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Differences in Carbon Sink by Land Use using Topographic Correction in Seoul, South Korea

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This study attempts to confirm the differences in carbon sink according to each type of land use by using the biotope map and reviewing carbon sink considering topography, and comparing those before–and–after topographic correction. The types of carbon sink were focused on Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI) and Net Primary Productivity (NPP).

Results indicate that the NPP values for 3 periods were found to be 142.885 gC/m^2/year (1999), 133.416 gC/m^2/year (2004), 163.650 gC/m^2/year (2009) on the average and the average NPP values have increased for 10 years. The NPP value for 10 years has been increased. The forest areas showed the highest NPP values (average 250.188 gC/m^2/year) and the NPP values (average 102.095 gC/m^2/year) of rivers and wetlands were lowest.

The NPP–values revised by topographical correction in forest areas showed bigger differences from NPP–values than other land use. The range of NPP–values showed from 0.001 gC/m^2/year to 326.342 gC/m^2/year. The NPP–values after topographical correction varied according to rugged terrain. The forest areas in South Korea have many curves different from other land use, and slopes have uneven topographical characteristics. In the case of residential areas and commercial areas transformed to even topography from uneven topography, the effects by topographical correction are found less.

Key words: NDVI, NPP, LAI, Carbon stock

INTRODUCTION

Atmospheric carbon dioxide has increased rapidly so the roles of plants and soil have become very important. Carbon sink refers to standing trees, bamboo, withered organic matter, soil, wooden goods and forest biomass energy (Carbon Sink Maintenance and Promotion Act, 2013). Carbon storage and emission sources can be classified into aboveground biomass including trunks, branches and leaves and below biomass including roots, withered organic matter and soil carbon such as organic matter of leaves and litter.

Among them, the study of aboveground biomass provides a strategy for green expansion and preservation. In particular, for the preservation and expansion of forest areas, studies using satellite images and GIS minimize damage and analyze wide areas (Potter *et al.*, 1993; Liu *et al.*, 1997; Gao *et al.*, 2004; Wang *et al.*, 2009). Out of them, studies on the correlation of NPP (Net Primary Productivity) and NDVI (Hobbs 1995; Paruelo *et al.*, 1997; Wang *et al.*, 2005) with LAI (Leaf Area Index) utilize numerous satellite images through comparison of satellite image data and practically measured data for carbon circulation and storage.

Some of these studies, however, do not have topographical consideration to measure carbon stocks. It is presumed that topographic consideration reduces radiative variations since each different land use has similar values (Jiang *et al.*, 2012). In the case of extensive mountainous terrain, due to irregular surface, solar incidence angles, scattering degrees and reflection angles are different from each other so that it is important to find the appropriate values. Therefore, finding appropriate values by considering topography is an important element in measuring carbon storage.

Satellite images have been often used to classify land use. Various methods such as simultaneous performance of unsupervised and supervised classification (Keuchel *et al.*, 2003), that of ANN function and supervised classification (Zhang *et al.*, 2011), use of unsupervised classification (Huang *et al.*, 2008), that of supervised classification (Sandmeier and Itten, 1997; Cuo *et al.*, 2010) are used to classify land use, and for the comparative analysis of corresponding satellite image values and field data. However, because this approach is based on a probability model about the corresponding cluster, it cannot reflect the actual environments.

Since 2,000, South Korea has been updating land use and relevant biotope maps every 5 years to support the capital Seoul. This biotope map has various attribute data including land use, vegetation cover, average building coverage ratio and impervious coverage ratio. It had relatively high accuracy compared to supervised or unsupervised classification because it was revised through satellite images and field surveys. This study attempts to confirm the differences in carbon sink according to each

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different land use by using the biotope map and reviewing carbon sink considering topography, and comparing those before–and–after topographic correction. The types of carbon sink were focused on NDVI, LAI and NPP.

MATERIALS AND METHODS

1. Study site

The study site was in Seoul, the capital of the Republic of Korea producing a biotope map for sustainable development regarding the rapidly changing urban environment. This map was developed in 1999 and a biotope map has been updated every 5 years–2000, 2005 and 2010. Seoul was selected because it has the longest history of the production of a biotope map and can easily be analyzed through multi–temporal satellite image acquisition (Fig. 1).

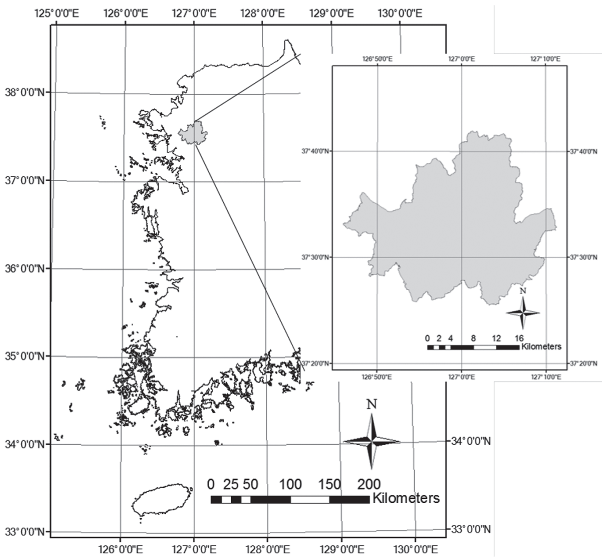

Fig. 1. Study site of Seoul, South Korea.

For satellite data, Landsat TM, and ETM^{+} images were used. Even though a biotope map was produced in 2000, 2005 and 2010, it was made one year before the announcement of the final current survey, and the images of 1999, 2004 and 2009 were utilized (Table 1). Acquiring data on the same date has limits due to problems caused by satellite orbits and climate change. Therefore, each image was taken in early June and only one good quality image with cloud conditions within 105 was used for each period. Due to cloud intervention as well as the rainy season in July and August, and SLC (Scan Line Corrector) in May 2003 of Landsat ETM^{+}, further good quality satellite images are not expected to be acquired. Satellite data were acquired from the website (http://glovis.usgs.gov/) provided by USGS as Table 1. This provides ease of data acquisition and consistency of data analysis. The temperatures of 3 periods (1999, 2004 and 2009) were analyzed to confirm each difference.

The area changes in each land use in Seoul are not huge. When it comes to Table 2, commercial, agricultural, forest and landscape areas have been reduced, and river and wetland, residential, traffic and urban infrastructure areas have increased over the past 10 years. But the width of these area changes can be relatively smaller than the area changes of other cities. Because the land use type of Seoul is systematized, it implies a smaller possibility that a bigger scope change happens.

Table 1. Information on Landsat Imagery from 1999 to 2009 in Seoul

Data acquired	Scene center time	Satellite	Sensor	Datum/map projection
1999. 6. 30	11:03:44	Landsat 7	ETM+	WGS 84 / UTM zone 52N
2004. 6. 3	10:52:08	Landsat 5	TM	
2009. 6. 1	10:59:06	Landsat 5	TM	

Table 2. Changed rate of each land–use of each Year (Unit: %)

Land use \ Year	2000	2005	2010	Δ(2004–1999)	Δ(2009–1999)	Δ(2009–2004)
Commercial area	19.321	18.847	18.688	–0.474	–0.633	–0.159
Agricultural area	5.057	4.907	4.026	–0.15	–1.031	–0.881
Forest area	24.006	22.790	22.577	–1.216	–1.429	–0.213
Landscaping area	6.276	6.011	6.065	–0.265	–0.211	0.054
Residential area	17.969	18.817	19.538	0.848	1.569	0.721
River and wetland	5.545	6.474	6.476	0.929	0.931	0.002
Transportation area	10.433	10.592	10.853	0.159	0.42	0.261
Unused area	2.328	1.782	2.011	–0.546	–0.317	0.229
Urban infrastructure and factory	9.066	9.781	9.766	0.715	0.7	–0.015
Total	100	100	100	0	0	0

2. Analysis Method

2.1 Extracting Carbon Sink

Carbon sink depends on the types of vegetation. The carbon stocks of Seoul were estimated through NDVI, LAI and NPP.

The NDVI can be calculated by utilizing the reflection angle between the red band and the near infrared ray band because the reflection angle of vegetation was low in the red area and high in the near infrared ray area. Formula 1 was used to calculate NDVI. NIR as the near infrared ray area corresponds to Band 4 of Landsat TM/ETM image and Red to Band 3.

$$\mathrm{NDVI} = \frac{NIR - Red}{NIR + Red} \quad (1)$$

Emissivity (ε) correction was required because the values extracted by NDVI have a large temporal and spacious variability according to variations such as soil type, vegetation, soil moisture (Valor and Caselles, 1996). Due to insufficient emissivity measurement data of extensive areas, satellite observation data were utilized to calculate emissivity (Zhang *et al.*, 2006). The emissivity calculation can be estimated by using NDVI, and the emissivity estimation suggested by Zhang *et al.* (2006) was used (Table 3).

LAI was utilized by the formula suggested by Govind *et al.* (2009) and NPP was calculated by the formula suggested by Chen *et al.* (2007). Both LAI and NPP are provided by Canada and can differ from South–Korea's conditions. However, these formulas that are the results of comparing satellite data and field data simultaneously are trustworthy. It was necessary to have a comparative analysis with our phenomenon but due to difficult data acquisition, LAI and NPP were reviewed through overseas cases. This does not intend to consider absolute NPP. It was because it emphasized how the variation of NPP values changes according to topographic changes followed by each land use.

Table 3. Emissivity calculated by NDVI

NDVI	Land surface emissivity (ε)
NDVI < –0.185	0.995
–0.185 ≤ NDVI < 0.157	0.970
0.157 ≤ NDVI < 0.727	1.0094+0.047ln(NDVI)
NDVI > 0.727	0.990

$$\mathrm{LAI} = e\left(\frac{NDVI - 0.5118}{0.1923}\right) \ (R^2 = 0.78) \quad (2)$$

$$\mathrm{NPP} = 206.2 \times \mathrm{LAI} + 95.3 \ (R^2 = 0.86) \quad (3)$$

Where LAI is the leaf area index; NPP is the net primary production.

Table 4. Formulas of topographic correction

Classification	Formula	Reference
COS	$\rho_{\lambda i} = \rho_i\left(\frac{\cos\theta_s}{\cos\gamma_s}\right)$	Teilet *et al.* (1982)
C–correction	$\rho_{\lambda i} = \rho_i\left(\frac{\cos\theta_s + C_\lambda}{\cos\gamma_s + C_\lambda}\right)$ $C_\lambda = \left(\frac{b_\lambda}{m_\lambda}\right)$ $\rho_i = b_\lambda + m_\lambda \cos\gamma_i$	Teilet *et al.* (1982)
Minnaert correction	$\rho_{\lambda i} = \rho_i\left(\frac{\cos\theta_s}{\cos\gamma_i}\right)^l$	Minnaert (1941)
Modified Minnarert correction [Colby, (1991)]	$\rho_{\lambda i} = \rho_i \cos\eta_i\left(\frac{\cos\theta_s}{\cos\gamma_i \cos\eta_i}\right)^l$	Colby (1991)
Modified Minnarert correction [Lu *et al.* (2008)]	$\rho_{\lambda i} = \rho_i \frac{\cos\eta_i}{(\cos\eta_i \cos\gamma_i)^l}$	Lu *et al.* (2008)
Modified Minnarert correction [Richter *et al.* (2009)]	$\rho_{\lambda i} = \rho_i \cos\left(\frac{\cos\theta_s}{\cos\beta_i}\right)^l$ $\beta_i = \theta_s + t$	Richter *et al.* (2009)

Where $\rho_{\lambda i}$ is the corrected pixel value; ρ_i is the original value; θ_s is the solar zenith angle; γ_i is the incidence angle; C_λ is the quotient of intercept (b_λ) and slope (m_λ) of the regression line; b_λ and m_λ are the regression coefficients; η_i is the slope angle; β_i is the empirical variable depending on θ_s; t depends on θ_s, when $\theta_s < 45°$, $t = 20°$; $45° \leq \theta_s \leq 55°$, $t = 15°$; $\theta_s > 55°$, $t = 10°$; l is the Minnaert constant; $\rho_{i\cos}$ is the reflectance values resulting from C–correction.

2.2 Topographic correction

First of all, for topographic correction, the following formula was applied according to geometric relationships between the sun and topography.

$$\cos\gamma_i = \cos\theta_s \cos\eta_i + \sin\theta_s \sin\eta_i \cos(\phi_a - \phi_a) \qquad (4)$$

Where γ_i is the incidence angle; θ_s is the solar zenith angle; η_i is the slope angle; ϕ_a is the solar azimuth angle; ϕ_a is the slope aspect.

The topographic correction formula has been made in various ways (Table 4). Among them, COS (cosine correction) (Teilet *et al.*, 1982) was known to be less accurate than other correction formulas and the adjusted Minnarert correction formula shows high accuracy (Hantson and Chuvieco, 2011; Vanonckelen *et al.*, 2013). After the result of the comparative analysis of diverse topographic correction formulas (Vanonckelen *et al.*, 2013), the most accurate Lu *et al.* (2008) correction formula was used.

2.3 Interpretation Method

The result was interpreted in two ways; 1) The comparison of NDVI, LAI and NPP of each land use by year and 2) the comparison of NDVI, LAI and NPP of each land use according to topographic correction were performed. Kruskal–Wallis test as a nonparametric test was performed for each analysis result in order to confirm the independence of the average values of NDVI, LAI and NPP by each period or each land use. This test was used for estimating whether independent samples come from respectively different parent populations and used when the sampling distribution in the environmental data has similar and symmetric structure (Ruxton and Beauchamp, 2008). IBM SPSS Statistics 20.0 was used for statistical analysis and ArcGIS 9.3 was used for spatial analysis.

RESULTS AND DISCUSSION

1. Comparing NDVI, LAI and NPP by year

1.1 NDVI

The entire average values of NDVI by year were 0.105 for 1999, 0.076 for 2004 and 0.146 for 2009. The whole average values of NDVI according to those before–and–after topographic correction showed less differences. This showed that the energy of vegetation during the period of seasonal transfer from spring to summer was raised. The forest areas (0.411 for 1999, 0.367 for 2004 and 0.499 for 2009) showed NDVI with the highest values as those before–and–after topographic correction. The landscape areas showed the second highest values similar to the agricultural areas. Below 0 refers to inactive vegetation so those areas were river and wetland, commercial areas and unused areas. The residential and traffic areas close to 0 were considered as the low vitality of vegetation.

Compared to 1999, NDVI of river areas and wetlands in 2004 and 2009 rose. This can be regarded as the result of the increase of river and lake areas from Cheonggyecheon restoration and wetland preparation. Even though the size of forest areas has been continuously reduced and residential areas have been increased for 10 years, each NDVI value has been increased. The changing period and process of tree growth can be formed differently and the forest quality within the area can be improved as much as the decrease. This was an important point because the NDVI values of forest areas are remarkably higher than residential areas; the quality of vegetation itself has big differences.

The areas with high impermeable pavement ratios such as roads and buildings and the areas with high permeability such as forest and agricultural land showed differences in NDVI values. High ratio of impermeable pavement areas show relatively lower NDVI values compared to high permeability areas (Yuan and Bauer, 2007). The results of this study also showed that the NDVI values of forest and agricultural land with high permeability were relatively high.

The NDVI values of each land use by 3 periods showed slight differences. However, the comparison of 3 periods using the average NDVI values of each land use did not show significant differences. It was also confirmed by Kruskal–wallis test result ($H=0.836$, 2d.f., $P=0.658>0.05$)) that there was no difference.

In general, NDVI values were in following order; forest area > landscape area > agricultural area > urban infrastructure facility and factory area > traffic area > residential area > unused land > commercial area > river area and wetland.

1.2 LAI

The entire average–values of LAI by year were 0.229 for 1999, 0.183 for 2004 and 0.327 for 2009. The average LAI value of the forest areas was highest and the LAI values of river and wetland were lowest. Commercial areas, residential areas and unused areas were the second lowest, and landscape areas and agricultural areas were lower than forest areas but the energy of vegetation could be confirmed.

The LAI values of each land use by 3 periods showed slight differences. However, the comparison of 3 periods about the average LAI values of each land use did not show significant differences. It was also confirmed by Kruskal–wallis test result ($H=0.700$, 2d.f., $P=0.705>0.05$)) that there was no difference.

In general, as NDVI, average LAI values were in following order; forest area > landscape area > agricultural area > urban infrastructure facility and factory area > traffic area > residential area > unused land > commercial area > river area and wetland.

1.3 NPP

The whole average NPP (gC/m^2/year) was 142.443 (1999), 133.026 (2004) and 162.718 (2009) before topographic correction, and 142.885 (1999), 133.416 (2004) and 163.650 (2009) after topographic correction and there were differences by year and in values before–and–after topographic correction. Somewhat less NPP was shown in 2004 compared to 1999 and it increased slightly in 2009.

The NPP values of each land use by 3 periods showed slight differences. However, the comparison of 3 periods with the average NPP values of each land use did not show large differences. It was also confirmed by Kruskal–wallis test result (H=0.734, 2d.f., P=0.693>0.05)) that there was no difference.

In general, as NDVI and LAI, average NPP values were in following order; forest area > landscape area > agricultural area > urban infrastructure facility and factory area > traffic area > residential area > unused land > commercial area > river area and wetland.

2. Comparison of NDVI, LAI, NPP Before and After Topographic Correction

2.1 NDVI

NDVI records from –1 to 1. Comparing NDVI before and after topographic correction, forest areas showed 0.003 difference on the average, and among the forest areas in 2009, the area with the biggest difference shown was the forest area behind the Radiological Hospital of the Korea Institute of Radiological & Medical Sciences located at Nowon–gu, Seoul as 0.182. The average slope–angle of this area was 46.65°, its direction was westward and the average altitude was 96.81 m with an area of 1,615.03m^2. The forest stand was black locust (*Robinia pseudoacacia*) forest. The decisive reason with regard to difference of NDVI–values was different slope angles. The surface area of vegetation increased the result because the average slope–angle was over 45° as a steep slope–angle. NDVI of this area was 0.335 before topographic correction and 0.517 after topographic correction.

Among urban infrastructure facilities and factory areas, the Seoul Digitech High School site recorded –0.003 in 2009. The size of the area was approximately 1073m^2, the slope–angle was 23.03° and westward, vegetation was sparse and the impermeable pavement ratio was 100% on the Seoul Biotope Map. The reason why it showed a much lower value compared to the existing NDVI values was that the direction was northwestward. Even though the slope–angle of the area was around 23° that was expected to increase the surface area and NDVI, the NDVI showed a relatively lower value because the satellite image was taken at 11:00 a.m. and the solar altitude was around 65° and the area had a northwestward slope–angle. The reason can be understood by examining the attributes of the topographic correction formulas. The topographic correction formulas can be changed by determining a light incidence angle or reflection angle, and in general, BRDF (Bidirectional reflectance distribution function) is used that presumes that the light incidence point and reflection point are the same. After dividing Lamberian Reflectance use indicating that the apparent brightness of such a surface is the same to an observer regardless of the observer's angle of view, and non–lamberian reflectance, it was applied to topographical correction formulas. At this moment, the main variables influencing topographical correction formulas are decided by azimuth, soil altitude and rugged terrain. When the azimuth is northwestward, solar light at 65° height receives relatively less solar radiation compared to the southward slope, and accordingly, the NDVI value can decrease. For reference, the NDVI value around it also showed lower values compared to existing values. They were all northwestward.

In order to confirm any difference in the average values of NDVI by land use according to before and after topographic correction, Kruskal–Wallis test was performed. As a result, there were differences in the average NDVI values according to before and after topographic correction by land use as below 0.05, significant level (H=23.605, 8d.f., P=0.003<0.05). In other words, the NDVI values of land use in Seoul showed differences from each other compared to those of NDVI shown by topographic correction (Table 5).

2.2 LAI

Comparing LAI before–and–after topographic correction, forest areas showed 0.012m^2/m^2 difference on the average, and among the forest areas in 2009, *Pinus rigida* with the area of around 255.384 m^2 behind Jungsan

Table 5. Comparing before and after values of NDVI

Classification	1999			2004			2009		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Commercial area	0.000001	–0.000209	0.010230	–0.000002	–0.000570	0.007365	0.000005	–0.000505	0.013871
Agricultural area	0.000075	–0.000437	0.006482	0.000136	–0.000080	0.006708	0.000101	–0.000120	0.007928
Forest area	0.002556	–0.000488	0.074219	0.002902	–0.002361	0.122161	0.003561	–0.000851	0.181973
Landscaping area	0.000218	–0.000909	0.025653	0.000353	–0.002163	0.036163	0.000453	–0.000657	0.040689
Residential area	0.000014	–0.000307	0.004993	0.000006	–0.000617	0.032372	0.000028	–0.000183	0.041928
River and wetland	0.000014	–0.000307	0.004993	0.000001	–0.000190	0.000699	0.000001	–0.000065	0.001192
Transportation area	0.000002	–0.000384	0.004158	0.000003	–0.000119	0.010574	0.000006	–0.001810	0.005233
Unused area	0.000001	–0.000119	0.013244	–0.000009	–0.000283	0.017867	0.000004	–0.000104	0.031583
Urban infrastructure and factory	0.000039	–0.001474	0.009049	0.000061	–0.003308	0.010949	0.000093	–0.003374	0.016409
Total	0.000638	–0.001474	0.074219	0.000696	–0.003308	0.122161	0.000852	–0.003374	0.181973

High School located at Ilwono–dong, Seoul, showed differences. The average slope–angle of this area was 41.15° and its direction was northwestward and the average altitude was 66.5 m and area is 255.384 m^2. The LAI value of black–locust forest stand behind the Radiological Hospital of the Korea Institute of Radiological & Medical Sciences mentioned above was 0.629 m^2/m^2. The reason why the difference of the two areas was the difference in the existing NDVI values. The corrected NDVI value of the area above *Pinus rigida* was 0.714 and black–locust forest stand behind the Radiological Hospital was 0.517. The NDVI differences in the two areas were 0.182, the NDVI value of *Pinus rigida* forest stand, located in the mountain at the back of the Radiological Hospital and 0.155, black–locust forest stand located in the mountain at the back of Jungsan High School. Compared to the correction differences of NDVI, the existing NDVI values showed differences. As the result of NDVI, the areas that showed the lowest difference was Seoul Digitech High School site that recorded –0.00446 in 2004 among urban infrastructure facilities and factory areas.

In order to confirm any difference in the average values of LAI by land use according to before–and–after topographic correction, Kruskal–Wallis test was performed. As a result, there were differences in the average NDVI values according to before and after topographic correction by land use as below 0.05, significant level ($H=22.797$, 8d.f., $P=0.004<0.05$). The LAI values by land use in Seoul showed differences from each other in those of LAI shown by topographic correction (Table 6).

2.3 NPP

Comparing LAI before–and–after topographic correction, forest areas showed 2.47 gC/m^2/year difference on the average, and among the forest areas that showed the biggest difference, *Pinus rigida* behind Jungsan High School located at Ilwono–dong, Seoul, showed a difference of 326.342 gC/m^2/year (Table 7). The existing NPP was 359.440 gC/m^2/year and the corrected NPP was 685.782 gC/m^2/year that showed a big difference. The reason for the big difference was understood to be that the area showed a very high NDVI and the steep slope

Table 6. Comparing before and after values of LAI

Classification	1999			2004			2009		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Commercial area	0.000005	–0.000061	0.018986	0.000005	–0.000125	0.011201	0.000015	–0.000113	0.058690
Agricultural area	0.000143	–0.000127	0.022149	0.000177	–0.000020	0.020123	0.000289	–0.000031	0.046936
Forest area	0.008728	–0.000139	0.320963	0.007974	–0.000709	0.566234	0.019253	–0.000274	1.582646
Landscaping area	0.000556	–0.000235	0.104209	0.000827	–0.000551	0.078897	0.002185	–0.000212	0.258500
Residential area	0.000018	–0.000081	0.008468	0.000011	–0.000169	0.042707	0.000033	–0.000046	0.118581
River and wetland	0.000018	–0.000081	0.008468	0.000001	–0.000020	0.002301	0.000002	–0.000018	0.007740
Transportation area	0.000003	–0.000103	0.004791	0.000005	–0.000031	0.008404	0.000012	–0.000568	0.011515
Unused area	0.000003	–0.000027	0.009436	0.000001	–0.000084	0.015126	0.000014	–0.000023	0.063127
Urban infrastructure and factory	0.000045	–0.000446	0.029213	0.000082	–0.000810	0.027049	0.000208	–0.000794	0.069026
Total	0.002146	–0.000446	0.320963	0.001887	–0.00081	0.566234	0.004521	–0.000794	1.582646

Table 7. Comparing before and after values of NPP

Classification	1999			2004			2009		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Commercial area	0.001	–0.013	3.915	0.001	–0.026	2.310	0.003	–0.023	12.102
Agricultural area	0.030	–0.026	4.567	0.036	–0.004	4.149	0.060	–0.006	9.678
Forest area	1.800	–0.029	66.183	1.644	–0.146	116.757	3.970	–0.057	326.342
Landscaping area	0.115	–0.048	21.488	0.170	–0.114	16.268	0.450	–0.044	53.303
Residential area	0.004	–0.017	1.746	0.002	–0.035	8.806	0.007	–0.010	24.451
River and wetland	0.004	–0.017	1.746	0.000	–0.004	0.475	0.000	–0.004	1.596
Transportation area	0.001	–0.021	0.988	0.001	–0.006	1.733	0.003	–0.117	2.374
Unused area	0.001	–0.006	1.946	0.000	–0.017	3.119	0.003	–0.005	13.017
Urban infrastructure and factory	0.009	–0.092	6.024	0.017	–0.167	5.578	0.043	–0.164	14.233
Total	0.442	–0.092	66.183	0.389	–0.167	116.757	0.932	–0.164	326.342

increased the area.

The NPP–value per unit area was higher in mixed forest or deciduous forest than evergreen forest (Yoo *et al.*, 2012). *Pinus rigida* forest stand showed high NPP value because those area was smaller than the surrounding deciduous oak forest and *betula davurica* forest. There may be several more reasons. First, because the *Pinus rigida* with a small area showed a high NPP, the *Pinus rigida* with a wide area should have shown a high NPP but it did not. A large–scale forest stand of *Pinus rigida* located at the back of Seoul National University has the area of 329,361.56 m^2 but its NPP was just 235.274 gC/m^2/year. Therefore, the size of an area could not represent NPP. Second, it can be considered to be average trap about stand area. The average value of the slope angle and direction within each forest–stand area refers to the mean value divided by the number of all those values in a forest–stand area. In case of a wide area, the distribution range of each value can vary but in case of a narrow area, the range of each value can be small because the resolution of the images used for this study was fixed at 30 m. The values within 900 m^2 have limits to represent the values of the land use. Furthermore, because the average value of the slope angle and direction within a forest–stand with a wide area was the average value of the area as themselves, it can easily distort the data analyzed by satellite images. Third, the vegetation energy of the *Pinus rigida* in the area can actually be much better than the surrounding stand.

The areas showed big differences in NPP in Seoul were mostly forest areas. The area marked in white had no difference in NPP regardless of the topographical correction; and that in brown showed a difference in NPP by more than 80 gC/m^2/year by topographical correction. Fig. 2 showed drawings that model the differences of NPPo (existing NPP data) and NPPm (NPP data after topographical correction).

In conclusion, according to the topographical correction, the NPP in forest areas showed bigger differences from NPP than other land use. The differences range from 0.001 gC/m^2/year to 326.342 gC/m^2/year. It is judged that NPP differences after topographical correction were shown because forest areas in South Korea have many curves different from other land use, and slopes have uneven topographical characteristics. In the case of residential areas and commercial areas where humans are active, because they are transformed to even topography from uneven topography, the effects by topographical correc-

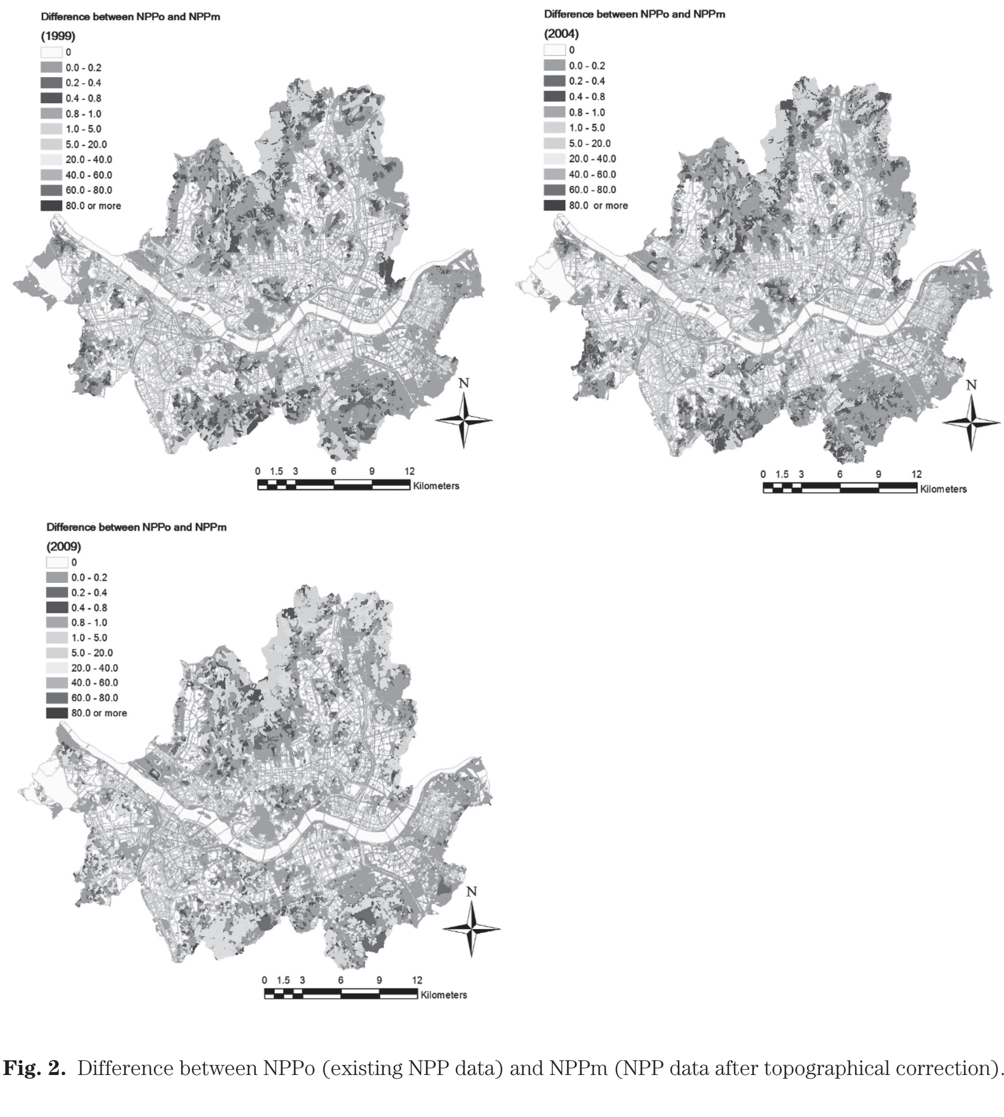

Fig. 2. Difference between NPPo (existing NPP data) and NPPm (NPP data after topographical correction).

tion are found less.

In order to confirm any difference in the average values of NPP by land use according to topographic correction, Kruskal–Wallis test was performed. As a result, there were differences in the average NPP values compared to those before–and–after topographic correction by land use as below 0.05, significant level (H=22.813, 8d.f., P=0.004<0.05). The NPP values by land use in Seoul showed differences from each other compared to those of NPP shown by topographic correction.

CONCLUSIONS

This study interpreted the actual conditions of carbon sink of each land use considering topography through NDVl, LAI and NPP that can review the types of carbon sink by using the biotope map. The NPP values for 3 periods were 142.885 gC/m^2/year (1999), 133.416 gC/m^2/year (2004), 163.650 gC/m^2/year (2009) on the average and the average NPP values have increased for 10 years. The forest areas showed the highest NPP values (average 250.188 gC/m^2/year) and the NPP values (average 102.095 gC/m^2/year) of rivers and wetlands were the lowest. The NPP values of each land use by 3 periods showed slight differences. However, there was no big difference in statistical tests for comparing 3 periods of the average NPP values by each land use.

In conclusion, according to topographical correction, NPP in forest areas showed bigger differences from NPP than other land use. The differences range from 0.001 gC/m^2/year to 326.342 gC/m^2/year. The NPP differences after topographical correction were shown because forest areas in South Korea have the rugged and uneven terrain compared to other land use. In case of residential areas and commercial areas where humans are active, the topographical correction was less effective because they are transformed from uneven to even topography.

NPP of places with human activities such as residential areas, commercial areas and traffic areas was low for all 3 periods (1999, 2004 and 2009). These areas were subsumed into a scarcity of wood and soil for carbon storage. Accordingly, a foundation to incorporate much more wood and soil to raise carbon stock to create a healthy urban ecosystem should be prepared. In order to expand carbon storage space, trees and soil should be promoted much more than at the present time. However, the promotion of trees and soil in a city is quite difficult because existing cities have systemized space customized to the convenience of human beings and are very wide or not easy to change. The trees and soil installed above artificial spaces such as rooftop gardens or greenwalls even in the current cities can help to promote carbon stocks.

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