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Article

The Impact of Green Space Changes on Air Pollution and Microclimates: A Case Study of the Taipei Metropolitan Area

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Abstract: In order to achieve a sustainable urban environment, the increase of green space areas is commonly used as a planning tool and adaptation strategy to combat environmental impacts resulting from global climate change and urbanization. Therefore, it is important to understand the change of green space areas and the derived impacts from the change. This research firstly applied space analysis and landscape ecology metrics to analyze the structure change of the pattern of green space area within the Taipei Metropolitan Area. Then, partial least squares were used to identify the consequences on microclimate and air pollution pattern caused by the changing pattern of green space areas within the districts of the Taipei Metropolitan Area. According to the analytical results, the green space area within Taipei Metropolitan Areas has decreased 1.19% from 1995 to 2007, but 93.19% of the green space areas have been kept for their original purposes. Next, from the landscape ecology metrics analysis, in suburban areas the linkages, pattern parameters, and space aggregation are all improving, and the fragmentation measure is also decreasing, but shape is becoming more complex. However, due to intensive land development in the city core, the pattern has becomes severely fragmented and decentralized causing the measures of the linkages and pattern parameters to decrease. The results from structural equation modeling indicate that the changing pattern of green space areas has great influences on air pollution and microclimate patterns. For instance, less air pollution, smaller rainfall patterns and cooler temperatures are associated with improvement in space aggregation, increasing the larger sized green space patch.

Keywords: green space change trend; air pollution; microclimate; landscape ecology metrics; structural equation modeling

1. Introduction

The threat of disaster brought on by global climate change has captured the attention of most of the world's nations. Solutions to these threats fall primarily into two categories: mitigation and adaptation. The former emphasizes removing the causes of climate change to reduce the effects of the problems it poses. One result of this effect includes reducing the source of greenhouse gas emissions (or strengthening the sequestration of greenhouse gases), and thereby treating the root of the problem [1]. Current mitigation strategies target the reduction of greenhouse gas emissions in specific sectors (such as energy, industry, transportation, residential, commercial, *etc.*). The latter solution—adaptation—emphasizes responding and adjusting to the results of climate change, while reducing the damage it causes, possibly turning it to an advantage [2]. The current strategies of adaptation include comprehensively adjusting on a socio-economic level (such as strategies for land use, water resource management, public health and public construction, *etc.*). However, solutions of mitigation and adaptation compete with each other and conflict with regard to policy implementation and limited administrative resources [3,4]. These solutions can share benefits in a few special cases, such as in planting trees, developing and managing of green space, *etc.* In this paper, we will discuss the green space issues.

Green space, for the purposes of this paper, is open space covered by plants [5,6]. Green spaces are semi-natural areas [7] that not only have the environmental function of blocking noise [8], reducing carbon emissions and air pollution [9–12], conserving water and soil [13,14], adjusting the microclimate and moderating temperatures [12,15–19], but also have the ecological functions of recovering fertility, preserving ecologically sensitive areas, providing the habitat and feeding spaces for various species [20,21], and stabilizing ecological systems [22]. Moreover, green space has the landscape functions of buffering interferential land use while enhancing environmental beauty and visual aesthetics. It also has the socio-cultural functions of strengthening social cohesion and place identity by providing environmental education, recreation and cultural exchange [23–25]. Additionally, green space provides the health benefits of reducing tension and improving people's sense of satisfaction and happiness [26–28]. Thus, not only is green space the key to solving problems associated with climate change and over-urbanization, but it also plays a significant role in creating a sustainable urban environment that provides social and ecological balance. Therefore, the United Nations Conference on Sustainable Development (UNCSD), Organization for Economic Co-operation and Development (OECD), UKSDI (UKSDI is UK government sustainable development framework indicator) and Towards Sustainable Europe all use green space as an important indicator for evaluation sustainable development.

The development and planning of green space can affect strategies of mitigation and adaptation simultaneously. Furthermore, changes to green space impact biological habitat, biodiversity, hydrologic cycle [29], soil properties [30], , and carbon storage [22]. Additionally, the impact of green space change on air pollution and microclimate is most important. Previous studies of air pollution and microclimate in urban area emphasize anthropogenic factors (such as building intensity, transportation, industrial development) [31–40]. There are few research papers that discuss the green space effects on air pollution and microclimates. Thus, the relationship among green space change, air pollution and microclimate is critical and calls for intensive study.

Previous research into the subject of green space has been exceptionally fruitful [9–11,22,29], but most studies have only evaluated the total areas of green space. However, when making a green space plan, not only should the total area be calculated, but also what is included within the same area must be considered. Should we plan big city parks or create a higher number of smaller community parks? How will their size and shape influence the functions of the green space? Past research has paid less attention to the structural change of green space and the impact of green space changes. Moreover, the spatial scale of analysis has been limited to the urban and community scale, seldom analyzing the districts within the large-scale metropolitan areas. Most natural development of green space is cross-border, thus analysis should include metropolitan districts and larger-scale geographic areas to acquire more reliable and valid results.

Because green space in metropolitan areas provides many functions, the development and planning of green space is an important way to mitigate and to adapt the environmental impact of climate change and over-urbanization while helping to achieve sustainable development goals. The level of urban development is different in each metropolitan area, and so the degree to which green space is impacted by development is different. In order to make green space planning effective, one must take into account the trends and impact of green space alterations. In addition, factors of air quality and microclimates are key for the residents' health. Because of this fact, green space alterations' impact on air pollution and microclimate requires closer examination. Therefore, for this paper, we will first apply spatial analysis and landscape ecology metrics to analyze structural changes in the pattern of green space within the districts of the Taipei metropolitan area. Then, we will use partial least squares to identify the impact on microclimate and air pollution patterns brought on by the changes to green space patterns.

This paper consists of six parts. The research motives and purpose, contents and previous research outcomes have been described in this section. The second part contains an outline of the research design, including the analytical framework, method and definition of variables, and hypotheses. The description of the empirical sample is provided in the third section. The analysis of the trend of green space changes is provided in the fourth part. The fifth section contains an analysis of green space changes' on air pollution and microclimates, and an explanation of the results of model calibrations as well as empirical analysis. The conclusions and suggestions are proposed in the final section.

2. Research Design

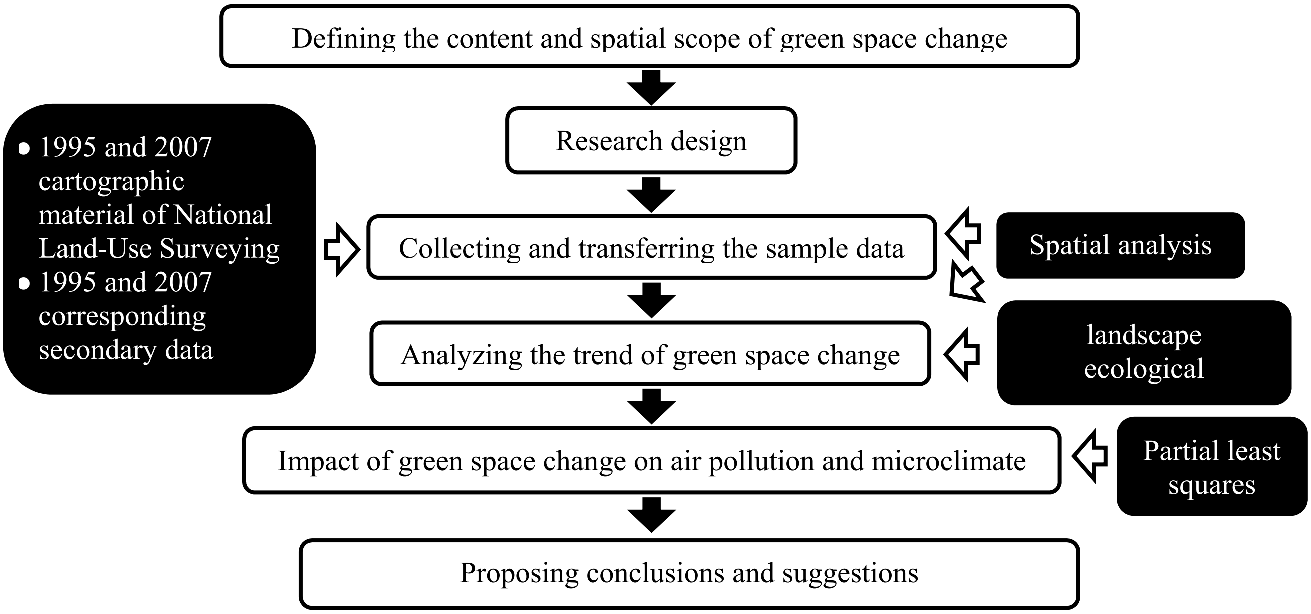
2.1. Analytical Framework

The contents of various steps in this framework include the following (See also Figure 1):

(1) Defining the content and the spatial scope of green space changes: Confirm the research category and scope of green space change.
(2) Developing the research design: Determine the method, variables and hypotheses based on the theme and purposes of this study.

(3) Collecting and transferring the sample data: Collect and convert corresponding secondary data and cartographic material of the National Land-Use Survey from 1995 and 2007 through spatial analysis.
(4) Analyze the trend of green space change: Identify the state of green space change and migration between different land uses through land transfer matrix and spatial analysis. Additionally, analyze the spatial structure/composition change of green space through landscape ecology metrics.
(5) Discovering the impact of green space change on air pollution and the microclimate: Analyze the effect of green space change on air pollution and the microclimate, and identify the critical effect through partial least squares (PLS).
(6) Proposing conclusions and corresponding suggestions.

Figure 1. Analytical framework.



2.2. Method

2.2.1. Spatial Analysis

Spatial analysis is the method we employed to analyze spatial location, spatial distribution, spatial form, spatial space, spatial relationships and spatial change of object/events by topological, geometric, and geographic properties. The content of spatial analysis includes spatial data conversion and production, map rendering, exploratory data analysis, spatial statistics and simulation analysis [41,42].

For this paper, we used spatial analysis from the Geographic Information System (GIS) to process spatial data conversion, map rendering and spatial change analysis. With regard to spatial data conversion, we converted the spatial data from vectors into grid form, and re-categorized the land-use patterns of the Taipei Metropolitan Area from cartographic material provided via the National Land-Use Survey for 1995 and for 2007. Additionally, we used the Universal Kriging method (Universal Kriging method is Kriging with a local trend. The local trend or drift is a continuous and slowly varying trend surface on top of which the variation to be interpolated is superimposed. The local trend is recomputed for each output pixel and the operation is therefore more similar to the Moving Surface operation than to the Trend Surface operation [43,44].) to interpolate the missing data on air pollution and the microclimate in the districts of the Taipei Metropolitan Area. Through map rendering, this study illustrates green space change. For spatial change analysis, we identified the trends of green-space changes and migration between different land uses within the Taipei Metropolitan Area through a land transfer matrix, which was made by calculating transfer grids of land use from 1995 to 2007.

2.2.2. Landscape Ecological Metrics

Landscape Ecological Metrics can measure the context and structure of landscapes in different scales (such as patch level; class level and landscape level). This method is an important type of analysis utilized in landscape ecology (Landscape ecology emphasizes the interaction between spatial pattern, ecological process and scale, and focuses on the structure, function, change and management of landscape.) [45].

This paper uses Landscape Ecological Metrics to analyze the spatial structure of green space in the Taipei Metropolitan Area and its districts in 1995 and 2007. Moreover, it analyses the trend of green space change in the Taipei Metropolitan Area and its districts from 1995 to 2007.

2.2.3. Partial Least Squares

Partial Least Squares (PLS) is a form of structural equation modeling, distinguished from the classical method by being component-based rather than covariance-based.

The PLS algorithm is employed in PLS path modeling, a method of modeling a causal network of latent variables. The PLS model includes an inner model (The inner model is the part of the model that describes the relationships between the latent variables.) and an outer model (The outer model is the part of the model that describes the relationships between the latent variables and its observed variables.) [46]. PLS has an advantage in dealing with a reflective and formative model at the same time, strong predictive power, is suitable for analysis of small sample sizes, allows for analysis with multiple dependent variables and multiple independent variables, and avoids multicollinearity and limit on the sample distribution, such as dealing with interference data and missing data [46].

The sample size of this study is relatively small (only 48 administrative districts of Taipei metropolitan area), and the analytical model is reflective model. In addition, there are multiple dependent variables, multiple independent variables, and a complex relationship among those variables in the model. Thus, PLS is suitable for analyzing the impact of green space changes on air pollution and microclimate.

Because the sample size for this paper was relatively small, we adopted the Bootstrap Resampling Method for drawing 10,000 samples, and we used these samples to estimate the parameters and to verify our hypothesis. The Bootstrap Resampling Method is a nonparametric method that was proposed by Efron [47], and it adopts resampling. Thus, even if the sample size of the PLS model is too limited, the PLS model can be estimated accurately through resampling methods.

2.3. Definition of Variables and Hypotheses

The empirical analysis includes the trend of green space change and the impact of green space changes on air pollution and the microclimate. Thus, the above mentioned variables and hypotheses will be defined in the following section.

2.3.1. Green Space Change Analysis

Analysis of green space change is achieved through such indicators as landscape ecology metrics. Landscape ecology metrics includes three levels: patch level, class level and landscape level.

The patch level is the sum of the grids, and is measured by calculating the characteristics of each patch (such as shape index, edge contrast index, *etc.*). The class level is the sum of a group of the same category of patches, and is indicated by calculating the characteristics of all types of classes (such as class area, core area, percentage of landscape, *etc.*). The landscape level is the sum of all patches or classes in the region, and is indicated by measuring the characteristics of all kinds of classes (such as Shannon's diversity index, relative patch richness, *etc.*) [45].

When examining the green-space change in the Taipei Metropolitan Area from 1995 to 2007, we used landscape ecology metrics of the class level for analysis. Since the indicators of landscape ecology metrics are numerous and complex, an explanation of some indicators requires repetition. Therefore, 14 front indicators of landscape ecology metrics were selected and analyzed for the purpose of research, such as Percentage of Landscape (PLAND), Number of Patches (NP), Patch Density (PD), Mean Patch Area (AREA_MN), Area-weighted Mean Patch Area (Area_AM), Largest Patch Index (LPI), Mean Shape Index (MSI), Area-weighted Mean Shape Index (AWMSI), Mean Nearest Neighbor Distance (ENN_MN), Area-weighted Mean Nearest Neighbor Distance (ENN_AM), Percentage of Like Adjacencies (PLADJ), Splitting Index (SPLIT), Radius of Gyration (GYRATE_MN), Area-weighted Radius of Gyration (GYRATE_AM), Clumpiness Index (CLUMPY), Aggregation Index (AI). The formula, units and methodology employed in measuring these 14 indicators are explained in appendix, Table A1.

2.3.2. Impact of Green Space Change

(1). Definition of latent variables and of observed variables.

The purpose of analyzing the impact of green space change is to learn whether green space changes will affect the microclimate changes and air pollution changes, and if so, the degree of that influence. Therefore, we have provided the definitions of the perspective, the latent variables and the observed variables in Table 1.

The perspective includes three parts: "change of green space," "change of air pollution" and "change of microclimate."

The "change of green space" perspective includes six latent variables: "change of landscape," "change of fragmentation," "change of aggregation," "change of area," "change of proximity" and "change of largest patch percentage." With the exception of the observed variable of "changed area of maintaining and switching to green space," the other observed variables for measuring each latent variable are the changed rates of the landscape ecology metrics index.

The "change of air pollution" includes one latent variable: "change of air pollution emission." The observed variables for measuring the latent variable are the changed rates of different air pollutants, such as sulfur dioxide, nitrogen oxide, airborne particulate, carbon dioxide, nitric oxide and nitrogen dioxide.

The "change of microclimate" includes two latent variables: "change of rainfall type" and "change of temperature." The observed variable for measuring the "change of temperature" latent variable is the "change of mean annual temperature," and the observed variables for measuring the "change of rainfall type" latent variable are the "change of mean annual rainfall," "change of light rainy days," "change of torrential rainy days," and "change of non-rainy days". According to Taiwan's Climate Change Science Report [48] and the rainfall classification of the Central Weather Bureau, a standard of 0.1 mm ≤ daily precipitation <1.0 mm is defined as "light rainy day," a standard of daily precipitation ≥50.0 mm is defined as a "torrential rainy day," and a standard of daily precipitation <0.1 mm is defined as a "non-rainy day".

Table 1. The variables of PLS model.

Perspective	Latent Variables	Latent Variables Code	Observed Variables	Observed Variables Code
change of green space	change of Landscape	CL	• change of PLAND • changed area of maintaining and switching to the green space	cPLAND cWAERA
	change of fragmentation	CF	• change of NP • change of PD • change of SPLIT	cNP cPD cSPLIT
	change of aggregation	CA	• change of PLADJ • change of CLUMPY • change of AI	cPLADJ cCLUMPY cAI
	change of area	CR	• change of AREA-MN • change of AREA-AM	cAREA-MN cAREA-AM
	change of proximity	CN	• change of ENN-MN • change of ENN-AM	cENN-MN cENN-AM
	change of largest patch percentage	CP	• change of LPI	cLPI
change of air pollution	change of air pollution emission	CAP	• change of SO_2 emission • change of NO_x emission • change of PM emission • change of CO_2 emission • change of NO emission • change of NO_2 emission	SO_2 NO_x PM CO_2 NO NO_2
change of microclimate	change of rainfall type	CRT	• change of mean annual rainfall • change of light rainy day • change of torrential rainy day • change of non-rainy day	Rain lrd brd nrd
	change of temperature	CST	• change of mean annual temperature	Temp

(2). Set of hypothetical relationship

The PLS model constructed for this study includes an outer model and an inner model. In the hypothetical relationship of the outer model, with the exception of the relationships between the "changes of rainfall type" the latent variables and the "change of mean annual rainfall," the "change of light rainy days" observed variables were negative, and the other relationships of latent variables and observed variables were positive. The hypothetical relationships of the inner model include the impact of green space change on air pollution change and the microclimate change, and the impact of air pollution change on the microclimate change (Table 2).

Table 2. Hypothetical relationship of latent variables in PLS model.

Endogenous latent variables/ exogenous latent variables	Change of Landscape	Change of fragmentation	Change of aggregation	Change of area	Change of proximity	Change of largest patch percentage	Change of air pollution emission
change of air pollution emission	−	+	−	−	+	−	none
change of rainfall type	−	+	−	−	+	−	+/−
change of temperature	−	+	−	−	+	−	+/−

The above mentioned hypothetical relationships are as follows:

(1) The impact of green space change on air pollution change and microclimate changes.

The number and area of green space changes negatively affect changes in air pollution emissions and the microclimate. Thus, the "change of landscape" latent variables of the "change of green space" perspective are assumed to be opposite to the "change of air pollution emission," the "change of rainfall type" and "change of temperature" latent variables.

A large green space is synergistically helpful in reducing air pollution, the temperature and changes of rainfall type. Therefore, reducing the size of the green area and the percentage of the largest patch negatively impacts air quality, temperature and rainfall type. Keeping with the above statement, for this paper, we assumed the "change of air pollution emission," "change of rainfall type" and "change of temperature" latent variables were affected by the "change of area" and "change of largest patch percentage" latent variables of the "change of green space" perspective.

The aggregate effect of green space is the same as the scale effect of large green space; it can reduce air pollution, the temperature, and the change of rainfall type. Thus, the "change of aggregation" latent variables of the "change of green space" perspective are assumed to be opposite to the "change of air pollution emission," "change of rainfall type" and "change of temperature" latent variables.

The greater the nearest neighboring distance of green space, the more dispersive the patches and the less their effect in reducing air pollution, the temperature and the change of rainfall type. Moreover, the fragmentation of green space also has the same effect as the proximity of green space. Thus, the "change of fragmentation" and "change of proximity" latent variables of the "change of green space" perspective are assumed to be comparable to the "change of air pollution emission," the "change of rainfall type" and the "change of temperature" latent variables.

(2) The impact of air pollution change on microclimate change

Airborne particulate and sulfate aerosol reduce the volume of solar radiation and temperature through solar short wave radiation scattering (Because solar radiation enters into the atmosphere in the form of the short wave radiation, the more airborne particulate there are, the more the short wave radiation is reflected directly back into space. Thus, the above situation reduces the solar radiation reaching the earth surface). Air pollutants form easily in clouds, and clouds can reflect sunlight. In addition, clouds can warm through absorbing thermal radiation, as well as cool by diverting thermal radiation. The effect depends on the height and type of clouds [49–53]. Thus, the "change of air pollution emission" latent variables are assumed to affect the "change of temperature" latent variables.

Air pollutants are the source of cloud condensation nuclei (CCN). When air pollutants increase, the formation of rain is more difficult due to the number of cloud droplets increasing while the size of cloud droplets becomes smaller. Therefore, the formation of rain requires a substantially greater number of cloud droplets. Such a situation results in a change in the level of total rainfall and the number of rainy days, decreasing the number of light rainy days while increasing the frequency of torrential rainy days [52,54]. Thus, the "change of air pollution emission" latent variables are assumed to affect the "change of rainfall type" latent variables.

3. Data

3.1. Empirical Area

In this paper, we are examining the rapid development of green space change in the Taipei Metropolitan Area, and the impact of green space change on air pollution and on the microclimate. In surveying the development of each metropolitan area in Taiwan, we found it apparent that the Taipei Metropolitan Area has attracted the largest population and greatest number of industries, and these developments have taken place rapidly. Thus, the Taipei Metropolitan Area is suitable as an empirical research subject. In this paper, the spatial scale of empirical analysis includes the 48 administrative districts of Taipei City, New Taipei City and Keelung City.

3.2. Description of the Empirical Sample

The empirical analysis focuses on the trend of green space change and the impact of green space change on air pollution and on the microclimate. Thus, the above empirical sample is described as follows:

(1) Green space change analysis

For this paper, we collected the empirical sample from the National Land-Use Survey for 1995 and 2007, and took the land use (attributes) of each grid in the empirical area by reclassifying land use categories through GIS technology (Figures 2 and 3). The empirical sample uses the land transfer matrix and landscape ecological metrics as the input data for calculations. The data type of the empirical sample is the nominal scale.

Figure 2. Taipei metropolitan area land use investigation in 1995.

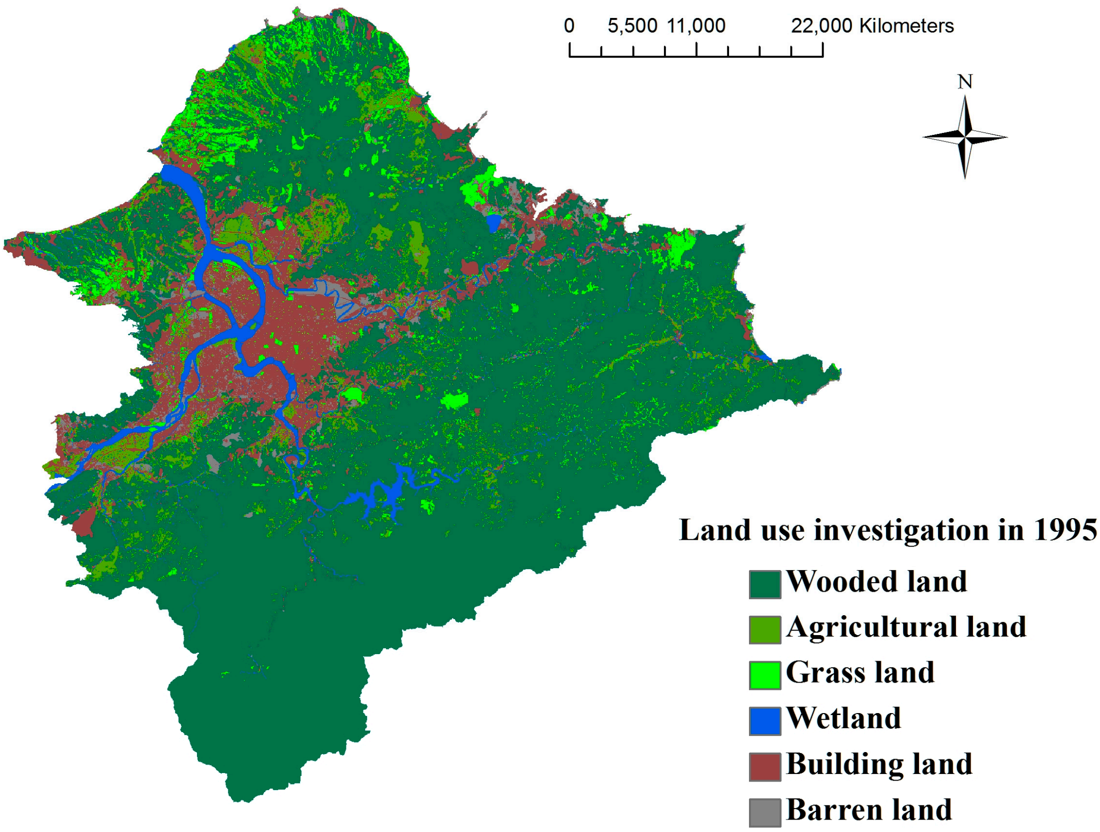
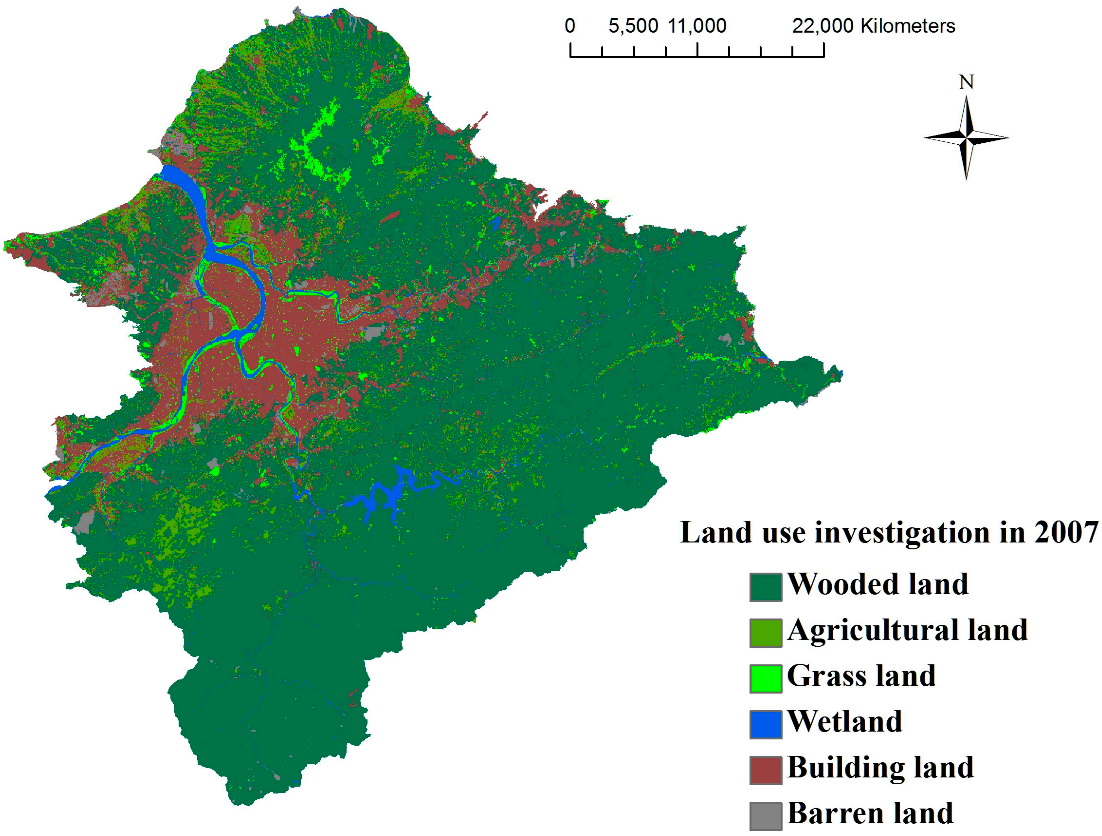


Figure 3. Taipei metropolitan area land use investigation in 2007.



(2) Impact of green space change.

In PLS modes, all empirical samples of observed variables are numerical data, and the units are percentages. The empirical sample of the "change of green space" perspective was collected from the National Land-Use Survey for 1995 and 2007, and was calculated by landscape ecological metrics and GIS technology. Additionally, the empirical sample of the "change of air pollution" and "change of microclimate" perspectives were gathered from the Environment Protection Agency for 1995 and 2007, and calculated by the Universal Kriging method to interpolate those missing data for air pollution and microclimates in the districts of the Taipei Metropolitan Area.

4. Trend of Green Space Change

4.1. States of Green Space Changes

According to the results of the green space transfer matrix in the Taipei Metropolitan Area from 1995 to 2007 (Table 3), green space area was reduced by 2339.5 hectares (occupies 1.19%), and 93.19% of the green space still retains its original use. According to the migration status, most green space is used for construction (occupies 4.87%), and increases in green space were created from wetland reclamation (occupies 32.38%) and barren land (occupies 38.15%), based on forestation and riverbank improvements.

Further analysis of green space in each sub-category of land use (such as wooded land, agricultural land, and grass land) finds that wooded land area has increased by 3377.5 hectares (occupies 2.03%), agricultural land area has decreased by 2323.5 hectares (occupies 12.05%) and grass land area has decreased by 3393.5 hectares (occupies 31.92%). According to the migration status of each sub-category of land use, 90.37% of the wooded land still maintains its original use, and the majority of agricultural land and grass land has been transfer to wooded land.

Table 3. Green space transfer matrix of Taipei Metropolitan Area from1995 to 2007 (Unit: ha).

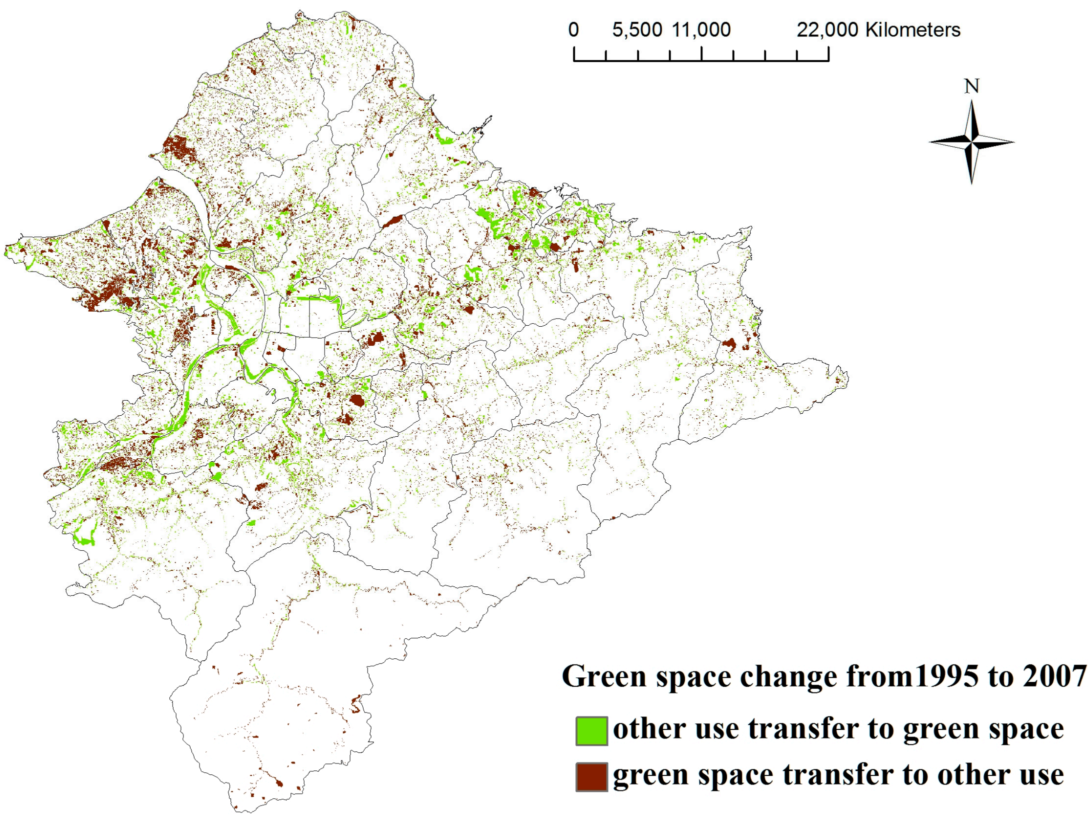
Land use area in 1995		**Land use area in 2007**							
		Green space				**Wetland**	**Building land**	**Barren land**	**Total**
		Wooded land	**Agricultural land**	**Grass land**	**Total**				
Green space	Wooded land	150,204.5	6524.5	2333.5	159,062.5	953.75	4989.25	1198	166,203.5
	Agricultural land	7917	6591.25	874	15,382.25	279	2975.25	648.5	19,285
	Grass land	5056.5	2036.25	1224	8316.75	186.5	1592.25	537	10,632.5
	Total	163178	15152	4431.5	182,761.5	1419.25	9556.75	2383.5	196,121
Wetland		1735.75	532.75	1326.5	3595	4877.5	1297.5	287.25	10,057.25
Building land		384.25	491.5	503.25	1379	283.75	25,376	1201.75	28,240.5
Barren land		1995.5	360.25	702.75	3058.5	188	2953.5	721.5	6921.5
Total		167,293.5	16,536.5	6964	190,794	6768.5	39,183.75	4594	241340.3
Area change		1090	−2748.5	−3668.5	−5327	−3288.75	10,943.25	−2327.5	-

Notes: 1. Left hand side represents the land use categories in 1995, and the land use categories in 2007 is on the top; 2. The number in the table represents the transferred areas from 1995 to 2007.

The districts of suburban and sub-core areas in the Taipei Metropolitan Area have decreased their maximum amount of green space, which change may have been caused by green space being transferred to public construction land or to large-scale residential land. In contrast, the built-up districts in the Taipei Metropolitan Area have preserved green space from development because the small amount of green space available is too limited to be advantageous to development, in addition to the fact that local residents guard it as a precious resource (Figure 4).

In summary, the green space area of the Taipei Metropolitan Area has been decreasing slightly, and most of the remaining green space is being transferred to the development of building projects. However, the area of green space has also increased from reclaimed wetlands (occupies 32.38%) and barren land (occupies 38.15%) based on forestation and riverbank improvements. Green space can still maintain its original function while not suffering serious damage from urban development.

Figure 4. Taipei metropolitan area green space change from1995 to 2007.



4.2. Results of Landscape Ecological Metrics

In accordance with the results of landscape ecological metrics is shown in Table 4 and the spatial change status of green space in the Taipei Metropolitan Area from 1995 to 2007 is shown in Appendix.

As shown in Table 4 and Appendix (Figure A1), the total green space area has been decreasing slightly, the green space still has a large proportion (occupies 80%) of the overall landscape and plays a vital role. The number and density of the green space patches is incremental, pointing to the more fragmented trend of the green space. In the change of the green space patches area, it shows the area of the large patch increasing and the area of small patch decreasing. In the change of the green space shape, it shows the shape of the entire green space tending toward simple shapes, while the shape of the large patch tends toward a complex shape. In the change of the green space aggregation, it indicates green space is still highly centralized (above 90%). In the change of the green space proximity, it represents the distribution of the entire green space tending toward aggregation and the distribution of the large patch showing no change. In the change of the green space extendibility, it demonstrates the connection of the large patch increase and of the small patch reduction, as it closely relates to the area change of large and small patches.

According to the results of landscape ecological metrics, Table 4 and Appendix (Figures A2–A4) also show the sub-category changes of green space in the Taipei Metropolitan Area from 1995 to 2007.

Comparing landscape ecological metrics in change of the green space, the results of wooded land are similar except for the increase of the total wooded land area. It is not significant change of the wooded land proximity.

In light of the landscape ecological metrics for change of the agricultural land, the decrease of the total agricultural land area and its small proportion (occupies 7%) of overall landscape indicates that agricultural land is not in the primary position. The increasing of the number and density of the agricultural land patches, and the decreasing of the agricultural land patches area show a more fragmental trend with agricultural land from 1995 to 2007, and the large patch is more critical. In the change of the agricultural land shape, it indicates that the shape of all agricultural land is being simplified, closely related to an anthropogenic subdivision. In the change of the agricultural land aggregation, it means the centralization of agricultural land has been reduced, and it also closely relates to the anthropogenic subdivision. In the change of the agricultural land proximity, it represents the distribution of the entire agricultural land, and the large patch shows no change. In the change of the agricultural land extendibility, it means the connection between the entire agricultural land and the large patch is being reduced.

According to the landscape ecological metrics, the change of grass land, the decrease of the total grass land area and the small proportion of the overall landscape mean the grass land is not in the main position. Compared with landscape ecological metrics change of the agricultural land, the results for the grass land are similar. However, the grass land is more fragmented and decentralized than the agricultural land.

Table 4. Landscape ecological metrics results of green space in Taipei Metropolitan Area.

landscape ecological metrics	**Green space**		**Wooded land**		**Agricultural land**		**Grass land**	
	1995	**2007**	**1995**	**2007**	**1995**	**2007**	**1995**	**2007**
PLAND	80.11	79.15	67.89	69.27	7.88	6.93	4.34	2.96
NP	1433	2450	1531	2456	6313	9524	3918	5637
PD	0.59	1.00	0.63	1.00	2.58	3.89	1.60	2.30
AREA_MN	136.86	79.10	108.56	69.045	3.05	1.78	2.71	1.28
AREA_AM	104,529.1	164,396.1	99,271.33	148,504.8	149.67	112.62	111.06	79.44
LPI	55.81	72.85	51.28	64.8	0.4	0.38	0.22	0.21
MSI	1.31	1.26	1.36	1.25	1.30	1.23	1.24	1.15
AWMSI	19.59	36.59	30.11	51.33	4.24	4.06	3.30	2.73
PLADJ	95.41	93.90	93.25	91.80	62.26	52.52	64.31	51.58
ENN_MN	154.95	137.05	137.52	138.41	152.8	148.06	203.76	210.74
ENN_AM	100.65	100.35	100.63	100.41	119.2	120.48	148.80	162.10
SPLIT	2.92	1.88	3.63	2.38	20,767.1	31,379.9	50,762	104,239
GYRATE_MN	81.61	62.37	85.15	55.8	56.08	45.68	52.7	41
GYRATE_AM	14,120.05	18,448.3	14,408.84	18,302.39	472.2	414.56	413.53	429.23

5. Impact of Green Space Change

5.1. Model Calibrations and Verifications

For calibrating and verifying the impact model, we first analyzed the reliability and validity of the outer model, and then verified the explanatory power and significance of the path coefficient in the inner model. Finally, this paper verifies the goodness of the fit in the empirical model through goodness of the fit (GoF) index. (GoF index is a global criterion of goodness-of-fit, and was proposed by Tenenhaus *et al*. [55].)

(1) Outer model verification

In the test of reliability, Bollen [56] considered the significance of the coefficient value in which the t-value of observed variables must be greater than 1.96 ($\alpha = 0.05$, under two-tailed test) showed that the observed variable could reflect the meaning of the latent variable and that the outer model was suitable. The loadings of observed variables in this paper are significant, except for the "change of torrential rainy day" observed variables. This means that the most observed variable can reflect the meaning of the latent variable, and that the outer model is suitable (Table 5). The composite reliability (CR) in the empirical model is between 0.72 and 1 (Table 6); the value is higher than the standard (0.7) [57,58] proposes. The above results demonstrate the internal consistency of latent variables and meet the requirements of construct reliability.

In the test of validity; the square roots of the average variance extracted (AVE) for each latent variable are all greater than the correlation coefficient of the latent variable and other latent variables; which means the latent variable in the model has discriminating validity [59,60]. In addition; the composite reliability value of the latent variables is greater than 0.7; and the AVE value of latent variables are all greater than 0.5. As follows; the latent variables in the model have convergent validity [57,61].

Table 5. Results of loadings and test statistics in outer model development.

Perspective	Latent Variables	Observed Variables	Loadings	Z-value	Significance
change of green space	change of Landscape	• change of PLAND	0.849	4.186	***
		• changed area of maintaining and switching to the green space	0.956	4.508	***
	change of fragmentation	• change of NP	0.933	9.461	***
		• change of PD	0.933	9.461	***
		• change of SPLIT	0.679	3.486	***
	change of aggregation	• change of PLADJ	0.996	11.101	***
		• change of CLUMPY	0.981	8.120	***
		• change of AI	0.996	11.110	***
	change of area	• change of AREA-MN	0.966	14.067	***
		• change of AREA-AM	0.952	14.170	***
	change of proximity	• change of ENN-MN	0.967	5.544	***
		• change of ENN-AM	0.963	4.508	***
	change of largest patch percentage	• change of LPI	1.000	-	

Table 5. *Cont.*

Perspective	Latent Variables	Observed Variables	Loadings	Z-value	Significance
change of air pollution	change of air pollution emission	• change of SO_2 emission	0.888	30.560	***
		• change of NO_x emission	0.987	190.027	***
		• change of PM emission	0.920	34.084	***
		• change of CO_2 emission	0.873	53.975	***
		• change of NO emission	0.893	37.403	***
		• change of NO_2 emission	0.974	148.107	***
change of microclimate	change of rainfall type	• change of mean annual rainfall	-0.686	2.909	**
		• change of light rainy day	-0.895	4.211	***
		• change of torrential rainy day	0.296	1.819	
		• change of none rainy day	0.385	1.997	*
	change of temperature	• change of mean annual temperature	1.000	-	

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6. Goodness of fit in model development.

Perspective	Latent Variables	Cronbach's α	CR [a]	Average	R Square
change of green space	change of Landscape	0.892	0.907	0.895	
	change of fragmentation	0.818	0.854	0.841	
	change of aggregation	0.991	0.994	0.982	
	change of area	0.913	0.958	0.919	
	change of proximity	0.927	0.965	0.932	
	change of largest patch percentage	1.000	1.000	1.000	
change of air pollution	change of air pollution emission	0.965	0.972	0.883	0.479
change of microclimate	change of rainfall type	0.701	0.718	0.699	0.328

Note: [a] CR means composite reliability.

(2) Inner model verification

According to the results of the inner model, the R^2 of "change of air pollution emission," "change of rainfall type" and "change of temperature" respectively are 0.4789, 0.3282 and 0.4656 (Table 6). According to the classification of explanatory power by Chin [62], the explanatory power for the impact of green space change on air pollution and on the microclimate is above the medium level.

Based on the significant test results of the path coefficient (Table 7), all latent variables in the "change of green space" perspective significantly affect the "change of air pollution emission" latent variable. The "change of landscape," "change of fragmentation," "change of area" and "change of air pollution emission" latent variables significantly affect the "change of rainfall type" latent variable. Finally, the "change of landscape," "change of fragmentation," "change of aggregation," "change of area," "change of largest patch percentage" and "change of air pollution emission" latent variables significantly affect the "change of temperature" latent variable.

Table 7. Empirical results of path coefficient in inner model.

Endogenous latent variables/exogenous latent variables	Change of Landscape	Change of fragmentation	Change of aggregation	Change of area	Change of proximity	Change of largest patch percentage	Change of air pollution emission
change of air pollution emission	−0.3619 **	0.2067 *	−0.2268 *	−0.2158 *	0.1161 *	−0.2211 *	-
change of rainfall type	−0.1162 *	0.1028 *	0.0088	−0.1042 *	0.0949	−0.1076	0.2726 *
change of temperature	−0.3523 *	0.2328 *	−0.1108 *	−0.1912 *	0.3148	−0.2022 *	−0.1707 *

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

(3) Goodness of fit in model

In this paper, the results have verified the goodness of fit in the empirical model through the GoF index as proposed by Tenenhaus *et al.* [55]. The GoF index was obtained as the geometric mean of the average communality index and the average R2 value. The GoF of the empirical model equals 0.61, a value higher than the 0.36 that Wetzels *et al.* [63] suggested, implying a suitable goodness of fit.

5.2. Results Analysis

The results of this study have verified the hypotheses and proposed the effects (such as direct effect, indirect effect, and total effect) of latent variables through PLS analysis (Figure 5). Among the effects, the indirect effect was calculated by the product-of-coefficients approach from Sobel [64], and tested the significance of the indirect effect with the Aroian test (The formula of Aroian test: $(a \times b)/SQRT\left(b^2 \times S_a^2 + a^2 \times S_b^2 + S_a^2 \times S_b^2\right)$, a, b is non-normalized coefficient, S_a^2, S_b^2 is the standard errors of a, b.) [65,66]. The effects of the latent variables are stated respectively as follows (Figure 5):

(1) The impact of green space change on air pollution change and microclimate change

According to the empirical results of the "change of landscape" latent variables, the number and area of green space change negatively affects the change of air pollution emission and microclimate. The total effect of the green space area and the amount of air pollution change was −0.3619, and the total effect was derived entirely from the direct effect. The total effect of the green space area and the amount of rainfall patterns change was −0.1876, which summarizes the direct effect (−0.1162) and the indirect effect (−0.0714) from air pollution change. The direct effect of green space area and the number of temperature changes was −0.3523, and the total effect equaled the direct effect based on the statistical test of indirect effects not being significant.

According to the empirical results of the "change of area" and "change of largest patch percentage" latent variables, the changed size of the green area and the changed percentage of the largest patch negatively affect the air quality and the temperature. In addition, the changed size of the green area also negatively affects the rainfall type. Thus, the empirical results prove the existence of scale effect. The total effect of "change of area" and "change of largest patch percentage" on "change of air pollution emission" respectively were −0.2158 and −0.2211. The total effect of "change of area" and "change of largest patch percentage" on "change of temperature" respectively were −0.1912 and −0.2022. The total effect of "change of area" on "change of rainfall type" was −0.1042. Moreover, these influences were all entirely from the direct effect.

According to the empirical results of the "change of aggregation" latent variables, the aggregate effect of green space change negatively affects the change of air pollution emission and temperature. Thus, the empirical results prove the existence of the aggregate effect. The total effect of green space aggregation on air pollution change was −0.2268, and the total effect of green space aggregation on the temperature change was −0.1108. Furthermore, the influences were all entirely from the direct effect.

According to the empirical results of the "change of fragmentation" latent variables, the fragmentation of green space change positively affect the change of air pollution emissions and the microclimate. Thus, the empirical results are proof of the existence of the fragmented effect. The total effect of "change of fragmentation" on "change of air pollution emission," "change of rainfall type" and "change of temperature" respectively were 0.2067, 0.1028 and 0.2328. Additionally, the influences were entirely from the direct effect. According to the empirical results of the "change of proximity" latent variables, the connection of green space change positively affects the change of air pollution emissions. The total effect of "change of proximity" on "change of air pollution emission" was 0.1161, and the influences were all entirely from the direct effect.

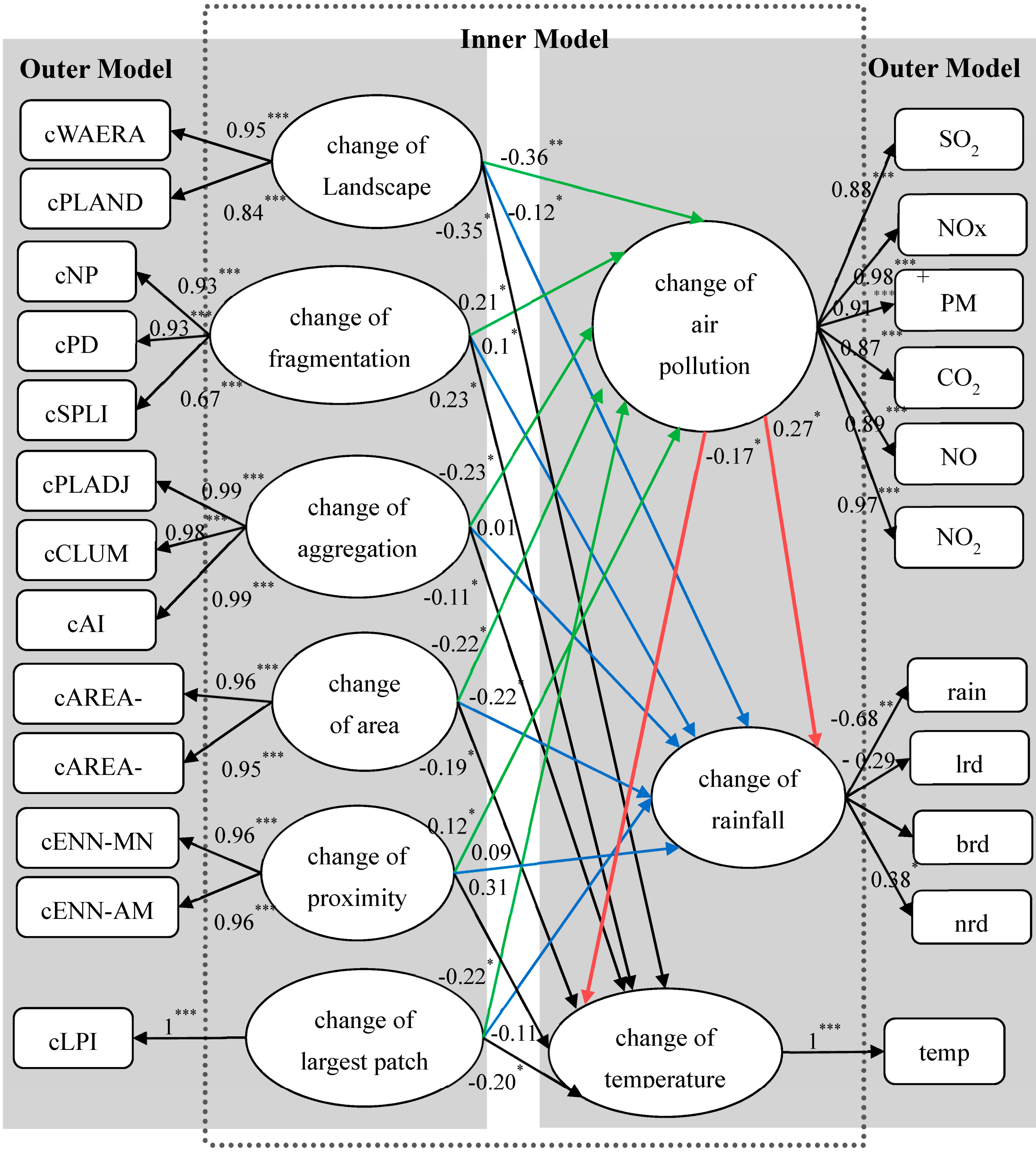
In summary, the green space functions to reduce air pollutants, to reduce temperatures, and to improve rainfall types. Additionally, green space also has the effect of scale and aggregation on these functions. Thus, increasing the number, aggregation, area, scale/size of the green space and decreasing the fragmentation and proximity of green space can strengthen its function of reducing air pollutants, cooling temperatures and improving rainfall types.

(2) The impact of air pollution change on microclimate change

According to the empirical results, air pollution emissions changes negatively affect temperature change, which means the cooling effect is higher than the warming effect. This result may be the cause of solar short wave radiation scattering and cloud cooling. The total effect of "change of air pollution emission" on "change of temperature" was −0.1707, and the influences were entirely from the direct effect.

According to the empirical results, the air pollution emissions changes positively affect rainfall type change, with the total effect being 0.2726. This result means that higher emissions of air pollution would reduce the frequency of the light rainy days and the mean annual rainfall, while increasing the number of non-rainy days. This result may reflect the cause of increases in the number of cloud droplets and the scale of cloud droplets becoming smaller.

Figure 5. The calibration results of the modified model.



Notes: 1. Green lines: the impact of "change of green space" on "change of air pollution", Blue lines: the impact of "change of green space" on "change of rainfall", Black lines: the impact of "change of green space" on "change of temperature", Red lines: the impact of "change of air pollution" on "change of rainfall" and "change of temperature". 2. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

6. Conclusions and Suggestions

Faced with the threats posed by global climate change while striving for the goal of sustainable development, increasing and conserving the green space area not only simultaneously achieves the effect both of mitigation and adaptation, but also helps in solving the problem of urbanization and non-sustainability. Recently, green space has often been transferred to other land uses because of the high level of urbanization. As a result, the environmental impact of reducing green space area is gradually becoming more significant. Therefore, for this research, we first applied space analysis and landscape ecology metrics to analyze the structural change of the pattern of green space areas within the 48 districts of the Taipei Metropolitan Area. We then used partial least squares to identify the consequences on microclimate and air pollution patterns caused by the changing patterns of green space area.

According to the empirical results, this paper concludes as follows:

(1) According to the analytical results, the green space area within the Taipei Metropolitan Areas has decreased 1.19% from 1995 to 2007, but 93.19% of the green space area have kept their original purposes.
(2) The results of landscape ecological metrics show the more fragmented trend of the green space. Regarding the change of the green space area, the large patch area is shown as increasing and the small patch area as decreasing. Regarding the change of the green space shape, the shape of the entire green space is shown as tending toward being simple, while the shape of the large patch tends toward being complex. The changes in green space aggregation mean that green space is still highly centralized. The changes in green space proximity represent the distribution of the entire green space tending toward aggregation, and the distribution of the large patch shows no change. The changes in green space extendibility demonstrate the connection between the large patch increase and the small patch reduction, as it closely relates to the area changes of the large and small patches.
(3) The results from the PLS model indicate that the changing pattern of green space area has a great influence on air pollution and microclimate patterns. For instance, less air pollution, smaller rainfall patterns, and cooler temperatures are associated with improvements in space aggregation, increasing the large sized green space patch. These results are similar to the research findings by Beatley [9], Jo [10], Yang *et al.* [11], Shin and Le [15], Herb *et al.* [16], and Leuzinger *et al.* [17]. However, they didn't discuss the patterns of green space, they only emphasized the total areas of green space. Although anthropogenic heat release is one of the important factors affecting air pollution and microclimates [32,36] in urban areas, we would assume that green space changes and anthropogenic heat release increase are major factors affecting the air pollution and microclimate pattern in cities.
(4) According to the results of the PLS model, the air pollution emissions change negatively affects the temperature change because of the cooling effect being higher than the warming effect. These results are similar to the findings by De Oliveira *et al.* [49], Koronakis *et al.* [50], and Wei and Hsu [52]. Moreover, the air pollution emission change positively affects the rainfall type change, which means the higher emission of air pollution reduces the occurrence of light rainy days and the mean annual rainfall and increases the number of non-rainy days. These results are consistent with Allen and Ingram [54].

Finally, in this paper we propose several suggestions based on the empirical results:

(1) The transfer of green space always occurs in the core area, in the sub-core area, and in the surrounding area. Thus, an urban growth boundary should be designated to avoid urban sprawl and the loss of green space.

(2) The trends and locations of wooded lands, agricultural lands and grass lands are different, and the conservation policies for green space should be adjusted for these different forms. The wooded land in suburbs should be effectively conserved to avoid decreases in the core areas and sub-core areas. Agricultural land should avoid arbitrary releases and transfers to land for development and construction while maintaining the integrity of the land. The grass land should be the focus of concern with regard to its change in the suburbs and sub-central area, and enhanced with conservation to avoid its loss.

(3) Green space has the function of reducing air pollutants, cooling temperatures and improving rainfall types. In addition, green space has the effect of scale and aggregation with regard to these functions. Thus, the development of the green space concept (such as a green city, garden city, green infrastructure) and policy (green space conservation) can be one of the solutions to climate change. Moreover, laws and governmental mechanisms relating to green space should be drafted immediately to help implement green policies.

(4) In this paper, we have only analyzed the changes from 1995 to 2007 due to limitations in data. If sufficient data can be provided in the future, these changes can be analyzed over a longer term.

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Author Contributions

Hsiao-Lan Liu is responsible for the conceptual design and actively involved in all steps of its implementation. Yu-Sheng Shen is responsible for developing the methodological framework.

Appendix

Table A1. The indicators of landscape ecology metrics (class level).

Indicator	Formula	Units	indicator content and measuring purpose
Percentage of Landscape (PLAND)	$\left(\sum_{j=1}^{n} a_{ij} \middle/ A\right)(100)$ a_{ij}: area of patch j (class i). A: total landscape area.	%	PLAND equals the percentage the landscape comprised of the corresponding patch type. The higher PLAND is, the more important the patch of corresponding class is. This paper use PLAND to analyze the importance of green space in landscape.
Number of Patches (NP)	n_i n_i: number of patches in the landscape of patch type (class) i.	None	NP equals the number of patches of the corresponding patch type. The higher NP is, the more fragmented the patch of corresponding class is. This paper use NP to analyze the fragmentation of green space in landscape.
Patch Density (PD)	$(n_i/A)(10{,}000)(100)$ n_i, A: definition as before.	Number per 100 hectares	PD equals the percentage the landscape comprised of the patches of the corresponding class. The higher PD is, the more fragmented the patch of corresponding class is. This paper use PD to analyze the fragmentation of green space in landscape.

Table A1. *Cont.*

Indicator	Formula	Units	indicator content and measuring purpose
Mean Patch Area (AREA_MN)	$\left(\sum_{j=1}^{n} a_{ij} \Big/ n_i\right)(\frac{1}{10000})$ a_{ij}, n_i：definition as above.	Hectares	AREA_MN provides the measure of patch area in corresponding class. The higher AREA_MN is, the larger the patch of corresponding class is. This paper use AREA_MN to analyze the size of green space patch in landscape.
Area-Weighted Mean Patch Area (AREA_AM)	$\sum_{j=1}^{n}\left[a_{ij}\,(a_{ij} \Big/ \sum_{j=1}^{n} a_{ij})\right](\frac{1}{10000})$ a_{ij}: definition as before.	Hectares	AREA_AM provides the measure of area-weighted patch area in corresponding class. The higher AREA_ AM is, the larger the patch of corresponding class is. This paper use AREA_MN to analyze the size of green space patch in landscape based on reducing the impact of small patches changes, and to compare with AREA_MN.
Largest Patch Index (LPI)	$\left(MAX(a_{ij}) / A\right)(100)$ a_{ij}, A: definition as before.	%	LPI equals the percentage of the landscape comprised by the largest patch. The higher LPI is, the more important the patch of corresponding class is. This paper use LPI to analyze the contribution of largest patch, and to identify the advantage category in landscape.
Mean shape index (MSI)	$\sum_{j=1}^{n}\left(0.25\, p_{ij} / \sqrt{a_{ij}}\right) \Big/ n_i$ p_{ij}: perimeter of patch j (class i). a_{ij}, n_i: definition as above.	None	MSI provides the measure of patch shape in corresponding class. The higher MSI is, the more complex the patch shape in corresponding class is. This paper use MSI to analyze the complexity of the green space patch shape in corresponding class.
Area-Weighted Mean Shape Index (AWMSI)	$\sum_{j=1}^{n}\left[\left(0.25\, p_{ij} / \sqrt{a_{ij}}\right)\left(a_{ij} \Big/ \sum_{j=1}^{n} a_{ij}\right)\right]$ p_{ij}, a_{ij}: definition as above.	None	AWMSI provides the measure of area-weighted patch shape in corresponding class. The higher AWMSI is, the more complex the patch shape in corresponding class is. This paper use AWMSI to analyze the complexity of green space patch in corresponding class based on reducing the impact of small patches changes, and to compare with MSI.
Mean Nearest Neighbor Distance (ENN_MN)	$\sum_{j=1}^{n'} h_{ij} \Big/ n'_i$ h_{ij}：distance between patch j (class i) to patch of the corresponding type; n'_i： number of patches in the landscape of patch type (class) i which having nearest neighbor distance.	Meter	ENN_MN provides the measure of patch distance in corresponding class. The higher ENN_MN is, the more dissipative the patch in corresponding class is. This paper use ENN_MN to analyze the proximity of each green space patches in corresponding class.

Table A1. *Cont.*

Indicator	Formula	Units	indicator content and measuring purpose
Area-Weighted Mean Nearest Neighbor Distance (ENN_AM)	$\sum_{j=1}^{n}\left[h_{ij}\left(a_{ij}\Big/\sum_{j=1}^{n}a_{ij}\right)\right]$ h_{ij}, a_{ij}：definition as above.	Meter	ENN_AM provides the measure of area-weighted patch distance in corresponding class. The higher ENN_AM is, the more dissipative the patch in corresponding class is. This paper use ENN_AM to analyze the proximity of each green space patches in corresponding class based on reducing the impact of small patches changes, and to compare with ENN_MN.
Percentage of Like Adjacencies (PLADJ)	$\left(g_{ii}\Big/\sum_{k=1}^{m}g_{ik}\right)(100)$ g_{ii}: number of like adjacencies between pixels of patch type (class) i based on the double-count method. g_{ik}: number of adjacencies between pixels of patch types (classes) i and k based on the double-count method.	%	PLADJ equals the percentage of cell adjacencies involving the corresponding patch type that are like adjacencies. PLADJ equals 0 when the corresponding patch type is maximally disaggregated and there are no like adjacencies. In contrast, The higher of PLADJ means high aggregation of the same type patch. This paper use PLADJ to analyze the aggregation of green space patches in corresponding class.
Splitting Index (SPLIT)	$A^2\Big/\sum_{j=1}^{n}a_{ij}^2$ a_{ij}, A: definition as above.	None	SPLIT provides the measure separation of patch in corresponding class. SPLIT equals 1 when the landscape consists of single patch. SPLIT increases as the focal patch type is increasingly reduced in area and subdivided into smaller patches. This paper use PLADJ to analyze the separation of green space patches in corresponding class.
Radius of Gyration (GYRATE_MN)	$\sum_{r=1}^{z'}\left(h_{ijr}/z\right)$ h_{ijr}: distance between cell ijr (located within patch ij) and the centroid of patch ij (the average location), based on cell center to cell center distance. z: number of cells in patch ij.	Meter	GYRATE_MN provides the measure of patch connection and extendibility in corresponding class. The higher GYRATE_MN is, the more connected the patch in corresponding class is. This paper use GYRATE_MN to analyze the connection of green space patch in corresponding class.
Area-Weighted Radius of Gyration (GYRATE_AM)	$\sum_{j=1}^{n}\left[\sum_{r=1}^{z'}\left(h_{ijr}/z\right)\left(a_{ij}\Big/\sum_{j=1}^{n}a_{ij}\right)\right]$ h_{ijr}, a_{ij}, z: definition as above.	Meter	GYRATE_AM provides the measure of area-weighted patch connection in corresponding class. The higher GYRATE_AM is, the more connected the patch in corresponding class is. This paper use GYRATE_AM to analyze the connection of green space patch in corresponding class based on reducing the impact of small patches changes, and to compare with GYRATE_MN.

Table A1. *Cont.*

Indicator	Formula	Units	indicator content and measuring purpose
Clumpiness Index (CLUMPY)	$\begin{cases}(G_i - P_i)/(P_i) & for \quad G_i < P_i < 0.5 \\ G_i - P_i/1 - P_i & else\end{cases}$ $G_i = g_{ii} \Big/ \left[\left(\sum_{k=1}^{m} g_{ik}\right) - \min\ e_i\right]$ P_i: proportion of the landscape occupied by patch type (class) *i*. min e_i: minimize the perimeter under the compact patch type (class) *i* of fixed grid number. g_{ii}, g_{ik}: definition as above.	None	CLUMPY provides the measure of patch aggregation in corresponding class. CLUMPY equals -1 when the focal patch type is maximally disaggregated. CLUMPY equals 0 when the focal patch type is distributed randomly, and approaches 1 when the patch type is maximally aggregated. This paper use CLUMPY to analyze the aggregation of green space patch in corresponding class.
Aggregation Index (AI)	$[g_{ss}/(\max\rightarrow g_{ss})](100)$ g_{ss}: number of like adjacencies between pixels of patch type (class) *s* based on the *single-count* method. max→g_{ss}: maximum number of like adjacencies between pixels of patch type (class) *s* based on the *single-count* method.	%	AI provides the measure of patch aggregation in corresponding class. AI equals 0 when the focal patch type is maximally disaggregated. AI increases as the focal patch type is increasingly aggregated and equals 100 when the patch type is maximally aggregated into a single, compact patch. This paper use AI to analyze the aggregation of green space patch in corresponding class.

Source: Leitão *et al.*[45], McGarigal and Mark [67].

Figure A1. Change of landscape ecological metrics results from 1995 to 2007 (Green Space).

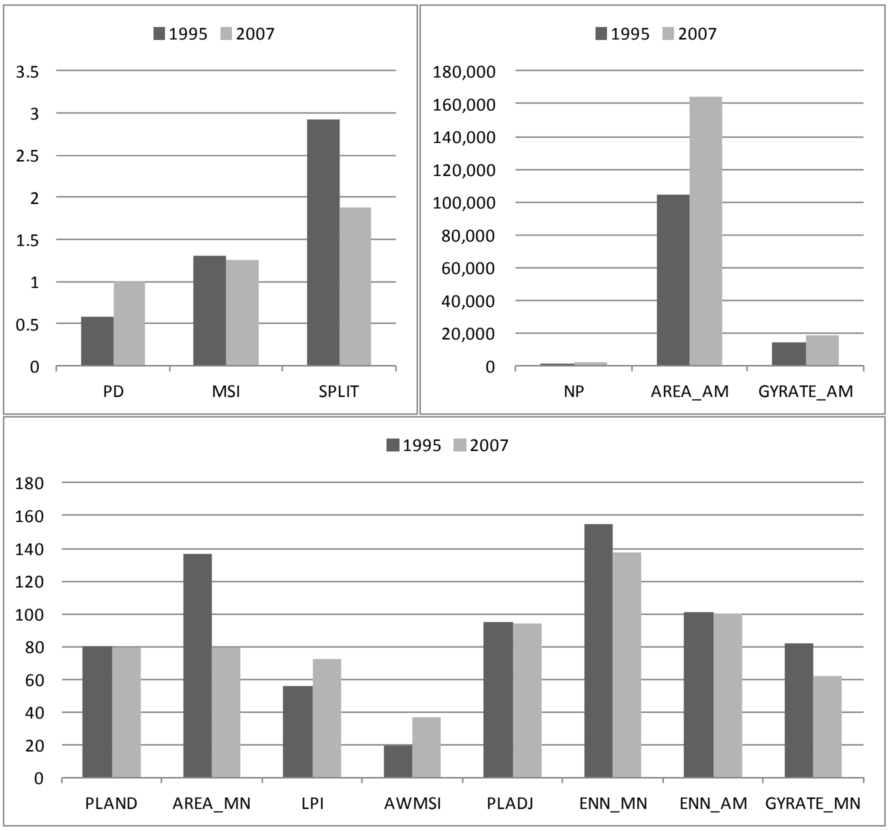


Figure A2. Change of landscape ecological metrics results from 1995 to 2007 (Wooded Land).

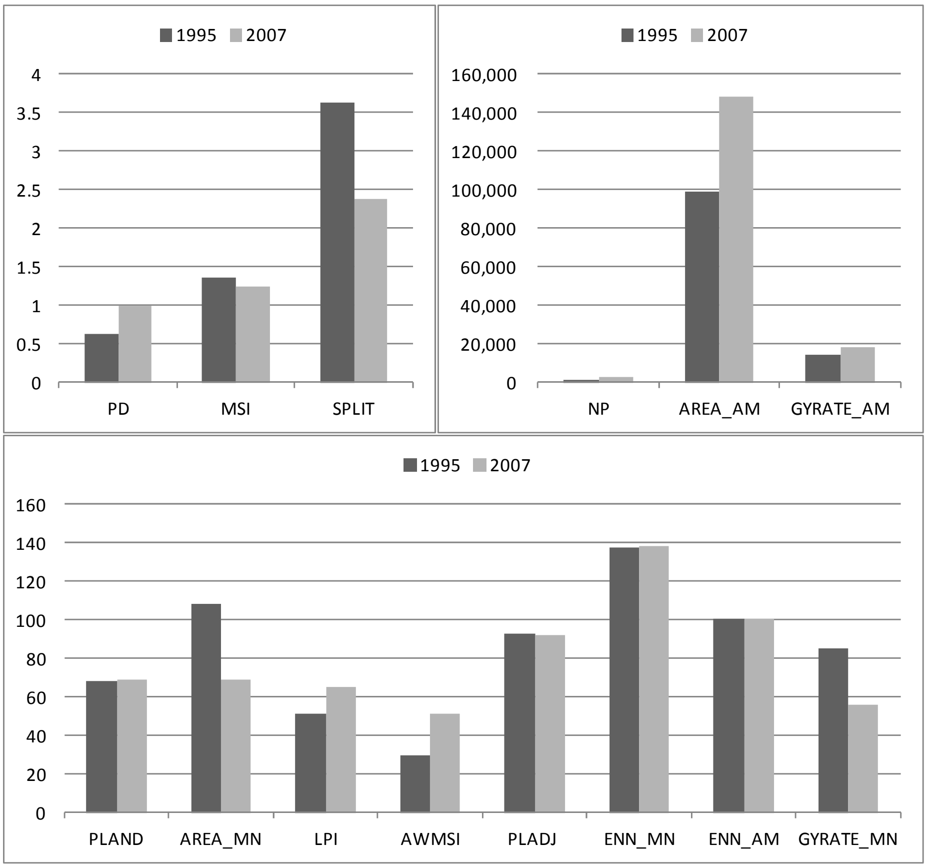


Figure A3. Change of landscape ecological metrics results from 1995 to 2007 (Agricultural Land).

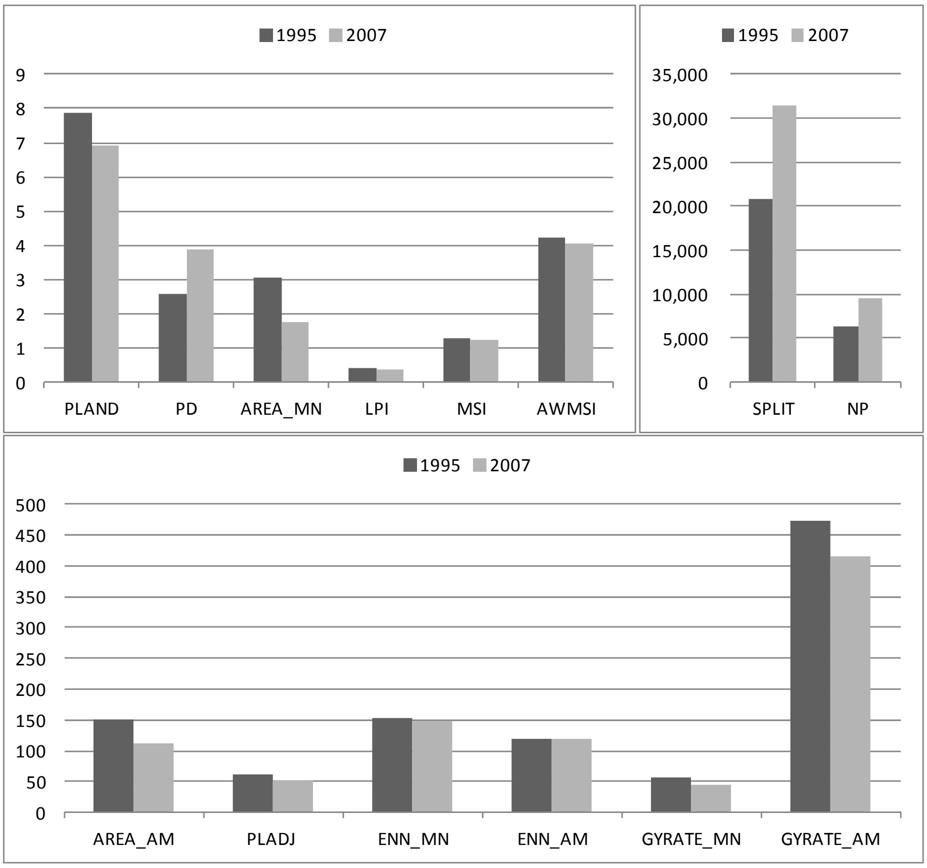
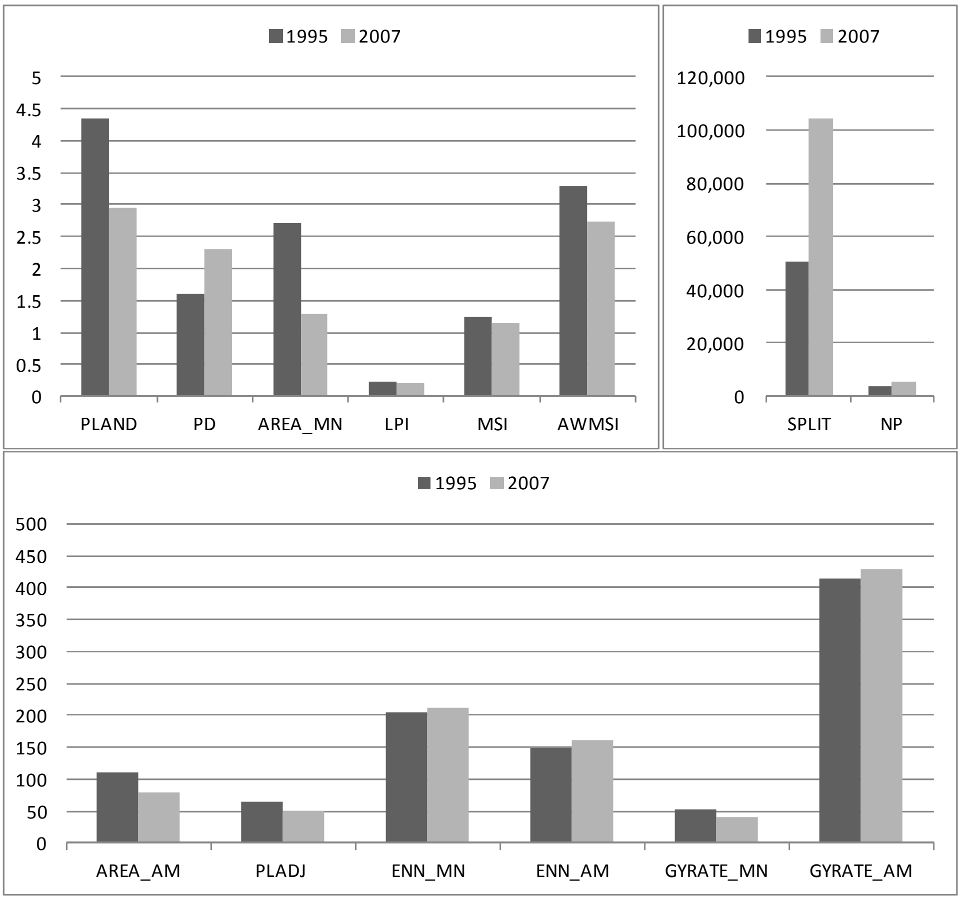


Figure A4. Change of landscape ecological metrics results from 1995 to 2007 (Grass Land).



Conflicts of Interest

The authors declare no conflict of interest.

References

1. Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; van der Linden, P.J.; Hanson, C.E. *Climate Change 2007: Impacts, Adaptation and Vulnerability—Working Group II Contribution to IPCC Fourth Assessment Report*; Cambridge University Press: Cambridge, UK, 2007.
2. Metz, B.; Davidson, O.R.; Bosch, P.R.; Dave, R. *Climate Change 2007: Mitigation of Climate Change—Working Group III Contribution to IPCC Fourth Assessment Report*; Cambridge University Press: Cambridge, UK, 2007.
3. Tol, R.S.J. Adaptation and mitigation: Trade-offs in substance and methods. *Environ. Sci. Policy* **2005**, *8*, 572–578.
4. Hunt, A.; Watkiss, P. Climate change impacts and adaptation in cities: A review of the literature. *Clim. Change* **2011**, *104*, 13–49.
5. Ahern, J. Planning for an extensive open space system: Linking landscape structure and function. *Landsc. Urban Plan*. **1991**, *21*, 131–145.

6. Flores, A.; Pickett, S.T.A.; Zipperer, W.C.; Pouyat, R.V.; Pirani, R. Adopting a modern ecological view of the metropolitan landscape: The case of a greenspace system for the New York City region. *Landsc. Urban Plan.* **1998**, *39*, 295–308.
7. Linehan, J.; Gross, M.; Finn, J. Greenway planning: Developing a landscape ecological network approach. *Landsc. Urban Plan*. **1995**, *33*, 179–193.
8. Fang, C.F.; Ling, D.L. Investigation of the noise reduction provided by tree belts. *Landsc. Urban Plan.* **2003**, *63*, 187–195.
9. Beatley, T. *Green Urbanism: Learning from European Cities*; Island Press: Washington, DC, USA, 2000.
10. Jo, H.K. Impacts of urban green space on offsetting carbon emissions for middle Korea. *J. Environ. Manag*. **2002**, *64*, 115–126.
11. Yang, J.; McBride, J.; Zhou, J.; Sun, Z. The urban forest in Beijing and its role in air pollution reduction. *Urban For. Urban Green*. **2005**, *3*, 65–78.
12. Gill, S.E.; Handley, J.F.; Ennos, A.R.; Pauleit, S. Adapting cities for climate change: The role of the green infrastructure. *Built Environ*. **2007**, *33*, 115–133.
13. Pauleit, S.; Duhme, F. Assessing the environmental performance of land cover types for urban planning. *Landsc. Urban Plan*. **2000**, *52*, 1–20.
14. Miller, G.T.; Spoolman, S. *Environmental Science: Problems, Concepts, and Solutions*; Thomson Brooks/Cole: Pacific Grove, CA, USA, 2008.
15. Shin, D.H.; Lee, K.S. Use of remote sensing and geographical information systems to estimate green space surface-temperature change as a result of urban expansion. *Landsc. Ecol. Eng*. **2005**, *1*, 169–176.
16. Herb, W.R.; Janke, B.; Mohseni, O.; Stefan, H.G. Ground surface temperature simulation for different land covers. *J. Hydrol.* **2008**, *356*, 327–343.
17. Leuzinger, S.; Vogt, R.; Körner, C. Tree surface temperature in an urban environment. *Agric. For. Meteorol*. **2010**, *150*, 56–62.
18. Shashua-Bar, L.; Hoffman, M.E. The Green CTTC model for predicting the air temperature in small urban wooded sites. *Build. Environ.* **2002**, *37*, 1279–1288
19. Shashua-Bar, L.; Hoffman, M.E. Vegetation as a climatic component in the design of an urban street: An empirical model for predicting the cooling effect of urban green areas with trees. *Energy Build*. **2000**, *31*, 221–235.
20. Song, I.J.; Hong, S.K.; Kim, H.O.; Byun, B.; Gin, Y. The pattern of landscape patches and invasion of naturalized plants in developed areas of urban Seoul. *Landsc. Urban Plan*. **2005**, *70*, 205–219.
21. Mathieu, R.; Freeman, C.; Aryal, J. Mapping private gardens in urban areas using object-oriented techniques and very high-resolution satellite imagery. *Landsc. Urban Plan*. **2007**, *81*, 179–192.
22. Whitford, V.; Ennos, A.R.; Handley, J.F. City form and natural process—Indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landsc. Urban Plan.* **2001**, *57*, 91–103.
23. Coley, R.L.; Kuo, F.E.; Sullivan, W.C. Where does community grow? The social context created by nature in urban public housing. *Environ. Behav*. **1997**, *29*, 468–494.
24. Thompson, C.W. Urban open space in the 21st century. *Landsc. Urban Plan*. **2002**, *60*, 59–72.
25. Chiesura, A. The role of urban parks for the sustainable city. *Landsc. Urban Plan*. **2004**, *68*, 129–138.

26. Grahn, P.; Stigsdotter, U.A. Landscape planning and stress. *Urban For. Urban Green.* **2003**, *2*, 1–18.
27. De Vries, S.; Verheij, R.A.; Groenewegen, P.P.; Spreeuwenberg, P. Natural environments-healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environ. Plan*. **2003**, *35*, 1717–1731.
28. Gobster, P.H.; Westphal, L.M. The human dimensions of urban greenways: Planning for recreation and related experiences. *Landsc. Urban Plan*. **2004**, *68*, 147–165.
29. Pauleit, S.; Ennos, R.; Golding, Y. Modeling the environmental impacts of urban land use and land cover change—A study in Merseyside, UK. *Landsc. Urban Plan*. **2005**, *71*, 295–310.
30. Meyer, W.B.; Turner, B.L. Human-population growth and global land-use cover change. *Annu. Rev. Ecol. Syst.* **1992**, *23*, 39–61.
31. Han, L.; Zhou, W.; Li, W.; Li, L. Impact of urbanization level on urban air quality: A case of fine particles (PM2.5) in Chinese cities. *Environ. Pollut*. **2014**, *194*, 163–170.
32. Civerolo, K.; Hogrefe, C.; Lynn, B.; Rosenthal, J.; Ku, J.Y.; Solecki, W.; Cox, J.; Small, C.; Rosenzweig, C.; Goldberg, R.; *et al*. Estimating the effects of increased urbanization on surface meteorology and ozone concentrations in the New York City metropolitan region. *Atmos. Environ*. **2007**, *41*, 1803–1818.
33. Li, B.; Wu, X. Economic structure and intensity influence air pollution model. *Energy Proced*. **2011**, *5*, 803–807.
34. Guttikunda, S.K.; Carmichael, G.R.; Calori, G.; Eck, C.; Woo, J.H. The contribution of megacities to regional sulfur pollution in Asia. *Atmos. Environ*. **2003**, *37*, 11–22.
35. Lindén, J.; Boman, J.; Holmer, B.; Thorsson, S.; Eliasson, I. Intra-urban air pollution in a rapidly growing Sahelian city. *Environ. Int*. **2012**, *40*, 51–62.
36. Arnfield, A.J. Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *Int. J. Climatol.* **2003**, *23*, 1–26.
37. Zhong, S.; Yang, X.Q. Ensemble simulations of the urban effect on a summer rainfall event in the Great Beijing Metropolitan Area. *Atmos. Res.* **2015**, *153*, 318–334.
38. Kantzioura, A.; Kosmopoulos, P.; Zoras, S. Urban surface temperature and microclimate measurements in Thessaloniki. *Energy Build*. **2012**, *44*, 63–72.
39. Weng, Q. A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China. *Int. J. Rem. Sens*. **2001**, *22*, 1999–2014.
40. Landsberg, H.E. *The Urban Climate*; Academic Press: New York, NY, USA, 1981.
41. Fotheringham, S.; Rogerson, P. *Spatial Analysis and GIS*; Taylor & Francis: London, UK, 1994.
42. Fischer, M.M.; Getis, A. *Handbook of Applied Sapatial Analysis: Software Tools, Methods and Applications*; Springer-Verlag Berlin Heidelberg: Berlin, German, 2010.
43. Selby, B.; Kockelman, K.M. Spatial prediction of traffic levels in unmeasured locations: Applications of universal kriging and geographically weighted regression. *J. Transp. Geogr*. **2013**, *29*, 24–32.
44. Brus, D.J.; Heuvelink, G.B.M. Optimization of sample patterns for universal kriging of environmental variables. *Geoderma* **2007**, *138*, 86–95.
45. Leitão, A.B.; Miller, J.; Ahern, J.; McGarigal, K. *Measuring Landscapes: A Planner's Handbook*; Island Press: Washington, DC, USA, 2006.

46. Hair, J.F.; Hult, G.T.M.; Ringle, C.M.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*; Sage: Thousand Oaks, CA, USA, 2014.
47. Efron, B. Bootstrap methods: Another look at the jackknife. *Ann. Stat.* **1979**, *7*, 1–26.
48. National Science Council. *Climate Change in Taiwan: Scientific Report 2011*; National Science Council: Taipei, Taiwan, 2011.
49. De Oliveira, A.P.; Machado, A.J.; Escobedo, J.F.; Soares, J. Diurnal evolution of solar radiation at the surface in the city of São Paulo: Seasonal variation and modeling. *Theor. Appl. Climatol.* **2002**, *71*, 231–250.
50. Koronakis, P.S.; Sfantos, G.K.; Paliatsos, A.G.; Kaldellis, J.K.; Garofalakis, J.E.; Koronaki, I.P. Interrelations of UV-global/global/diffuse solar irradiance components and UV-global attenuation on air pollution episode days in Athens, Greece. *Atmos. Environ*. **2002**, *36*, 3173–3181.
51. Graedel, T.E.; Crutzen, P.J. *Atmosphere, Climate, and Change*; Scientific American Library: New York, NY, USA, 1994.
52. Wei, K.Y.; Hsu, H.H. *Global Change: An introduction*; Ministry of Education: Taipei City, Taiwan, 1997. (In Chinese)
53. Ding, Z.D. *Energy Crisis*; Wu-Nan Book Inc.: Taipei City, Taiwan, 2009. (In Chinese)
54. Allen, M.R.; Ingram, W.J. Constraints on future changes in climate and the hydrologic cycle. *Nature* **2002**, *419*, 224–232.
55. Tenenhaus, M.; Amato, S.; Esposito Vinzi, V. A global goodness-of-fit index for PLS structural equation modeling. Available online: http://www.old.sis-statistica.org/files/pdf/atti/RSBa2004p739-742.pdf (accessed on 23 November 2014).
56. Bollen, K.A. *Structural Equations with Latent Variables*; Wiley: New York, NY, USA, 1989.
57. Fornell, C.; Larcker, D.F. Structural equation models with unobservable variables and measurement errors. *J. Mark. Res.* **1981**, *18*, 382–388.
58. Hulland, J. Use of partial least squares (PLS) in strategic management research: A review of four recent studies. *Strateg. Manag. J.* **1999**, *20*, 195–204.
59. Hair, J.F.; Anderson, R.E.; Tatham, R.L.; Babin, B.; Black, W.C. *Multivariate Data Analysis*; Prentice-Hall: Upper Saddle River, NJ, USA, 2006.
60. Esposito Vinzi, V.; Chin, W.W.; Henseler, J.; Wang, H. *Handbook of Partial Least Squares: Concepts, Methods and Applications*; Springer: Berlin, German, 2010.
61. Tabachnick, B.G.; Fidell, L.S. *Using Multivariate Statistics*; Allyn and Bacon: Boston, MA, USA, 2001.
62. Chin, W.W. The partial least squares approach for structural equation modeling. In *Modern Methods for Business Research*; Taylor & Francis: London, UK, 1998; pp. 295–336.
63. Wetzels, M.; Odekerken-Schröder, G.; van Oppen, C. Using PLS path modeling for assessing hierarchical construct models: Guidelines and empirical illustration. *MIS Q*. **2009**, *33*, 177–195.
64. Sobel, M.E. Some new results on indirect effects and their standard errors in covariance structure models. *Soc. Methodol.* **1986**, *16*, 159–186.
65. MacKinnon, D.P.; Krull, J.L.; Lockwood, C.M. Equivalence of the mediation, confounding, and suppression effect. *Prev. Sci*. **2000**, *1*, 173–181.
66. Shrout, P.E.; Bolger, N. Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychol. Methods* **2002**, *7*, 422–445.

67. McGarigal, K.; Marks, B.J. *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure, USDA Forest Technique Report*; Pacific Northwest Research Station: Portland, OR, USA, 1995.