Study on Carbon Sequestration of Taipei's Green Land using Remote Sensing and GIS

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ABSTRACT: The application of remote sensing on carbon sequestration has been growing concerns recently. This study focuses on carbon sequestration of Taipei's green land using remote sensing and GIS. The research processes include (1) calculating vegetation index from SPOT images in 1993 and 2007; (2) extracting Taipei's green land (i.e., forestland and grassland) according to the land-cover map generated by SPOT image classification and the land-use map obtained from National Land Surveying and Mapping Center; (3) estimating carbon sequestration of green land based on the model of vegetation index and Net Primary Productivity (NPP); (4) analyzing carbon sequestration change of Taipei's green land from 1993 to 2007; and finally (5) making a comparison of green land's carbon sequestration estimated by land-cover and land-use maps.

The result is as follows. The area of Taipei's green land decreases from 1993 to 2007 due to urban sprawl, and this leads to some decrease in the NPP and carbon sequestration as well. However, among green land, the NPP and carbon sequestration of forestland are higher than grassland. As for the comparison of green land's carbon sequestration, the amount calculated by land-cover map is higher than that by land use map, which points out that the NPP and carbon sequestration estimated by remote sensing or GIS technologies may be different. But, obviously remote sensing and GIS technologies are a timely and feasible approach for green land to estimate carbon sequestration and monitor its change. The result obtained from this study can be extended to Taipei's green land planning in future.

1. INTRODUCTION

The issue of carbon sequestration has been concerned in Taiwan recently. Vegetation plays an important role in the carbon sequestration of carbon and the forests not only have the potential of carbon sequestration but also have reducing greenhouse gas emissions. In estimation the carbon sequestration ways, there are several methods: such as the sampling of ground biomass, flux tower, model estimation, and remote sensing technique (Aerial Survey Office of Forest Bureau, 2009). Among these methods, remote sensing technique provides immediately, effectively, and large-scale way. And in remote sensing technique process, it should use land-use maps and land-cover maps to estimate different land types' carbon sequestration. Because of the image classification involving with classification accuracy as well as the follow-up carbon sequestration estimating issues, it must be discretion. This study estimates green land's carbon sequestration and compares the distinction of land-cover with land-use maps.

2. MATERIALS AND METHODS

2.1 Study Area and Materials

2.1.1 Study Area: Taipei is located in the north part of Taiwan. It encompasses an area of 271.7997 sq. km and has a population of 2.62 million. The area is divided into twelve districts (Fig. 1). Taipei is strongly affected by the geography. The climate shows evident spatial variation.

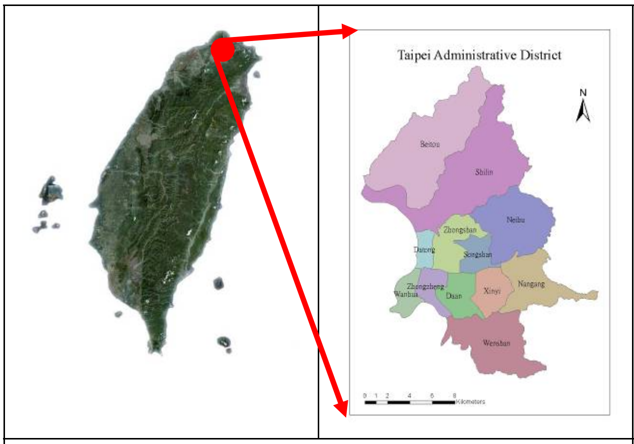


Fig.1 Study area

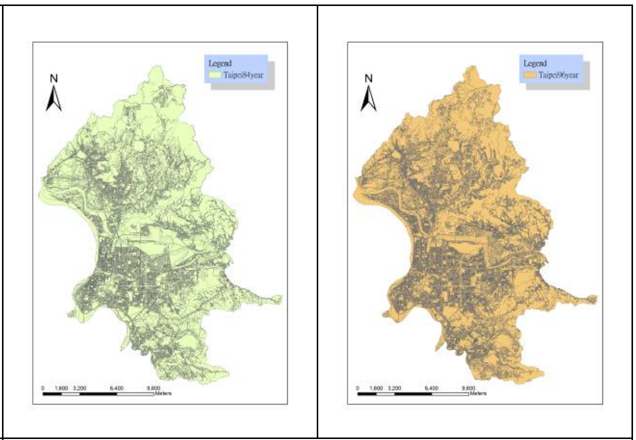


Fig.2. Land-use maps in 1993 (left) and 2007 (right)

2.1.2 Materials: This study uses National Land Surveying and Mapping of 1993 and 2007 (Fig2) production's land-use map, and according SPOT-2 image on December 25, 1993 and SPOT-4 image on December 17, 2007, to produce vegetation index map. And then to use satellite image classification produces generate land-cover map.

2.2 Methods

This study includes National Land Surveying and Mapping division of the IPCC land summarized, the type of satellite image classification and retrieval of images of NDVI, the application of radiation use efficiency model estimates Taipei carbon sequestration, carbon sequestration analysis of two variants of the last relatively land-use and land-cover to estimate carbon sequestration under the difference.

2.2.1 SPOT Image Classification

This study use Hybrid Classification method for SPOT image classification. And reference Intergovernmental Panel on Climate Change was published in 2006, "Good Practice Guidance for Land Use, Land-Use Change and Forestry, GPG-LULUCF" classification of land types. Including Forest land, Cultivated land, Grass land, Water land, Settlement land, Other land of six types, and increase the shadow types. The overall land cover map classification accuracy is 85.00% in 1993 and 90.25% in 2007, respectively (Fig.3).

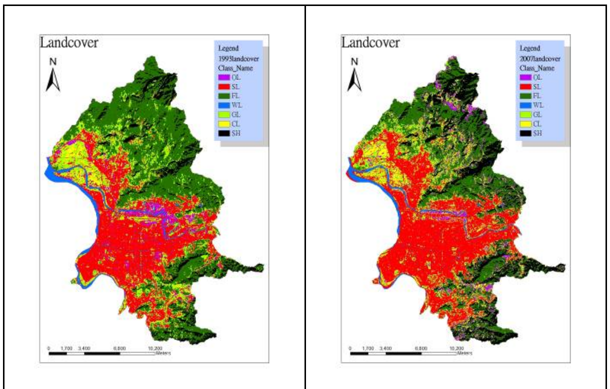


Fig.3 land-cover map in 1993(left) and 2007 (right)

2.2.2 Calculation of Vegetation Index in Green land: Two kinds of vegetation indices are used in this study. They are Normalized Difference Vegetation Index (NDVI) and Simple Ratio Vegetation Index (SR). The NDVI is commonly used in the application of vegetation index. It is calculated by near-infrared (NIR) and red (RED) bands as equation (1). The NDVI range is between -1 and 1, which means there is high-density vegetation when the NDVI is close to 1. On the other hand, the land-use type is not vegetation when the NDVI is less than 0.

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

The SR is calculated by the NDVI as equation (2). The index represents the richness of vegetation, but it is affected by the region and seasonality.

(2)…… $$SR(x,t) = \left[\frac{1 + NDVI(x,t)}{1 - NDVI(x,t)}\right]$$

To calculate the vegetation indices of green land, this study extracts the area of green land according to the land-use and land-cover classification map. However, shadow is commonly occurred in forestland. It can influence the value of NDVI (or SR) and the estimation of carbon sequestration. Use the shadow area of land-cover map which removed the shadow of forest areas to avoid affecting the actual value of forest land.

2.2.3 Estimation of Carbon Sequestration in Green land According to the Model derived from the NDVI and Net Primary Productivity (NPP): According to the model of radiation use efficiency (Monteith, 1972), this step applies the NDVI and the SR to calculate the fraction of incident photosynthetically active radiation (FPAR) and absorbed incident photosynthetically active radiation (APAR), and then estimate the NPP of green land as follows.

2.2.3.1 Calculation of FPAR: Hatfield et al. (1984) and Los et al. (1994) indicated that FPAR has a linear relationship with the NDVI or the SR. Therefore, FPAR can be calculated by the NDVI as equation 3 or by the SR (i.e., changing NDVI into SR in equation 3).

(3)…… $$FPAR(x,t) = \frac{\left(NDVI(x,t) - NDVI_{i,\min}\right)\times\left(FPAR_{\max} - FPAR_{\min}\right)}{\left(NDVI_{i,\max} - NDVI_{i,\min}\right)} + FPAR_{\min}$$

where $FPAR_{\max}$ and $FPAR_{\min}$ are assumed to be 0.001 and 0.95.

In addition, Los (1994) also pointed out that the FPAR estimated by the NDVI was higher than the real value, but the FPAR estimated by SR was lower than the real value. Therefore, the average of two FPAR obtained from the NDVI and SR was suggested to reduce the error. For this reason, this study adopts equation (4) to estimate the FPAR.

(4)…… $$FPAR(x,t) = \alpha FPAR_{NDVI} + (1-\alpha)FPAR_{SR}$$

where $FPAR_{NDVI}$ and $FPAR_{SR}$ are obtained from equation (1) and equation (2); α is an adjustment factor of the NDVI and SR, and is assumed forestland to be 0.5, grassland to be 0.45 (Jiang, 2009).

2.2.3.2 Calculation of APAR: APAR is related to the global solar radiation and the plant characteristics itself. It is calculated by equation (5).

(5)………………………………………………………………….. $APAR(x,t) = SOL(x,t) \times FPAR(x,t) \times 0.5$

where $SOL(x,t)$ represents the global solar radiation for pixel x at time t (unit：MJ/m^2). In this study, the SOL values provided by Department of Agriculture, Central Weather Bureau (Zhuzihu Weather Station) are 224.72 (MJ/m^2) in December, 1993 and 164.94 (MJ/ m^2) in December, 2007.

2.2.3.3 Estimation of NPP and carbon sequestration in Green land: This step uses the APAR and the actual light use efficiency (ε) to estimate the NPP of green land. The equation is as follows:

(6)……………………………………………………………………….. $NPP(x,t) = APAR(x,t) \times \varepsilon(x,t)$

where $\varepsilon(x,t)$ denotes the actual light use efficiency of pixel x at time t (unit: $gC \bullet MJ^{-1}$) and assume forestland to be 0.985, grassland to be 0.542; because forestland is regarded as "evergreen broad-leaved forest" in this study (Zhu, 2006).

2.2.4 Analysis of Green land Carbon Sequestration from 1993 to 2007: To estimate the carbon sequestration of green land, this step firstly multiples the NPP by green land area and then analyzes the change of carbon sequestration from 1993 to 2007. During the process, the conversion factor of carbon dioxide and carbon is assumed to be 0.367 (44/12).

3. RESULTS AND DISCUSSIONS

3.1 Calculation of Vegetation Index and area deviation in Green land

There have some error under Land use or land cover map of cutting each green land of NDVI values. After using the various types of vegetation index map decrease green land, it can receive the actual green land with vegetation; In Table.1, from the land-use method can be seen the mapping forestland errors in 1993, 402.84 ha, in 2007, 444.24 ha; the grassland errors in 1993, 272.12 ha, in 2007, 891.44 ha. In Table.2, from the land-cover method can be seen the forestland error is small, in 1993, 0.64 ha, in 2007, 1.32 ha but the grassland has larger error, in 1993, 974 ha, in 2007, 1,790 ha.

Table1 According to the land-use map generated under the various types of green land statistics

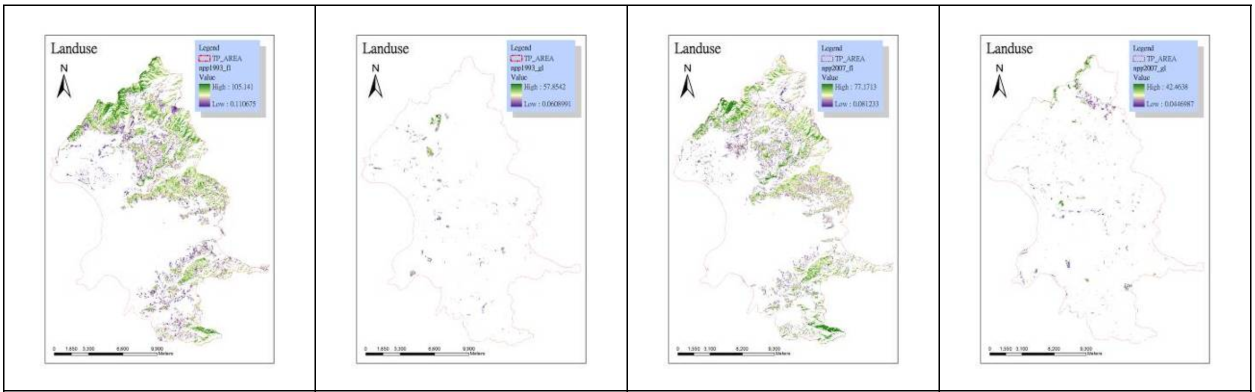
Year	Land type	Area(ha)	Removal negative (ha)	Error (ha)	NDVI-Mean
1993	**Forest land**	7,980.48	7,577.64	402.84	7,980.48
	Grass land	633.96	361.84	272.12	633.96
2007	**Forest land**	6,843.32	6,399.08	444.24	6,843.32
	Grass land	1,551.20	659.76	891.44	1,551.20

Table2 According to the land-cover map generated under the various types of green land statistics

Year	Land type	Area(ha)	Removal negative (ha)	Error (ha)	NDVI-Mean
1993	**Forest land**	8,078.16	8,077.52	0.64	8,078.16
	Grass land	4,399.04	3,425.40	973.64	4,399.04
2007	**Forest land**	6,576.72	6,575.40	1.32	6,576.72
	Grass land	3,823.08	2,033.08	1,790.00	3,823.08

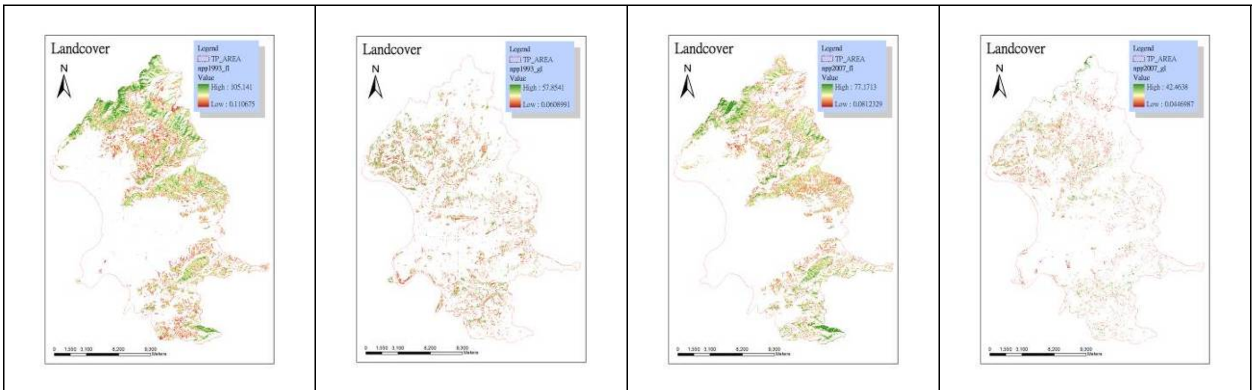
3.2 Estimation of Net Primary Productivity (NPP) and Carbon Sequestration in Green land

The results (Table 3) of two carbon sequestrations have been declined, and forest carbon sequestration is much higher than the grass; Among Fig.4, Fig.5 and Table 3, the area satellite image classification, NPP average, and the total carbon storage are greater than land surveying and mapping classification, but in the unit of carbon storage, the land surveying and mapping classification of grass is greater than the satellite image classification. The possible reason is part of the land surveying and mapping classification divisions have some errors. The errors are taking part higher forest land reflectance classification to grassland.



In 1993 Forest land | In 1993 Grass land | In 2007 Forest land | In 2007 Grass land

Fig.4 Taipei's green land NPP according to the land-use



In 1993 Forest land | In 1993 Grass land | In 2007 Forest land | In 2007 Grass land

Fig.5 Taipei's green land NPP according to the land-cover

Table 3. Through land use and land cover to estimate value

Year	Land type	Land-cover of statistics				Land-use of statistics			
		Area(ha)	NPP-Mean	(C-ton/yr)	(C-ton/ha/yr)	Area(ha)	NPP-Mean	(C-ton/yr)	(C-ton /ha/yr)
1993	**Forest land**	8,078	47.3408	22,944	2.8405	7,578	45.7807	20,815	2.7468
	Grass land	3,425	12.5633	2,324	0.6784	362	16.3481	319	0.8828
2007	**Forest land**	6,575	33.1792	13,090	1.9908	6,399	31.0693	11,929	1.8642
	Grass land	2,033	7.4923	823	0.4046	660	10.7546	383	0.5807

4. CONCLUSION

4.1 land-use and land-cover

Production of satellite image classification of land cover map within the forest types is higher accuracy. But in the grass, the accuracy was much lower than National Land Surveying and Mapping classification of land use map. The possible reason is the land cover map much closer to the true ground, but for lower reflectance value grasses are not accuracy. However the land-use map has some factors such as policy or human emotion, to suggest using land cover maps to calculate the carbon sequestration of the study.

4.2 Monitoring of carbon sequestration

From the result, 1993-2007 annual decline in total carbon sequestration and forest carbon sequestration per unit area is much higher than the grass Therefore, remote sensing technique is a feasible approach to monitor the change of carbon sequestration in green land. The result obtained from this study can be extended to a reference of Taipei green land planning in future.

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