ESTIMATION OF CARBON SEQUESTRATION USING SATELITE IMAGES OF IKONOS AND FORMOSAT2 IN TAIWAN

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ABSTRACT：As the warming phenomenon was getting attention globally in the past years, many countries placed importance on the increasing amount of carbon dioxide, and reached a consensus, signing the Kyoto Protocol in 1997, in Kyoto, Japan, with an effort to reduce the emission of carbon. The treaty allows that the carbon dioxide absorption and emission together with afforestation and deforestation, can be incorporated into net value of reduction, and this refers to the amount of reduction for the country. Therefore, forests play an important role in terms of absorbing and storing carbon dioxide; this has enormously contributed to attenuate the greenhouse effect. Forefathers' studies have shown that the combination of forest inventories and remote sensing has become the main method of assessment for carbon sink, carbon stocks, and carbon sequestration. This study aims at the comparison of carbon sequestration with the satellite images of IKONOS, FORMOSAT2, and forest investigation data. Furthermore, the vegetation indices of the Normalized Difference Vegetation Index (NDVI), Transformed NDVI (TNDVI), Ratio Vegetation Index (RVI), and Difference Vegetation Index (DVI), have been extracted from the two satellite images, and incorporated with the ancillary data for the analysis of Multiple Regression Analysis (MRA), Back Propagation Neural Networks (BPNN), Classification-Base Multiple Regression Analysis (CBMRA) and Classification-Base Back Propagation Neural Networks (CBBPNN). The forest ground survey data is provided by the Forestry Bureau of Taiwan. The results show that the estimation of carbon sequestration with satellite images is workable and effective, and IKONOS is better than FORMOSAT2.

1. Introduction

Global warming has caused every country to pay much attention to the violent addition of carbon dioxide for these years, and the United Nations signed an agreement on Climate Change to reduce the emission quantity in Kyoto, Japan, in 1997, called Kyoto Protocol. In this protocol, the net productivity of carbon stock and CO_2 emission by afforestation and deforestation are clearly merged into the calculation of emission reduction quantity, and it can be as the CO_2 reduction quantity in its country. Therefore, forest becomes very important owing to the main role of CO_2 stock and absorption, it retards greenhouse effect and has an important contribution. Bonn Covenant established firmly the standard of Kyoto Protocol in July 2001, and then carbon transaction has a common consensus globally. The right of carbon emission may be as business transactions, afforestation to store CO_2 can bring into countries' CO_2 reduction quantity it is called carbon sinks.

Forest inventories and remote sensing have become the main estimation method of carbon sink and carbon stocks and sequestration (Maselli et al., 2006; Muukkonen et al., 2005), the technique of remote sensing has many

advantages, such as great area, immediacy, high resolution, multi-frequency, extensive manipulation, and unceasing progress of new technology; so it gets more attention. Intergovernmental Panel on Climate Change Good Practice Guidance (IPCC GPG) (2003) had pointed out that the technique of remote sensing specially suits for estimation of the national land use, land use change, and forestry carbon pool (LULUCF), especially for the biomass estimation above the ground. So IPCC (Penman et al., 2004) brings up a proposal to integrate source of remote sensing and ecological models, which will estimate the need of convention of climatic change.

In this paper, ground investigation data combined with remote sensing image are applied to estimate the forest carbon storage quantity. We estimate the carbon sink difference of IKONOS-2 and FOMOSAT-2. The forest materials are supplied by forestry bureau, we check 55 permanent type area, estimate their volume of wood is 868.379 cubic meters, and calculate the index values of NDVI, TNDVI, RVI, VI, then compare with ground investigation data by methods of MRA, BPN, CBMRA, and CBBPN.

2. Methodology
2.1 Study Area
Nanzhuang working circle in Hsinchu forest region is about 15 km x 10 km, as in fig.1. The main forest area is about 9,132 ha, the higher part is in the northeast, the length of main river basin is 54 kilometers, and the drainage area is 446 km^2. The investigation data of forestry bureau shows the study area has 5 forest types as in table 1, there are natural broadleaf mixed forest, artificial coniferous forest, artificial needle mixed forest, artificial broad-leaf mixed forest, and artificial needle broad-leaf mixed forest.
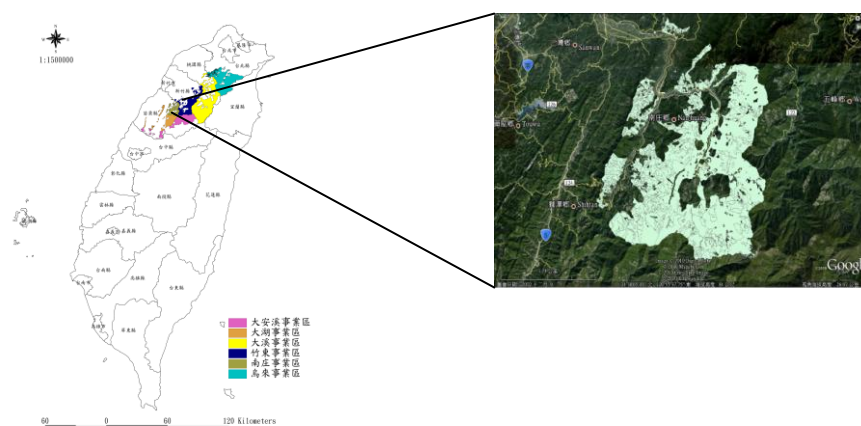

Fig. 1 Position of study area

Table 1 the forest pattern, area, and altitude in Nanzhuang working circle in Hsinchu forest region

Forest pattern	Area (ha)	Altitude (m)
Natural broadleaf mixed forest	5,007.19	$< 2,000$
Artificial coniferous forest	1,674.13	$825 - 2,300$
Artificial needle-leaf mixed forest	924.94	$> 1,000$
Artificial needle broad-leaf mixed forest	671.13	$1,400$ or < 600
Artificial broad-leaf mixed forest	854.57	$1,200$ or < 400
Total	9,131.96	

2.2 Study Method
Working procedure is as in fig. 2, it has two parts: one, estimation of forest timber volume in ground investigation data, the permanent test sites were established and provided by forestry bureau in 2003. The shape are all rectangle, their area has three types: 40 m×25 m(0.1 ha), 28.4 m×17.6 m(0.05 ha), 17.9 m×11.2 m(0.02 ha). We use random sampling method for those test sites, the investigation items include survey and record tree type, forest tree diameter at breast height (DBH), tree's height (H), number, crown class, and the calculation model of wood's volume, and we finished 55 test sites. The calculation of forest timber volume quantity is according to those formulas supplied by Forestry Bureau, as in table 2, those main tree types in Taiwan are Chamaecyparis formosensis, Cryptomeria, China fir, Taiwan cedar, broadleaf tree, Camphor tree cedar, and Shrub Oak. Two, in the image processing technique of remote sensing, there are geometric correction, calculation and analysis of DVI, RVI, TNDVI, and NDVI vegetation index.

We use geo-coded 2 meters FOMOSAT-2 image as reference for geometric correction, the image software tool is ERDAS IMAGINE and PCI, the RMSE is less than one meter. IKONOS-2 image has rational polynomial coefficient (RPC) file, it has the flying height, posture, and position parameters, and a set transformation coefficient

by rational function, which is convenient for geometric correction. (Wang, 2009) The vegetation index used in this paper are NDVI（Normalized Difference Vegetation Index）（Rouse et al., 1973）, TNDVI（Transformed Normalized Difference Vegetation Index）（Deering et al., 1975）, DVI（Difference Vegetation Index）（Tucker, 1979）, and RVI(Ratio Vegetation Index)（Jordan, 1969）, the mathematics formulas are as following:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$ ....(1)

$$TNDVI = \sqrt{NDVI + 0.5}$$...②

$$DVI = NIR - RED$$...(3)

$$RVI = \frac{NIR}{RED}$$...(4)

After that, we analyze volume of wood and vegetation index by simple linear regression, multiple regression analysis, non-linear reciprocal, logarithm, index, polynomial, and power, select the optimization regression analysis model, then compare with back-propagation networks (BPN), classification-base multiple regression analysis (CBMRA), and classification-base back-propagation network (CBBPN). After that, we select multiple regression analysis (MRA) to estimate the volume of wood and carbon sinks of whole study area.

The equation of multiple regression analysis (MRA) is as following:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + ... + \beta_k X_{ki} + \varepsilon_i \quad i=1,.....,n \quad ....(5)$$

Y_i = the ith really observed value of dependent variable
X_{ki} = the ith observed value of the kth independent variable
β_0 = intercept, constant item, a parameter in regression model
$\beta_1,...,\beta_k$ = regression parameters in regression model
ε_i = random error of the ith observed value
n = observed numbers
k = independent integer number, $k > 0$

A back-propagation network (BPN) includes input layer, output layer, and many hidden layers, as in fig. 3, it can process many complicated cases by the operation of neuron nodes, then output the result from output layer (Pao, 2008), the mathematic representation is as following:
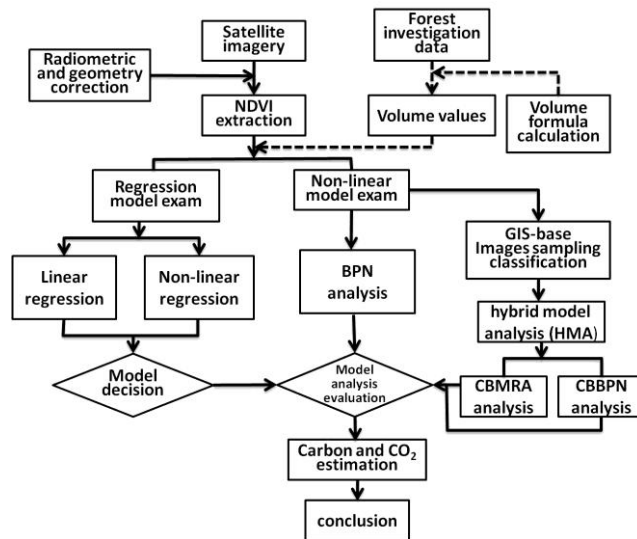

Fig. 2 the flowchart of this study

Table 2 standing wood volume formula in this study

Tree type	standing wood volume formula
Chamaecyparis formosensis	$V = 0.0000944 \times DBH^{1.9947405} \times H^{0.065696}$
Cryptomeria	$V = 5.99663 \times 10^{-5} \times DBH^{1.8753322} \times H^{0.974034}$
China fir	$V = 0.0023 + 2 \times 10\text{-}5 \times DBH^3 - 0.002 \times H + 0.0004 \times H^2$
Taiwan cedar	$V = -0.5772 + 0.002115 \times DBH \times H - 0.000305 \times H^2$
broadleaf tree	$V = 4.64 \times 10^{-5} \times DBH^{1.5353} \times H^{1.50657}$
Camphor tree cedar	$V = 8.628 \times 10^{-5} \times DBH^{1.8742} \times H^{0.8671}$

$$net_k = \sum_{i=1}^{n} W_{ki} X_i + b_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$Y_k = F(net_k) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Y_k : output signal of kth artificial neuron cell
$F(net_k)$: activation function of artificial neuron cell
net_k: sum of weighting input value and bias
W_{ki} : weighting value of ith dimension kth nerve cell
X_i: input data
n: input node numbers
b_k: bias value

The basic theorem of BPN is the idea of gradient steepest decent method (GSDM), minimize the error function, simultaneously, proceed feed-forward back-error propagation (FBP) algorithm operation by multi-layer perceptron (MLP), (Lek & Gue´gan, 1999) and adopt delta rule, it belongs to supervised learning method (SLM). When it executes, the input layer accepts independent variables, then proceeds operation of nonlinear variables relation, and creates network's weighting and linking relationship model, generally operation uses activation function of sigmoid function rule. The mathematic form of sigmoid is like this (Lek & Gue´gan, 1999, Mohanty & Majudar, 1996):

$$Sc(x) = \frac{1}{1 + e^{-cx}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$
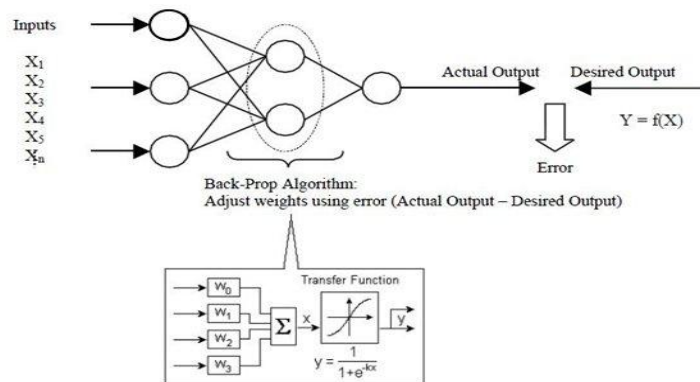

Fig. 3 framework of BPN's operation rule

Besides, the ground truth data is created by GIS, this research adopts GIS combined with satellite image to get the space information of test sites, it is called GIS-base image sampling classification (GBISC), then we use the idea of hybrid model analysis (HMA), (Yim & Mitchell, 2005) to combined with MRA and BPN analysis models, we call them as CBMRA and CBBPN, to proceed follow-up estimation analysis.

2.3 Estimation model of CO_2 sinks

The estimation method for CO_2 sinks per hectare usually adoptsthe principle of IPCC, first, mean specific weight of wood's volume is transformed into organism quantity of wood's volume, then it is transformed again into coefficient of C content to estimate C sinks. The estimation is in formula 9.

$$C_{plant} = W_E \times C_{con} \times (CO_2/C)$$

$$W_E = V_{Stem/ha} \times V_{whole/stem} \times W_0/V_g \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

C_{plant}: CO_2 sinks per hectare of wood's volume

W_E : organism quantity

$V_{stem/ha}$: Wood's volume per hectare

$V_{whole/stem}$: Transformation coefficient of wood's volume between whole trunk and main trunk

W_0/V_g : Transformation coefficient of weight and wood's volume

C_{con}: Transformation coefficient of C content

CO_2/C: Transformation coefficient of CO_2 and C

The whole trunk of a tree includes that trunk, branches, roots, and leaves, so the transformation coefficient between whole trunk and main trunk is about $1.3 - 2.0$, the mean value is 1.65. The transformation coefficient between weight and wood's volume is base on tree kind, pure artificial broad-leaf forest is 0.49, Natural broadleaf mixed

forest 0.49, pure artificial coniferous forest (China fir afforestation, Taiwan cedar afforestation, cryptomeria afforestation) 0.44, Artificial needle-leaf mixed forest 0.44, Artificial needle broad-leaf mixed forest 0.46, and artificial broadleaf mixed forest 0.49. In other coefficients, C content generally adopts 0.5, CO_2 and C use the molecular weight relation, the coefficient is equal to 3.67 (44/12).

3. Result and Discuss

We check 55 permanent test sites which was established by Forestry Bureau in 2003, related calculation of volume of wood is based on different tree kind, so the total volume of wood for natural broadleaf mixed forest is 384.77 m^3, other forest kinds are listed in table 3, and the total volume of all test sites is 868.37 m^3.

Table 3 wood's volume in test sites

Tree kind	Identification num (55 sites).	Wood's volume（m^3）
Natural broadleaf mixed forest	2,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,36,53	384.77
Pure artificial coniferous forest	24,30,37,38,39,40,41,42,43	170.61
Artificial needle-leaf mixed forest	20,21,22,23,25,31,32,33,34,35,46, 47,48,49,50	152.21
Artificial needle broad-leaf mixed forest	1,3,26,27,28,44,54,55,57,58	130.02
Artificial broadleaf mixed forest	19,56,59	30.76
Total	55 sites	868.37

We utilize individually FOMOSAT-2 and IKONOS-2 to calculate volume of wood by the four methods (MRA, RPN, CBMRA, and CBBPN), the RMSE of estimated results for MRA and RPN are not big either FOMOSAT-2 or IKONOS-2 image, but the RMSE of CBMRA and CBBPN methods drops from 3.52 to 2.9 and 3.51 to 2.79 for FOMOSAT-2 image, RMSE has the same effect for IKONOS-2 image, this means that CBMRA and CBBPN methods have better estimation, i.e., appropriate and accurate data classification can promote estimation precision.

The resolution of satellite image also can affect the estimation result, RMSE of FOMOSAT-2 is between 2.79 and 3.52, but IKONOS-2 is between 0.31 and 0.47. Estimation precision of IKONOS-2 image has obviously promotion. The whole data of study area is processed to get the total volume of wood, and then put it to formula 9 to get C and CO2 estimation quantities of whole study area, which is listed in table 4. The results show that the estimation difference quantity by BPN or CBBPN is less then MRA and CBMRA, so BPN or CBBPN model is better.

Table 4 Estimation of C and CO_2 for whole study area

Satellite	Method	Area （ha）	Wood's volume （m^3）	CO_2 sinks （ton）	CO_2 sinks （ton/ha）	C sinks （ton/ha）
FOMOSAT-2	MRA	9,131.9	5,454,475	4,736,711	518.70	141.33
	CBMRA	9,131.9	5,991,045	5,100,916	558.58	152.20
	BPN	9,131.9	4,198,580	3,544,021	388.09	105.75
	CBBPN	9,131.9	4,611,386	3,926,240	429.95	117.15
IKONOS-2	MRA	8,684.6	4,656,364.76	4,040,450.95	465.24	126.77
	CBMRA	8,684.6	4,641,237.56	3,982,911.68	458.62	124.96
	BPN	8,684.6	3,935,931.56	3,322,319.83	382.55	104.24
	CBBPN	8,684.6	3,923,123.68	3,366,657.35	387.66	105.63

4. Conclusion

This study shows that forest investigation conjugated with remote sensing technique can catch fine monitoring effect in forest organism quantity. Satellite image with high space resolution is excellent in estimation of volume of wood, i.e., RMSE of IKONOS-2 is less than FOMOSAT-2's in this study. The area of Taiwan is only 36 thousand km^2, forest covers 58.5%. The area supplied by forestry operation is only 400 thousand hectares; government ought

to carefully plan policy in forest operation, and has great contribution in carbon sinks. The optimum estimation model is by CBBPN method with IKONOS-2 image. If this study can be extended geographically, more economic and timely estimation of the biomass resource and improved environmental management could be possible.

Reference

Wang, R.-Y., Wang, Y.-C., Chen, C.-T., Chu, T.-H., (2009) Implementing RPC Block Adjustment Method on the Geometric Accuracy Rectification of High Resolution Satellite Imagery without Ground Control Point, Quarterly Jounal of Chinese Forestry, 42(3):363-379。

Deering, D. W., Rouse, J. W., Haas, R. H., and Schell, J. A. (1975) Measuring Forage Production of Grazing Units from Landsat MSS Data, Proc., 10th International Symposium on Remote Sensing of Environment ERIM2, pp.1169-1178.

IPCC, 2003, Good practice guidance for land use, land-use change and forestry. IPCC/IGES. Hayama. Japan.

Jordan, C. F. (1969) Derivation of leaf area index from quality measurements of light on the forest floor, Ecology, 50(2):663-666.

Lek, S., and Gue´gan, J. F. (1999) Artificial neural networks as a tool in ecological modelling, an introduction, Ecological Modelling, 120(2-3):65-73.

Maselli, F., Barbati, A., Chiesi, M., Chirici, G., and Corona, P. (2006) Use of remotely sensed and ancillary data for estimating forest gross primary productivity in Italy, Remote Sensing of Environment, 100(4):563-575.

Mohanty, K. K., and Majumdar, T. J. (1996) An artificial neural network (ANN) based software package for classification of remotely sensed data, Computers & Geosciences, 22(1):81-87.

Muukkonen, P., and Heiskanen, J. (2005) Estimating biomass for boreal forests using ASTER satellite data combined with standwise forest inventory data, Remote Sensing of Environment, 99(4):434-447.

Pao, H. T. (2008) A comparison of neural network and multiple regression analysis in modeling capital structure, Expert Systems with Applications, 35(3):720-727.

Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., and Wagner, F. (2004) Good practice guidance for land use, land-use change and forestry, The Intergovernmental Panel on Climate Change（IPCC）, Hayama, Japan7 IGES.

Rouse, J. W., Haas, R. H., Schell, J. A., and Deering, D. W. (1973) Monitoring vegetation systems in the great plains with ERTS, Third ERTS Symposium, NASA SP-351, 1:309-317.

Tucker, C. J. (1979) Red and photographic infrared linear combinations for monitoring vegetation, Remote Sensing of Environment, 8(3):127-150.

Yim, J., and Mitchell, H. (2005) Comparison of country risk models: hybrid neural networks, logit models, discriminant analysis and cluster techniques, Expert Systems with Applications, 28(1):137-148.