Chapter 11

# Do Degradation of Urban Greenery and Increasing Land Prices Often Come along with Urbanization?

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Additional information is available at the end of the chapter

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**Abstract**

In the wake of urbanization, driven by a variety of individual and socio-economic merits, human's basic residential needs and standard of living may be compromised in the urban areas, as the population agglomerates. However, the knowledge of the associations of urbanization with urban greenery and residential land prices is still in the pursuing process. This empirical research aims to contribute whether the degradation of essential living conditions is a trade-off for the pursued urban life. Hence, Taiwan is selected as the case to analyze the associated relations primarily between 1976 and 2016. The research methods involve descriptive statistics, the panel data analysis, and the cluster analysis. The panel data analysis demonstrates that degraded urban greenery and increasing residential land prices came along with the urbanization in Taiwan between 2001 and 2016. Policy implications include rethinking of the building coverage rate for renewed buildings for more plant-friendly ground, the adoption of building setback policy for more accessible mid-air mini-parks, and avoiding residential units as an investment commodity.

**Keywords:** urban greenery, land prices, urbanization

## 1. Introduction

The momentum of urbanization driven by a variety of forces is usually beyond the human capacity to change or detour. Individual's demand for moving to the urban areas for better job opportunities, standards of living, etc. is a primary force of urbanization. Some policies are also implemented to embrace such potential socio-economic benefits of urbanization as the compact city of sustainable urban form, and, to the extreme, the politically incorrect policy to contain human's pollution to their settlements. In turn, dealing with likely congestion issues caused by the urbanization is significant, which is particularly true since the global urban population is predicted to reach 69% in 2050 [1].

Rising housing costs, a likely issue emerging along with the urbanization, directly affect human's basic residential needs and standard of living. It is listed as one of the most crucial targets of the United Nation 2017's 17 sustainable development goals (SDGs), that is, ensuring adequate, affordable housing, inclusive settlements, and equality [2]. The city's green coverage, on the other hand, lays out the foundation of a sustainable urban built environment, decisively affecting such city's capacity as the mitigation and adaptation to climate change [3] and purification and maintenance of urban air quality [4]. Growing urbanization may drive some areas to thrive while others to shrink that may necessitate specifically customized spatial plans and strategies. Nonetheless, past research sheds limited light on the association between the urbanization and land/housing prices, and the research of the relationship between the urbanization and urban greenery is developing.

This research aims to contribute empirically to whether the degradation of essential living conditions is a trade-off for the pursued urban life in the wake of urbanization. The purposes of this research are twofold to analyze the impacts of urbanization on the urban green coverage and to analyze the association/impacts on land/housing prices. To fulfill these purposes, Taiwan is selected as the case to analyze the associated situations primarily between 1976 and 2016.

## 2. Urbanization, land/housing prices, and green coverage

This section provides some theoretical background on the urbanization, urban hierarchy that is highly associated with the urbanization, the associations of urbanization with land or housing prices, and the urban greenery.

### 2.1. Urban hierarchy, urbanization, and standard of living: inputs, outputs, and outcome

The urban hierarchy is associated with its service level of living environment and in turn the standard of living. The associated capacities of an urban area at certain urban hierarchy may include its financial sources, the capacities in administration and maintenance, the mandated implementation of spatial plans, etc., which constitute the input factors for formulating its built environment as the output. This input may be mandatory, or as a result of urbanization to cope with growing population or employment, that is the level of input and supply may also be the result of urban agglomeration. In return, the demand for public resources may also increase. The input resources and level of demand jointly decide the level of services for the public infrastructure of various kinds. Hence, the standard of living in the urban area usually is higher than that of the rural areas and can largely attribute to the planned result and economic agglomeration.

Nonetheless, the concentration of population is likely to cause such issues as congestion, regarding the quality of life, gridlock, the concentration of pollutants, urban heat island, less natural environment, and less affordable housing. Theoretically, the higher the degree of urbanization, the deteriorated these conditions could be. In particular, within an urban area, the conditions may be even worse in the highly urbanized sub-area, such urban core. Two of the most significant effects are degraded green open space and increasing land/housing cost, which decisively affects the fundamental needs for living and natural environment in the urban settings. However, little research has been devoted in these regards at the bourgeoning phase of urbanization research.

### 2.2. Urbanization and land/housing prices

The impact mechanism of urbanization on land/housing prices may go from the rural-urban migration to natural growth, together with urban plans and the resulted urban form, and to the effected land/housing demand and prices. Other than the natural change of population affecting a city's population, the migrations, either interregional or rural-urban, largely constitute the current rapid urbanization trend. As a result, both urban boundary and urban population grow significantly.

The urbanization may affect land and housing prices within a city or city region through a few routes. First, at the city region level, the housing and land demand increase as a result of population growth. City regions with different level of population growth as a result of the different degree of urbanization may experience different impact on housing/land prices. Second, the population size, a result of urbanization, of a city region may affect its land prices through the course of the overall needs for the land in the city region. Furthermore, density can represent the level of the demand or bid [5] for the land, given the land supply is limited, and the cap of the floor area is set by the government policy like in the urban plan and by the limits of the natural resources. Third, within a city region, the constituent sub-areas may also show different levels of urbanization, affecting the level of demand for the land and housing. The appearance of the degree of urbanization for a sub-area can be represented by density. Additionally, the degree of urbanization can be affected by the socio-economic conditions, accessibility, etc.

### 2.3. Urbanization and green coverage

The urbanized land grows in expanding urban boundary, converting green space in the urban area into built environment to house more population, or employment migration from the rural area. That is, land is urbanized as a response to the rural-urban immigration, and the reduction of green space comes as a price of urbanization. The reduction of green space in and around urban areas turns space into less natural, and the resulted negative impacts involve such loss of natural or semi-natural environment [6]. The green space loss will lead to the loss of low-temperature space [7], emerging urban heat island [8], deterioration of air quality, noise cancelation, beautification of urban built environment [4], outdoor open space for social, sporting, and active-life activities, the green infrastructure for flood mitigation [3], and disaster sanctuary, among others. The controversy is that as the urban population grows and expected to grow more, the green space would be replaced by the built environment on the one hand; while on the other hand, there could be more need for the green space to cope with the negative impacts due to the growing agglomeration of built environment, human activities such as employment and tourism, or population per se.

## 3. Research methods

The research methods involve descriptive statistics, the panel data analysis, and the cluster analysis. Two panel data analyses are developed to assess the associations of urbanization with green coverage and land prices. With the application of the cluster analysis, such constituent units as towns/districts are classified into various groups based on the degree of urbanization, green coverage, and land prices. The primary data sources include census data, employment, land prices, and satellite images. The software applied includes ArcGIS, Excel, SPSS, and Stata. Urbanization indexes adopted are composed of the Taiwan government's classification definitions and continuous variables to quantify the degree of urbanization. The normalized difference vegetation index (NDVI) [9, 10] is applied to extract the green land cover data from the Landsat satellite images [11].

## 4. Urbanization, green coverage, and land prices in Taiwan

This section provides the statistical background of urbanization, green coverage, and land prices in Taiwan, dating back as far as 1976, when the earliest data are available. The cross-analysis is also conducted to provide preliminary knowledge on the associations of the degree of urbanization with green coverage and land prices, respectively.

### 4.1. Urbanization in Taiwan: 1976–2016

This section of urbanization analysis of Taiwan adopts a definition of urbanization to develop an urbanization index to conduct a universal comparison with other countries; two major concerns are prioritized to serve this purpose: urban and rural areas can be differentiated, and the data for both areas are available. A variety of methods have been developed and applied to classify an area as an urban or rural area, based on which population living within is classified as urban or rural population. These methods for urban/rural classification include the direct dichotomy distinction from existing official documents or the distinction derived from the joint consideration of an array of aspects/variables, for example, population density, population size, and population growth rate. Among a few possible urban/rural definitions for the case of Taiwan, a place assigned with a mandatory urban plan is selected for defining an urbanized area and vice versa. This definition enjoys the pros of the existence of the needed data for this analysis, and furthermore, within the areas public infrastructure, well-designed spatial plans are required by law that leads to higher level of infrastructure in the urban area. Bear in mind that this polarized definition cannot tell the degree of urbanization, which is better for other purposes like the multivariate analysis in the following sections.

**Figure 1** shows the urbanization trend in Taiwan between 1976 and 2016. During these four decades, the total population grew by some 42% (or an average of about one percentage point annually), from some 16 million to some 23 million. During the same period, however, urban population grew double the rate of population growth by some 84% (or an average of two percentage points annually). Urbanization rate grew from some 61% in 1976 to 80% in 2016, among the highly urbanized nations in the world.

Before showing the urbanization situation in the sub-areas in Taiwan, an urban hierarchy system is introduced first that can lay up the base for the comparison between the degree of actual urbanization and the urban hierarchy defined by the Taiwan government. In a latest urban hierarchy system officially defined in the latest nationwide regional plan [13], each town/district is designated accordingly to one of the four levels: core, sub-core, local core, and others (**Figure 2**). These four levels are defined by its development conditions, such as the population size, growth rate, and level of public infrastructure on the one hand and are applied for spatial planning regarding future goals and strategies regarding infrastructure's investment and the level of services, etc. [13]. This urban hierarchy system divides Taiwan main island into six city regions (or "region-level living cycles" as literally translated; **Figure 2**) [14]: Taipei City-New Taipei City-Keelung City-Yilan County (01 TNKY), Taoyuan City-Hsinchu County-Miaoli County (02 THM), Taichung City-Changhua-Nantou County (03 TCN), Yunlin County-Chiayi County (04 YCT), Kaohsiung City-Pingtung County (05 KP), and Hualien County-Taitung County (06 HT) [14].

**Figure 3** displays the degree of urbanization in 2016 for each of the county/city in the main island of Taiwan; the most urbanized county/city is in the cores of North, Central, and Southern parts of Taiwan. The most urbanized areas with 90% of the population living in the urban areas are located in the cores of the urban hierarchy of the top three city regions, that is, 01 TNKY, 03 TCN, and 05 KP, plus Hsinchu City of 02 THM, and Chiayi City of 04 YCT.

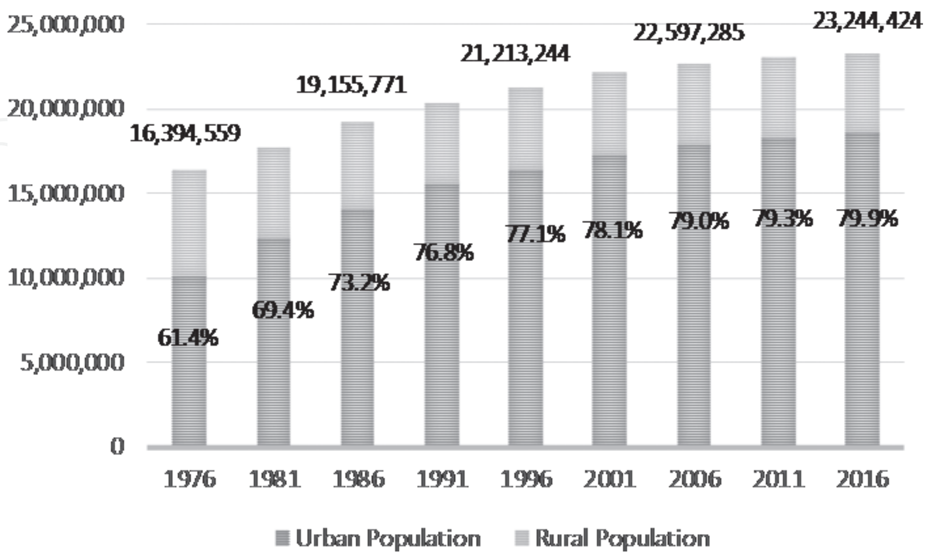


**Figure 1.** Urban population versus rural population in Taiwan (main island): 1976–2016. Data source: [12].

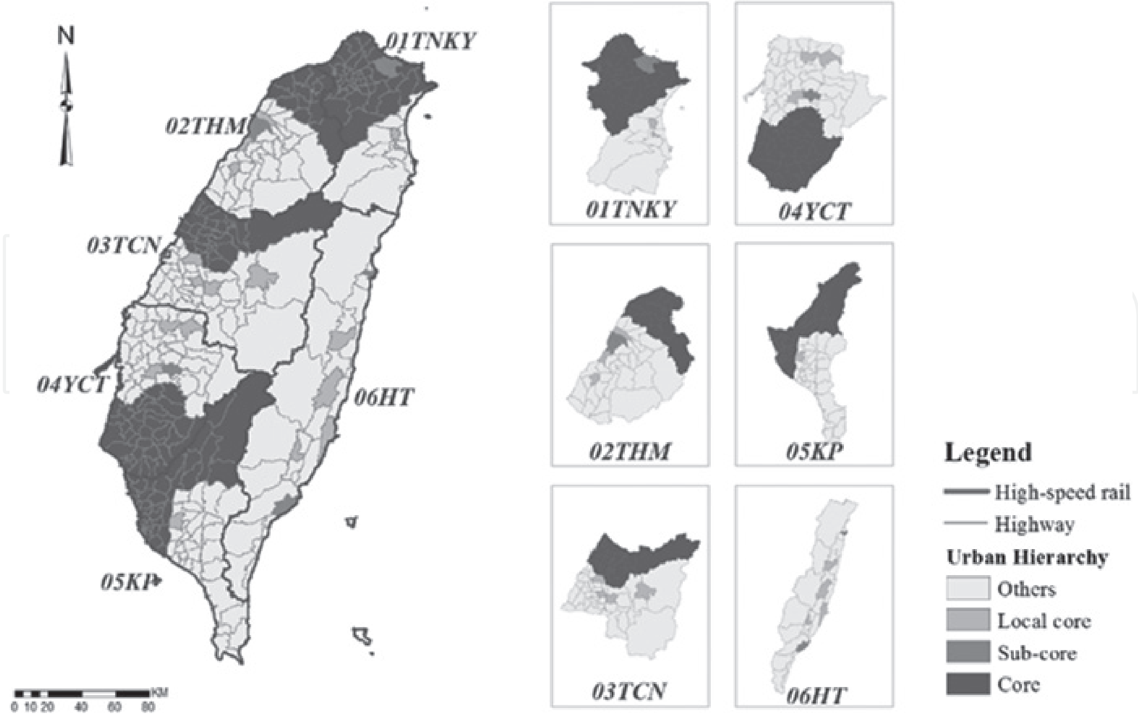


**Figure 2.** Urban hierarchy in Taiwan, 2013 by town/district. Data source: [13, 14].

### 4.2. Green coverage in Taiwan: 2001–2016

This section analyses the green coverage for Taiwan between 2001 and 2016, during which the free-quality satellite images are available for developing the green coverage data for this research. The main data source of the satellite image comes from the U.S. Geological Survey's (USGS) Landsat database [11]. The Landsat contains 30-meter resolution land coverage images appropriate for this research to develop NDVI that is often used to probe remote sensing data to tell whether the target area contains live green vegetation or not [9, 10]. Then, the green coverage data are derived for each 30-meter grip and aggregated for each town/district of Taiwan for the years 2001, 2006, 2011, and 2016. While taking advantage of the NDVI techniques in obtaining the green coverage information, it is important to note that there is a limit on accuracy rate due to a range of systematic reasons, including the degree of the original image resolution, clouds, and shade [5].

In 2001, the median green coverage rate of some 350 towns/districts across the island of Taiwan was 80%, with a range between 3.9 and 99.5% (**Table 1**). The green cover land surface has worsened between 2001 and 2016: annually, the median green land area has dropped by 0.07 $km^2$ and 0.12%. In general, the higher the urban hierarchy of a district/town, the lower is its green coverage level (**Figure 4**).

**Figure 5** displays the annual percentage point change in green coverage rate between 2001 and 2016. Over these 15 years, some areas' green coverage rates reduced relatively high, alternatively indicating increasing built environment, which occurred in few spatial patterns. The first pattern occurred in the outer districts or suburban areas of a city region,

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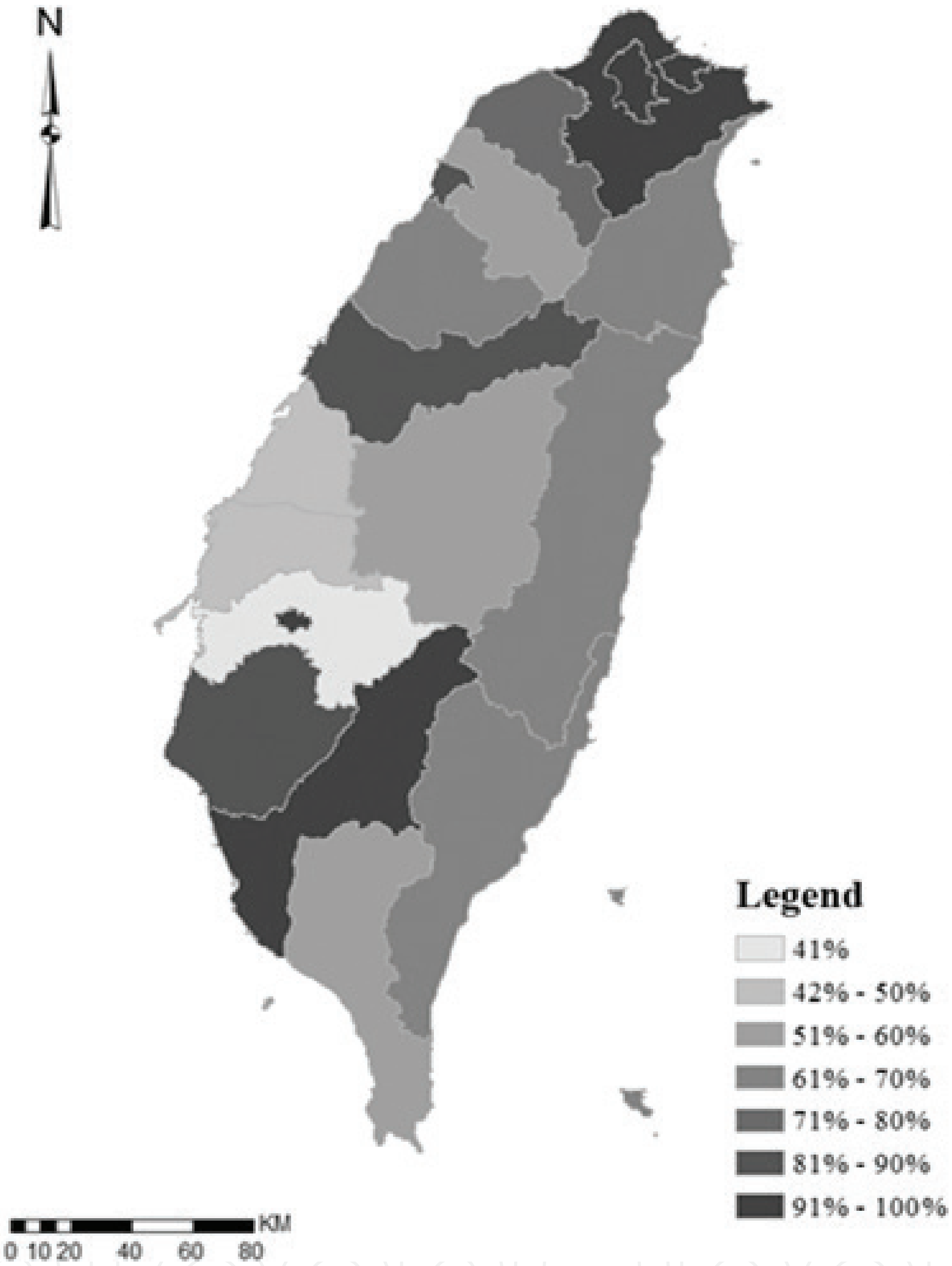


**Figure 3.** Percentage of urban population in Taiwan (main island), 2016, by county/city. Data source: [12].

where the most developed core districts were probably saturated for further development, such as in Taipei of the 01 TNKY city region; on the other hand, the outer districts with acceptable transportation accessibility afforded room to accommodate further development needs. The second pattern occurred in the sub-core or local core towns/districts, where there was still room for more development, such as in Keelung City and Yilan City of the 01 TNKY. The third pattern occurred in some rural towns possibly because of their unique local attractive factors for potential development, which might be boosted by such factor as improved intercity transportation, for instance, some towns in Yilan County of the 01 TNKY.

| | Mean | Median | S.D. | Min. | Max. | N |
|---|---|---|---|---|---|---|
| Green coverage rate in 2001 | 80.0% | 89.6% | 23.5% | 3.9% | 99.5% | 348 |
| Annual average change in green coverage land area, ($km^2$) 2001–2016 | −0.10 | −0.07 | 0.15 | −1.71 | 0.26 | 345 |
| Annual average percentage point change in green coverage rate, (%) 2001–2016 | −0.15% | −0.12% | 0.15% | −0.69% | 0.46% | 345 |

Data source: Calculated from the Landsat [11] with NDVI.

**Table 1.** Green coverage in Taiwan, 2001–2016, by town/district.

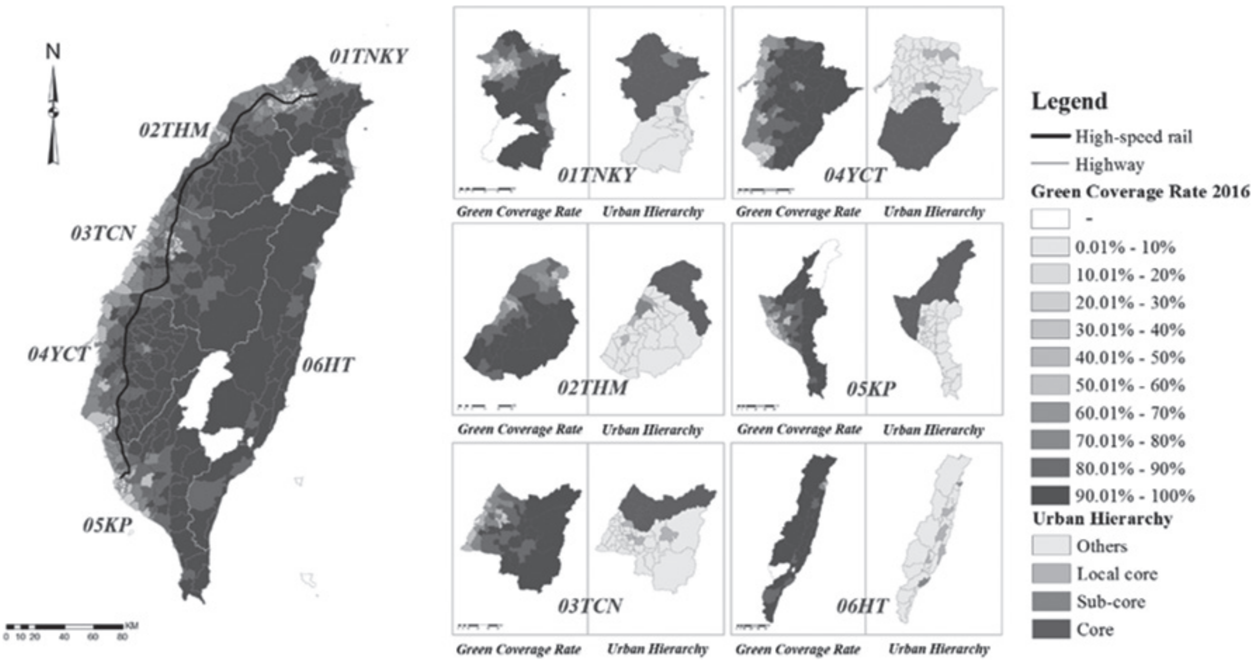


**Figure 4.** Green coverage rate in Taiwan, 2016, by town/district. Note: The blank areas are those suffering from large-scale landslides due to typhoons or heavy rain [15], which is excluded to avoid data distortion. Data source: Calculated from the Landsat [11] with NDVI.

Additionally, the cross-references between the change of green coverage rate and the urban hierarchy, representing the degree of urbanization, implicitly reveal some pros and cons of the Taiwan's four classes of urban hierarchy. On the one hand, some districts/towns at the top of the hierarchy tend to urbanize at a higher pace and vice versa. On the other hand, the four-class classification might not be delicate enough to distinguish the differences in the green coverage rate among the towns/districts of the same class, which drives the needs for quantitative variables of urbanization.

**Figure 6** shows the annual average change of green land area, as opposed to **Figure 5**, providing an absolute scale of change as in where large reductions of green land area occurred between 2001 and 2016. The previous three spatial patterns based on the change in the green coverage rate of **Figure 5** still hold in general, but the first and third patterns stand out as large-scale reductions of green coverage seem to occur in the outer districts or the core and rural towns with the unique local attractiveness for development.

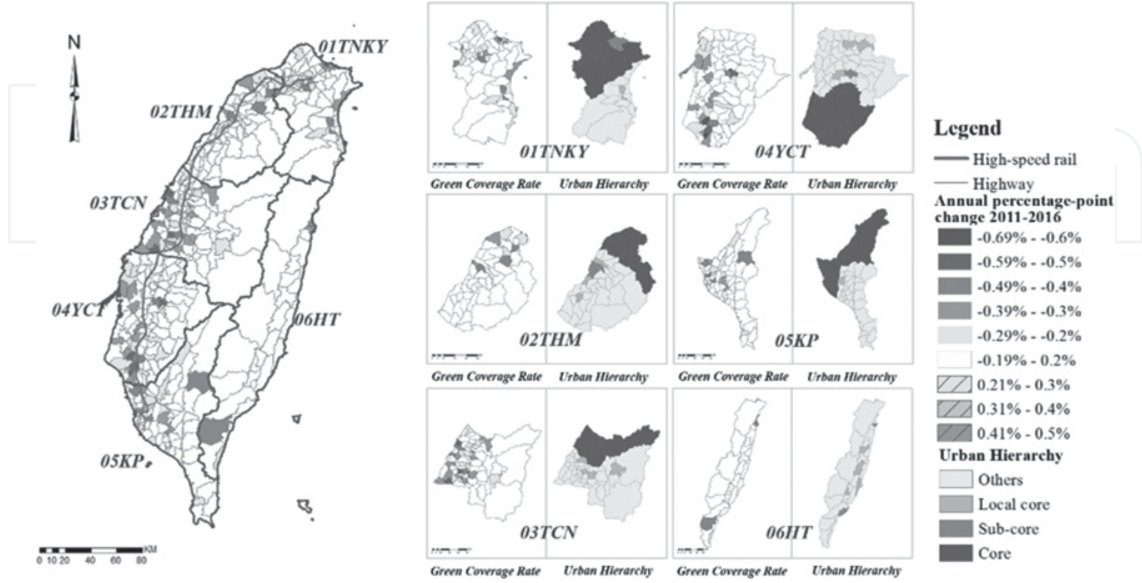


**Figure 5.** Annual average percentage point change in green coverage rate in Taiwan, 2001–2016, by town/district. Note: The white symbol ranges from −0.19 to 0.20% is designed to refer to none or marginal change. It is also designed to mitigate the possible error derived from NVDI. Data source: Calculated from the Landsat [11] with NDVI.

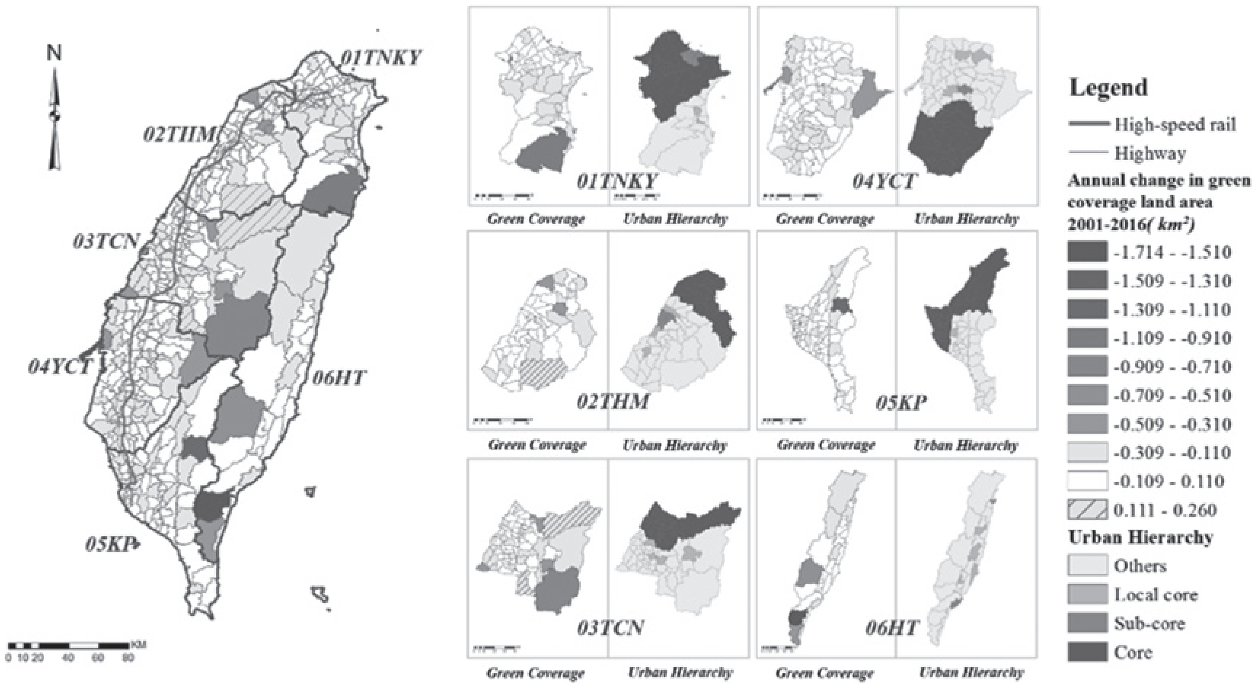


**Figure 6.** Annual average change in green coverage land area in Taiwan, 2001–2016, by town/district. Note: The white symbol ranges from −0.109 to 0.110 $km^2$ is designed to refer to none or marginal change. It is also designed to mitigate the possible error derived from NVDI. Data source: Calculated from the Landsat [11] with NDVI.

### 4.3. Land price index in Taiwan: 2001–2016

This section presents the residential land prices of urban areas in Taiwan for each town/ district majorly for the period of 2001–2016 and also in 1996 for analysis purposes. The Urban Land Price Index (ULPI) for the residential areas [16], the only land or housing price index for this spatial scale available in Taiwan, is collected as a proxy of a housing index, since the land price is a significant factor in the housing price, so they are highly correlated. The ULPI is the average land price of a selected sub-area with the median land price in a town/district's urban areas. The ULPI is available after 1993 for all residential, commercial, and industrial uses. The residential median land price indexes are then applied for the cross-sectional analysis and trend analysis for between 2001 and 2016, almost covering the latest ascending part of the housing price cycle in Taiwan, peaked around 2014–2015 [17]. Additionally, the land price of 1996 is also incorporated, since it provides a price reference of the previous cycle.

**Figures 7** and **8** show the residential median land prices of urban areas of each town/district for 2001 and 2016, respectively. The highest land price indexes across the country are located in Taipei City of the 01 TNKY for both years. Over these years, the highest land prices expanded overwhelmingly in the 01 TNKY and somewhat in 02 THM and 03 TCN. Also, some rural areas with great tourism attractiveness, including Kenting area in the 05 KP and Taitung in the 06 HT, became prosperous during this period, as reflected in their land price jump (**Figure 9**). It is worth noting that this land price index only reveals the median condition rather the extreme cases, such as luxury housing market, which skyrocketed overwhelmingly during the same period.

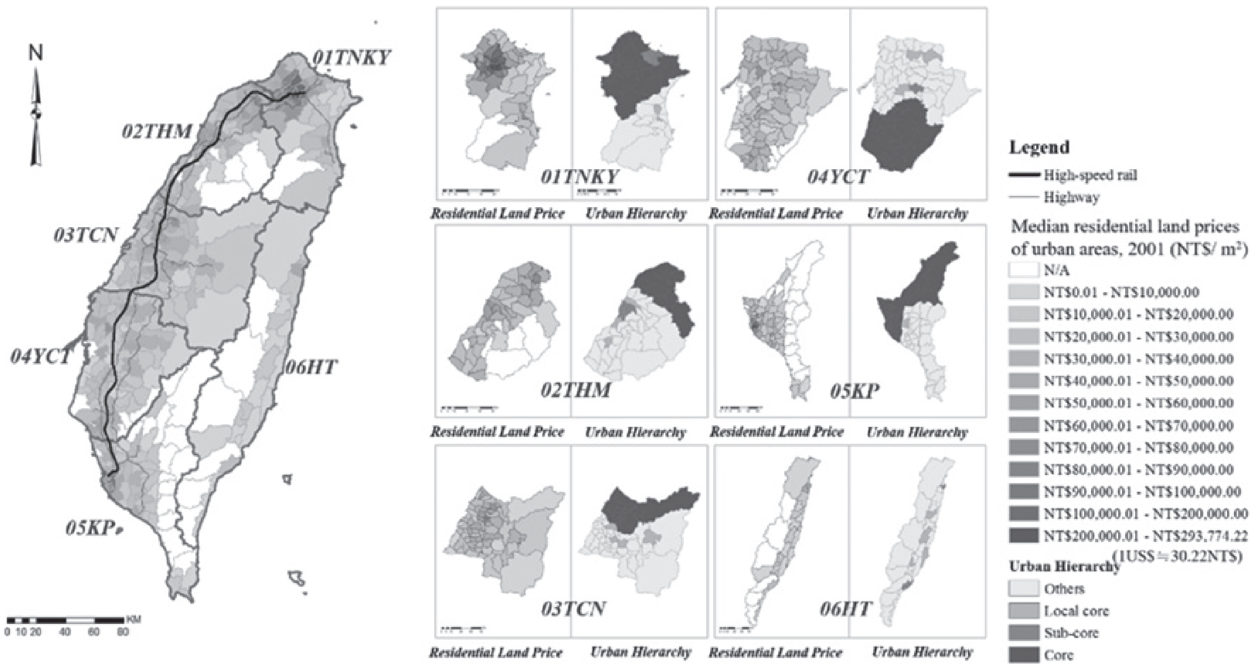


**Figure 7.** Residential median land price of urban areas in Taiwan, 2001, by town/district. Data source: [16]. The land prices have been adjusted by the consumer price index to the year 2001.

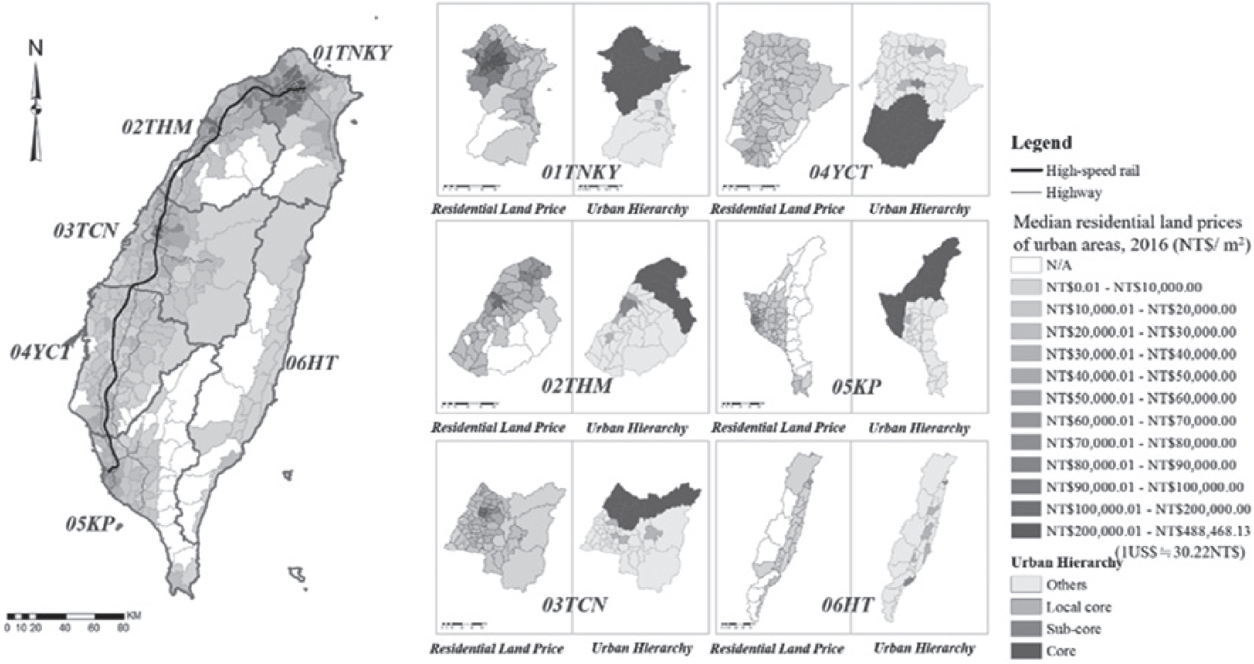


**Figure 8.** Residential median land price of urban areas in Taiwan, 2016, by town/district. Data source: [16]. The land prices have been adjusted by the consumer price index to the year 2001.

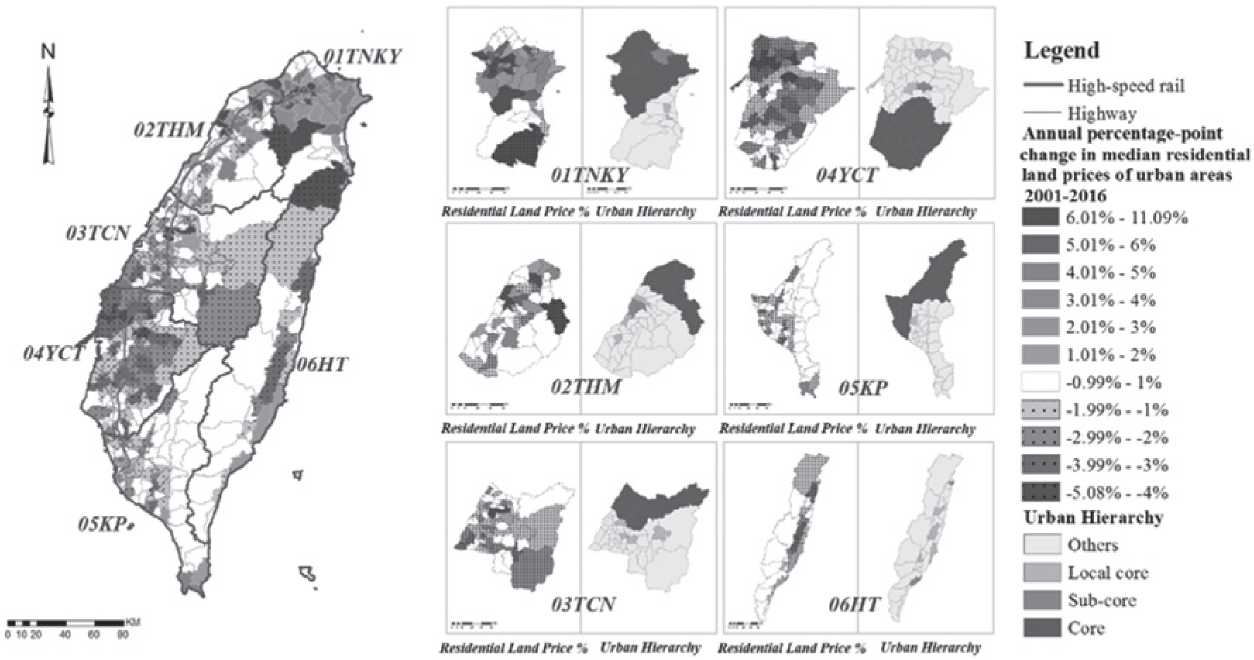


**Figure 9.** Annual percentage point change in residential median land price of urban areas in Taiwan, 2001–2016, by town/district. Data source: Calculated from Ref. [16]. The land prices have been adjusted by the consumer price index to the year 2001.

**Table 2** shows the annual average percentage point change in the residential median land price for the towns/districts in Taiwan. First, surprisingly the land prices decreased by one percentage point between the previous (i.e., 1996) and current (i.e., 2016) near-peaks of the

| Period | Mean (%) | Median (%) | S.D. (%) | Min. (%) | Max. (%) | N |
|---|---|---|---|---|---|---|
| 1996–2001 | −2.8 | −3.0 | 3.9 | −12.0 | 10.2 | 313 |
| 2001–2006 | −2.9 | −3.1 | 4.2 | −13.7 | 14.3 | 313 |
| 2006–2011 | −0.9 | −1.4 | 4.0 | −11.6 | 24.3 | 314 |
| 2011–2016 | 3.5 | 2.5 | 5.4 | −18.0 | 25.5 | 318 |
| 1996–2016 | −1.0 | −1.7 | 2.6 | −4.6 | 15.1 | 313 |

Data source: Calculated from Ref. [16]. The land prices have been adjusted by the consumer price index to the year 2001.

**Table 2.** Annual average percentage point change in residential median land price of urban areas in Taiwan, 1996–2016, by town/district.

residential price cycles. Second, opposite to the general impression that land prices increased between 2001 and 2016, they only increased between 2011 and 2016, which is probably because it is the median land prices rather than those housing whose prices jumped significantly such as the luxury housing and in the major city region like the 01 TNKY and hence grabbed the public attention.

### 4.4. Cross-analysis of green coverage and land price against urbanization

The differences in green coverage rate among the four classes of the urban hierarchy are statistically significant, and there is barely difference statistically across the city regions. The overall green coverage rate in Taiwan was 78% in 2016 (**Table 3**), the rest of which majorly consisting of the built environment and water body. The core and sub-core on average had the

| | City region 01 TNKY (%) | City region 02THM (%) | City region 03 TCN (%) | City region 04 YCT (%) | City region 05 KP (%) | City region 06 HT (%) | Total[e] (%) |
|---|---|---|---|---|---|---|---|
| Core | 62 | 78 | 66 | 76 | 60 | N/A | 67[c,d] |
| Sub-core | 71 | 54 | N/A | 74 | N/A | 71 | 68[d] |
| Local Core | 75 | 78 | 83 | 93 | 58 | 92 | 83 |
| Others | 90 | 93 | 83 | 87 | 89 | 93 | 88[a,b] |
| Total[f] | 74 | 76 | 77 | 83 | 69 | 85 | 77.6 |

Data source: Calculated from the Landsat [11] with NDVI.

[a]The mean difference with the "Core" is significant at the 0.05 level in pairwise comparison in ANOVA.

[b]The mean difference with the "Sub-core" is significant at the 0.05 level in pairwise comparison in ANOVA.

[c]The mean difference with the "Local Core" is significant at the 0.10 level in pairwise comparison in ANOVA.

[d]The mean difference with the "Others" is significant at the 0.05 level in pairwise comparison in ANOVA.

[e]The mean differences across all urban hierarchy types are significant at the 0.05 level in ANOVA.

[f]The mean differences across all city regions are not significant at the 0.05 level in ANOVA.

**Table 3.** Two-way ANOVA green coverage rate by urban hierarchy/degree of urbanization and by city region in Taiwan, 2016.

| | City region 01 TNKY | City region 02THM | City region 03 TCN | City region 04 YCT | City region 05 KP | City region 06 HT | Total[b] |
|---|---|---|---|---|---|---|---|
| Core | $4488 | $1460 | $1314 | $653 | $1104 | N/A | $2,024[a] |
| Sub-core | $718 | $2406 | N/A | $963 | N/A | $936 | $1145 |
| Local Core | $1825 | $1968 | $1060 | $592 | $788 | $270 | $1026 |
| Others | $787 | $785 | $499 | $389 | $445 | $237 | $499 |
| Total[c] | $1954 | $1655 | $958 | $649 | $779 | $481 | $1256 |

Data source: Calculated from Ref. [11]. The land prices have been adjusted by the consumer price index to the year 2001.
[a]The mean difference with the "Others" is significant at the 0.05 level in pairwise comparison in ANOVA.
[b]The mean differences across all the urban hierarchy types are significant at the 0.05 level in ANOVA.
[c]The mean differences across all the city regions are not significant at the 0.5 level in ANOVA.

**Table 4.** Two-way ANOVA median residential land price by urban hierarchy/degree of urbanization and by city region in Taiwan, 2016 (US$/M$^2$).

lowest green coverage rates of 67–68%, while the local cores' green coverage was 83%, only five percentage point short of the "others" class. City region-wise, the 05 KP had the lowest green coverage rate of only 69%, followed by the 01 TNKY, 02THM, and 03 TCN in the range of 74–77%.

There were statistically significant differences in the residential land prices across all the four classes of urban hierarchy as a whole in 2016, while most of the paired differences between classes were barely statically significant. The median residential land prices in the core towns/districts, on average, were twice as high as those in the sub-cores and local cores (**Table 4**). City region-wise, the highest land prices were located in the two northern city regions, that is, the 01 TNKY and 02 THM, doubling that of the 03 TCN and 05 KP. However, the overall differences across the city regions are not statistically significant.

## 5. Panel data regression: the relationships of urbanization with green coverage rate and land price

Two separate panel data regression analyses are conducted to assess the relationships of urbanization with the green coverage rate and the land price, respectively. This section goes beyond the previous bivariate analysis by adopting the multiple regression of panel data analysis to control the impacts of other possible factors. The panel data analysis is selected concerning the data structure of these empirical analyses, which contain data for some 350 towns/districts of Taiwan main island for the years 2001, 2006, 2011, and 2016. The town/district is selected as the analysis unit, since a larger spatial unit of county/city divides Taiwan main island into 19 units, providing less homogeneity of urbanization and an insufficient size of units for multiple regression. On the other hand, smaller spatial units do not provide data for all the required variables for the analysis.

In the two panel data analyses, the primary relationships to evaluate are how the degree of urbanization associates with the green coverage rate and the land price, respectively (Eqs. (1) and (2)). In both these two panel data models, two population-derived variables are adopted to quantify the degree of urbanization. One is the population size of a city region that quantifies the overall degree of urban agglomeration for the whole city region; the other is the population density of a town/district that quantifies the degree of urbanization within a sub-area of a city region. The regression models do not necessarily mean to prove the existence of a cause-effect relationship between the urbanization variables and the green coverage rate and the land price, but a correlation that proves the trend between two variables without a clear cause-effect explanation; the cause-effect relation may only exist given, at least, theoretical foundations. In these cases of the population size of city region, there may exist a correlation as a result of urbanization process, since it is also a result of urbanization process, like the green coverage rate and the land price; nonetheless, their theoretical cause-effect relationship is not clear.

Another definition of the city region for Taiwan, consisting of 36, is adopted over the 6 city region version, since it is more based on the daily activity rather than some political concern of the latter (**Table 5**). In both of the panel data regression models, region and county/city variables are incorporated as control variables to single out the net relationships of urbanization variables (**Table 5**). Curve estimations between the dependent and independent variables are first conducted before constructing the two panel data regressions to explore the most appropriate curve forms. In the panel data analysis, both fixed- and random-effects models are developed first, and then, the Hausman test is conducted to select the most appropriate model.

| **Variables** | **Mean** | **S.D.** |
|---|---|---|
| Dependent variable | | |
| Green coverage rate $_{t^*}$ (Town/District) | 78.2% | 24.6% |
| Inflation-adjusted land price $_t$ (USD/m$^2$; Base year: 2011)(Town/District) | US$1078 | US$1497 |
| Independent variable | | |
| Degree of urbanization | | |
| Population density $_t$ (Persons/km$^2$) (Town/District) | 2874 | 5810 |
| Population $_{t=2001}$ (City region, N. = 36) | 1,610,953 | 1,953,901 |
| Region, county/city | | |
| Region (0/1)(North, Central, South, East, N. = 4) | N/A | N/A |
| County/city (0/1)(N. = 19) | N/A | N/A |

No. of observations: 1396 (N. of towns/districts: 349; No. of time periods: 4 (2001, 2006, 2011, 2016).$^*$t stands for time period.

**Table 5.** Descriptive statistics of the variables for the panel data regression models.

### 5.1. Panel data regression of green coverage rate

Eq. (1) shows the panel data regression model of the green coverage rate:

$$\text{Green coverage rate}_t = a_0 + a_{Urban}{}^{*} X_{Urban,t} + \left(a_{Rgn} X_{Rgn} + a_{Cty} X_{Cty}\right) + e \quad (1)$$

where green coverage rate$_t$ is the green coverage rate of a town/district for the time period t; $X_{Urban}$ is the array of the variables quantifying the degree of urbanization; $X_{Rgn}$ and $X_{Cty}$ are the arrays of region and county/city variables, respectively; $a_0$ is the interception, and $a_{Urban}$, $a_{Rgne}$, and $a_{Cty}$ are coefficients, and $e$ is the residual.

Both the fixed-effects and random-effects models of the panel data analysis are developed and then based on the significant p-value in the Hausman test (**Table 6**), the fixed-effects model

| | **Panel data regression, fixed-effects** | | **OLS regression model** | |
|---|---|---|---|---|
| Dependent variable | Green coverage rate $_t$ (Town) | | Green coverage rate $_t$ (Town) | |
| Independent variable | **B** (Sig.) | **Std. Err.** | **B** (Sig.) | **Std. Err.** |
| Degree of urbanization | | | | |
| Pop. density $_t$ (Town) | −2.69e-06(0.02) | 1.14e-06 | −0.000032(0.00) | 7.18e-07 |
| Pop. $_{t=2001}$ (City region) | −1.19e-07(0.00) | 1.44e-08 | −8.16e-08(0.00) | 9.17e-09 |
| Pop.$^2$ $_{t=2001}$ (City region) | 5.56e-15(0.00) | 1.58e-15 | 1.11e-14(0.00) | 1.94e-15 |
| Region, county/city | | | | |
| Hsinchu County | | | 0.111(0.00) | 0.020 |
| Taoyuan County | | | 0.094(0.00) | 0.020 |
| Taipei City | | | 0.081(0.05) | 0.041 |
| New Taipei City | | | 0.076(0.03) | 0.034 |
| Chiayi County | | | 0.076(0.00) | 0.016 |
| Nantou County | | | 0.056(0.01) | 0.021 |
| Yilan County | | | 0.047(0.02) | 0.021 |
| Taichung City | | | 0.038(0.01) | 0.015 |
| Hsinchu City | | | −0.103(0.01) | 0.036 |
| Tainan City | | | −0.025(0.04) | 0.012 |
| Constant | 0.92 (0.00) | 0.015 | 0.898(0.00) | 0.007 |
| **Overall** | Prob. > F = 0.00<br>R-sq.: Within = 0.15<br>Between = 0.30<br>Overall = 0.30<br>Hausman Test: P-value = 0.00 | | Prob. > F = 0.00<br>Adj. R-sq.: 0.75 | |

**Table 6.** Green coverage rate models: fixed-effects panel data regression model and OLS regression model.

is selected over the random-effects model. The fixed-effects model shows that both the population size of the city region and the population density of the town/district are statistically significant factors negatively associated with the green coverage rate. This finding indicates the higher the population size of a city region or the higher the population density of a town/district, the lower is its green coverage rate, ceteris paribus. The causal relationship between the population density of the degree of urbanization and the green coverage rate may occur primarily due to higher competition in high-density areas between the demand for green open space and other land uses, such as residential, commercials, and road and parking of the built environment.

The fixed-effects model, however, does not reveal the content of the fixed effects regarding the differences among counties/cities or regions. One solution is an OLS regression model, adopting binary regressors for spatial or administrative units (**Tables 5** and **6**). An OLS

| | **Panel data regression, random-effects** | |
|---|---|---|
| Dependent variable | ln(Inflation-adjusted land price $_t$ (USD/m$^2$; Base year:2001)(Town) | |
| Independent variable | **B** (Sig.) | **Std. err.** |
| Degree of urbanization | | |
| ln (Pop. density $_t$ (Town)) | 0.31(0.00) | 0.020 |
| Pop. $_{t=2001}$ (City region) | 3.29e-08(0.00) | 6.44e-09 |
| Region, county/city | | |
| Taipei City | 0.48(0.00) | 0.06 |
| Hsinchu City | 0.29(0.00) | 0.08 |
| Hsinchu County | 0.28(0.00) | 0.05 |
| Yilan County | 0.24(0.00) | 0.05 |
| Miaoli County | 0.21(0.00) | 0.04 |
| Taoyuan County | 0.18(0.00) | 0.04 |
| New Taipei City | 0.16(0.00) | 0.05 |
| Nantou County | 0.13(0.01) | 0.05 |
| Yunlin County | 0.11(0.00) | 0.03 |
| Taichung City | 0.07(0.00) | 0.03 |
| Constant | 3.22(0.00) | 0.05 |
| **Overall** | Prob. > F = 0.00<br>R-sq.: Within = 0.04<br>Between = 0.83<br>Overall = 0.76<br>Hausman Test: P-value = 0.15 | |

**Table 7.** Land price random-effects panel data regression model.

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regression model shows that there exist fixed differences in the green coverage rates among counties/cities (**Table 6**). Some counties/cities in the Northern Taiwan such as Hsinchu County, Taoyuan City, Taipei City, and New Taipei City had higher green coverage rates than the average county/city. In contrast, Hsinchu City and Tainan City had lower green coverage rates.

### 5.2. Panel data regression of land price

Eq. (2) shows the panel data regression model of the land price:

$$\ln\left(\text{Inflation-adjusted land price}_t\right) = a_0 + a_{Urban}{}^{*} \ln\left(X_{Urban,t}\right) + \left(a_{Rgn} X_{Rgn} + a_{Cty} X_{Cty}\right) + e \quad (2)$$

where the inflation-adjusted land price $_t$ of a town/district is the median land price adjusted by the consumer price index to year 2001; $X_{Urban}$ is the array of variables quantifying the degree of urbanization; $X_{Rgn}$ and $X_{Cty}$ are the arrays of region and county/city variables, respectively (**Table 5**); $a_0$ is interception, and $a_{Urban}$, $a_{Rgn}$, and $a_{Cty}$ are coefficients, and $e$ is the residual.

Based on the curve estimation where power relationship has the highest R-squared value, log-log model is adopted for between inflation-adjusted land price and population density in the panel data regression. Both fixed-effects and random-effects models are developed, and then, the random-effects model is selected, since the p-value in the Hausman test was insignificant (**Table 7**). The random-effects panel data regression shows that the higher the degree of urbanization, the higher is its median land price, as supported by the statistically significant positive coefficients of the population density of the town/district, as well as the population of the city region. The high density of a town/district may cause high land prices due to the high demand for residences, which is also demonstrated in the bid-rent theory [18] that the high rent corresponds with the high building height or population density [19]. In addition, the median land prices of the towns/districts of some cities are higher than the others such as Taipei City, Hsinchu City and County, Yilan County, etc.

## 6. Cluster analysis of towns/districts, by green coverage and land price

This section is intended to classify the towns/districts in Taiwan based on their level of greenery and land price to address possible challenges or opportunities in the wake of urbanization.

The characteristics of towns/districts selected for the cluster analysis are the level of green coverage rate, residential land price, and their change patterns; the method is the two-step cluster analysis. The green coverage rate and residential land price are two important aspects of the standard of living that are highly associated with the level of urbanization. Adopting these two aspects to classify the towns/districts is intended to reveal the types of quality of life under different levels of urbanization. Additionally, not only the level of green coverage rate and residential land price but also their change patterns are adopted to provide both the latest levels but also changing fashions, respectively. Then, regarding the method of cluster analysis, the two-step cluster analysis and two traditional cluster methods hierarchical and k-means are all tried. The final selection of the method is the two step due to its results comply with expectation and theoretically sensible and reasonable to interpret.

Based on the levels and change patterns of greenery and residential land price, the towns/districts in Taiwan are classified into four clusters: (1) Gray expensive urban core; (2) green moderately priced suburbs; (3) green lowly priced suburbs; and (4) green rural areas (**Table 8**).

| Cluster | N (%) | Mean population density, 2016 (Persons/km$^2$) | S.D. | Range (Persons/km$^2$) |
|---|---|---|---|---|
| 1. Gray expensive urban core | 29 (9%) | 18,894 | 7279 | 3455–39,203 |
| 2. Green moderately priced suburbs | 45 (14%) | 3085 | 2999 | 19–12,476 |
| 3. Green lowly-priced suburbs | 95 (30%) | 2006 | 2278 | 90–14,071 |
| 4. Green rural areas | 143 (46%) | 639 | 1114 | 8–10,635 |
| Total | 312 (100%) | 3105 | 5881 | 9–39,203 |

F-test: 331.607, P-value: 0.000.

**Table 8.** ANOVA of town/District's population density, by cluster, 2016 Taiwan.

| Cluster | Green coverage rate, 2016[1] | | Residential median land price, 2016[2] (USD/m$^2$) | | Annual percentage point change of green coverage rate, 2001–2016[1] | | Annual percentage point change of residential median land price, 2001–2016[2] | |
|---|---|---|---|---|---|---|---|---|
| | Mean (%) | S.D. (%) | Mean | S.D. | Mean (%) | S.D. (%) | Mean (%) | S.D. (%) |
| 1. Gray expensive urban core | 15 | 10.2 | US $5016 | US $4515 | −0.09 | 0.13 | 2.1 | 3.68 |
| 2. Green moderately-priced suburbs | 75 | 16.5 | US $2349 | US $1831 | −0.16 | 0.12 | 4.8 | 2.61 |
| 3. Green lowly-priced suburbs | 75 | 15.1 | US $733 | US $410 | −0.31 | 0.12 | −1.4 | 1.60 |
| 4. Green rural areas | 90 | 7.4 | US $525 | US $330 | −0.06 | 0.08 | −1.4 | 1.48 |
| Total | 76 | 24.0 | US $1269 | US $62,577 | −0.15 | 0.15 | −0.17 | 3.03 |

[1]Data source: Calculated from the Landsat [11] with NDVI.

[2]Median urban land price of residential district inflation-adjusted to year 2011 [16].

**Table 9.** Cluster distribution and descriptive statistics of towns/districts in Taiwan, by green coverage rate, land price, and their growth patterns.

The first cluster is coined as the gray expensive urban core, since most of them were located in the urban core with the lowest green coverage rate of a mean of 15%, and the highest median residential land price (**Table 9**, **Figure 10**). This cluster is the most urbanized class, composed of less than 10% of all districts/towns with valid data, most of which were the most urbanized core constituents of the most developed city regions of the 01 TNKY and 05 KP, as well as some in the core of 03-TCN. In the last 15 years of 2001–2016, the green coverage rate of this cluster descended, and the median land prices were on the rise with an annual mean of 2.1 percentage points, only second to the second cluster of green moderately priced suburbs detailed below.

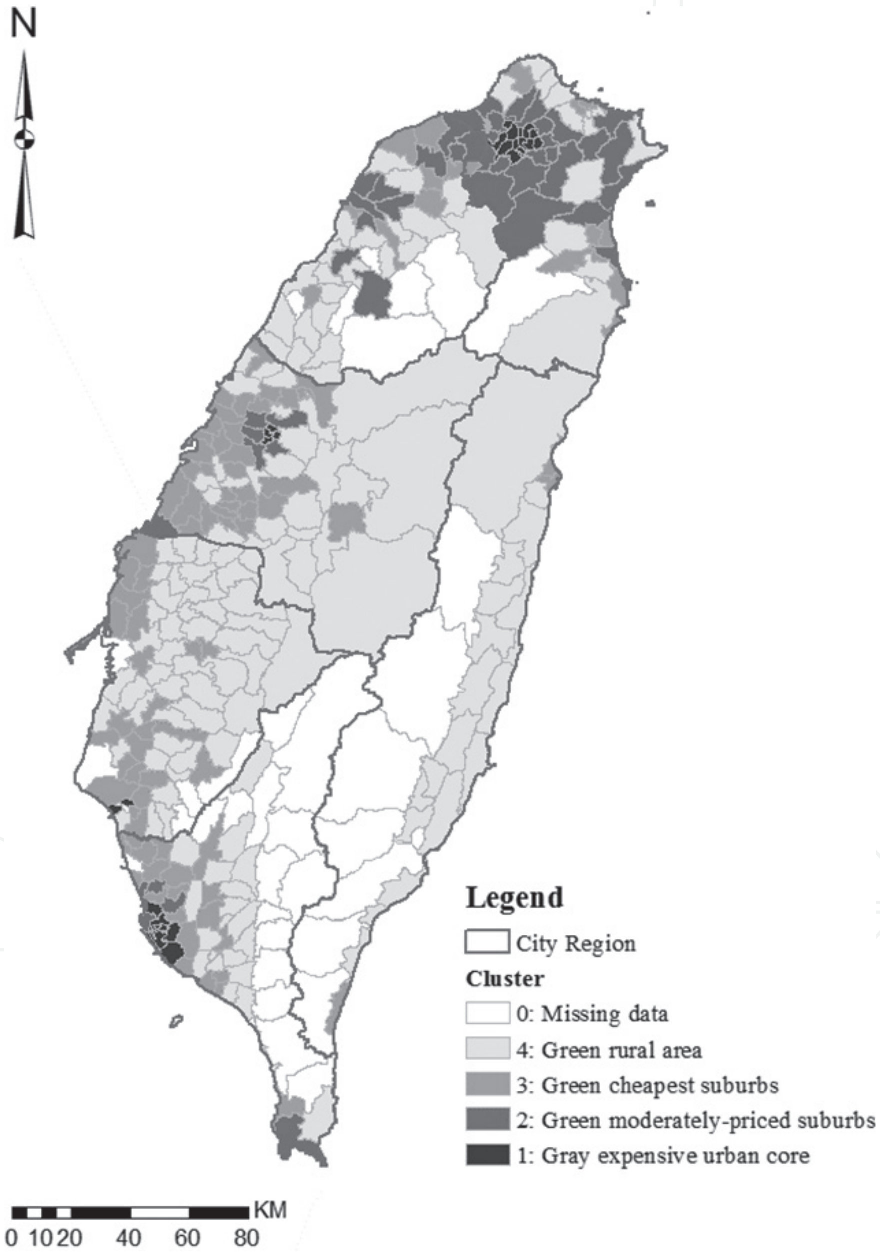


**Figure 10.** Cluster distribution towns/districts in Taiwan, by green coverage rate, land price, and their growth patterns.

The other three clusters all had higher green cover rates of 75% or more and lower residential land prices than the gray expensive urban core, indicating better natural environment and lower housing cost, but lower accessibility to the urban core (**Table 9**, **Figure 10**). The second cluster coined as the green moderately priced suburbs mostly contains districts/towns adjacent to the cluster gray expensive urban core, including some second-tier urban cores of the city region. Its median residential land price was only some half of the cluster gray expensive urban core, but its annual growth percentage point was the highest at about 5%. These inner parts of city regions of the cluster gray expensive urban core and/or cluster green moderately priced suburbs were the only urban areas with rising median residential land prices. Then, the cluster green lowly priced suburbs mostly lied further out from the urban core with significantly lower residential median land prices, but its residential prices decreased between 2001 and 2016. The rest is the rural areas unsurprisingly with the highest green coverage and lowest residential median land prices.

Overall, these four clusters comply with the degree of urbanization to some degree, the higher the degree of urbanization, the higher the residential land price and the lower the green coverage rate. The mean population density of the cluster gray expensive urban core was as high as about 19,000 persons per square km in 2016, followed by a large gap, by the second tier of the two clusters of green suburbs, and the green rural cluster (**Table 8**).

## 7. Conclusions and policy implications

Similar to many other fast urbanizing countries, Taiwan's urbanization grew considerably between 1976 and 2016 from 61 to 80%. Meanwhile, the population grew abruptly by 42%, which made sustainable urbanization an even more crucial issue, since the total urban population was enlarged at an even higher pace. This research focuses on the social and environmental aspects of sustainable urbanization regarding housing affordability and natural living quality in the urban areas, respectively. The panel data analysis demonstrates the negative associations between the green coverage rate and the degree of urbanization represented by the population density of the sub-area of a city region-town/district and the population size of the city region. Moreover, urbanization's relationship with the median land price is positive. In summary, degraded urban greenery and increasing residential land prices came along with the urbanization in Taiwan between 2001 and 2016.

Degraded living quality regarding urban greenery and housing affordability seems to come as the cons of urbanization, largely driven by the rural emigrants seeking for the better level of service in urban areas. Arguably, in the sense of "user pays," the local scale impacts of human development on the natural environment may be reduced to some degree for the other non-human stakeholders by confining human developments in urbanized areas, and there is still needs to resolve the degraded standard of living in urban areas. Other than a whole bunch of potential resolutions of raising the level of urban greenery by planting wherever possible, horizontally or vertically, on the ground or roof, two specific types of urban planning tools are emphasized here that may essentially affect accessible green space on the ground or in the buildings. The first one is to delicately reconsider building coverage rates for various land uses to allow the most possible natural plant-friendly ground, when the buildings are renewed; this will lay up the fundamental permeable settings in the urban area. The second is to consider the building setback policy to provide gardens located in the mid- or low-floors of a building, which are highly accessible to building users or even pedestrians. This type of mid-air gardens may also avoid strong sunlight blocked by the building itself. Due to their vertical locations in the building, as opposed to the roof garden, it can be more accessible and function better as a community mini-park.

Rising residential land/housing prices is probably a common, tough issue for many cities or counties. In the case of Taiwan, there was lack of cures at the peaks of the last two housing market cycles. There has even been some ignorable portion of vacant housing units in the greater Taipei area of the 01 TNKY city region, but the least possible expectation during the peak was for the housing prices to decline, much of which was to blame the situations and policy that allow housing units to become an investment commodity.

The low green coverage rate and high land price in the highest urbanized urban core may cancel out the benefits of urban agglomeration as in the high service level of public infrastructure. Whether the low mean green coverage rate of 15% of the gray expensive urban core cluster leads to unhealthy, unpleasant, inefficient, or unbalanced urban settings may not seem as initiative as it looks or even sensible to the general public. However, this condition may be planners' responsibility to think ahead to consider if this level has already passed the acceptable threshold. This greenery issue may also be further complicated by the concerns over when to adopt green cover land area as a whole or per capita green coverage when assessing various aspects. For instance, when considering the conversion of carbon dioxide produced by residents into oxygen needed for each resident, the index of per capita green coverage may make more sense. In contrast, the overall green coverage may serve to evaluate the natural landscape or streetscape in the urban settings.

Finally, based on the cluster analysis, the green moderately priced suburbs and green lowly priced suburbs had better greenery but lower residential prices. Governments may employ policies to leverage higher level of infrastructure in these towns/districts or even to establish another urban core to formulate a polycentric urban form. A rule of thumb for the government is to take advantage of the urban agglomeration by providing better infrastructure in needed urban areas and smartly drive residents to move to the places with less congestion issue. On the other hand, for the individuals or households, the suggestion would be to reconsider if some greener districts or cities with cheaper housing may serve their needs; however, they have never popped up on their residential wish list.

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