Journal of Geoinformatics, 12(2), pp. 67-77
Shimada, M., Isoguchi, O., Tadono, T. and Isono, K. 2009. PALSAR Radiometric and Geometric Calibration. IEEE Transactions on Geoscience and Remote Sensing 47(12), pp. 3915-3932.
Seto, K.C., Güneralp, B and Hutyra, L.R. 2012. Global Forecasts of Urban Expansion to 2030 and Direct Impacts on Biodiversity and Carbon Pools. PNAS 109, pp. 16083–16088.
United Nations Habitat. 2011. Cities and Climate Change: Global Report on Human Settlements 2011. UN-HABITAT pp.250
Velasco, E., Roth, M., Tan, S. H., Quak, M., Nabarro, S. D. A., and Norford, L. 2013. The Role of Vegetation in the CO2 Flux from A Tropical Urban Neighbourhood. Atmos. Chem. Phys, 13, pp.10185-10202.
Wang, Z., Cui, X., Yin, S., Shen, G., Han, Y., and Liu, C. (2013). Characteristics of Carbon Storage in Shanghai's Urban Forest. Chinese Science Bulletin, 58(10), pp.1130-1138.