# Linkage between Green Space Structures and Mental Disorder in Taiwan

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**Abstract:** A blooming body of researches indicate the green space confers numerous health benefits including alleviation of mental distress. Several recent reviews have summarized and evaluated the growing evidence base. However, most of the previous studies used the vegetation index, and tree cover density as the overall green space exposure indices. In fact, there are still more green space factors affecting human health, including the area, edge, distribution, shape, and proximity; however, very few studies had investigated it; especially, the incidence of the mental disorder. The study aims to investigate the relationship between green space structures and mental disorder in Taiwan. There were two green space indexes were used to be the greenness exposure including quantification green space structures and overall greenness index. First of all, the database of Land Use Investigation of Taiwan was used to select the green space like recreational, forest, and overall green space. After preparation, green space structures indices were calculated accordingly, including Patch Area, Shape Index, Fractal Dimension Index, and Proximity Index by using FRAGSRATS 4 (Computer Softeare Program, University of Massachusetts, Amherst, MA, USA). The overall greenness index including Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) were obtained from the global MODIS NDVI database. In addition, the National Health Insurance Research Database was used to define the study population who were first diagnosed the mental disorders according to ICD-9 codes from 290 to 319. Furthermore, the covariates databases were collected in this study, like air pollution, metrological, socioeconomic status databases. The spearman correlation analysis was used to select the variables through considering the collinearity. Cox proportional hazards models were applied to assess the relationship between green space exposure and mental diseases incidence after adjustments were made for the potential confounders. A negative association was found from most of the green space structures indices in whole Taiwan island. Our findings suggest more surrounding greenness, larger green space, more fragmentation, and more proximity may reduce the risk of mental disorder.

**Keywords**: Green Space Structures, Mental Disorder, Patch Area, Fractal Dimension Index, and Proximity Index

## 1. Introduction

Mental disorders are a behavioral or mental pattern that causes significant distress or impairment of personal functioning. Mental disorders are the leading cause of disability worldwide. Over 300 million people experience depression, equivalent to 4.4% of the world's population, and more than 260 million people experience anxiety disorder, representing 3.6% of the population worldwide (World Health Organization 2017). In Asia area, the prevalence of mental disorder is not only essential index for public health policy and planning, but also affluent contributing to health loss across the lifespan (Baxter et al. 2016; Ishikawa et al. 2018). In Taiwan, the prevalence of mental disorders was increasing from 1990 to 2010 (Fu et al. 2013). The differences in prevalence of major and minor psychiatric disorders between the sexes were significant (I-C Chien et al. 2004). Mental disorder can be caused several factors, such as genetic and environmental challenges (Berk et al. 2014; Berry et al. 2018; Kioumourtzoglou et al. 2017; Majeed and Lee 2017; Min and Min 2018; Navarro-Mateu et al. 2013; Rautio et al. 2018; Van den Berg et al. 2010), lifestyle changes (Beenackers et al. 2018; Berk et al. 2013; Dash et al. 2015; Mick et al. 2018; Twenge et al. 2018; Yang et al. 2018), economic impact (Batty et al. 2018; Berk et al. 2006; Hoebel et al. 2017; Jorm 2018), and social networks (Battin and Crowl 2017; Domènech-Abella et al. 2017; Zock et al. 2018).

Form the literature review, evidence is mounting that there is more benefit effect between greenspace and mental health (Frumkin et al. 2017; Markevych et al. 2017), which have shown positive relationship between green space availability and people's mental health, like reducing depression (Cohen-Cline et al. 2015; Gascon et al. 2015; McEachan et al. 2016; Taylor et al. 2015) and reducing anxiety (Beyer et al. 2014; Bratman et al. 2015; Song et al. 2015). However, the most of the previous studies were used the vegetation index, and tree cover density to be the overall green space exposure index. In fact, there is still more green space factors, green space structures, affecting human health (Shen and Lung 2017; Tsai et al. 2018a; Tsai et al. 2018b).

In recent years, the green space structures were applied to investigate the green space effect on human health (Shen and Lung 2016, 2017; Tsai et al. 2018a; Tsai et al. 2018b) and three characteristics were used including the area and edge, distribution, shape, and proximity of the green space. These characteristics were based on the theories, invoking green space exposure related psychological mechanisms, have been identified like Stress Recovery Theory (SRT), which emphasizes the role of nature in relieving physiological stress (Ulrich 1983; Ulrich et al. 1991); Attention Restoration Theory (ART), which emphasizes the role of nature in relieving mental fatigue (Kaplan and Kaplan 1989; Kaplan and Talbot 1983; Kaplan 1995); Prospect and refuge theory, which emphasizes environments that meet feeling secure will often provide people with the capacity to observe (prospect) without being seen (refuge) (Appleton 1996). However, only one study was investigated the association between green space structure and mental health (Tsai et al. 2018b) and in this study, Tsai et al. recommend the future research should perform longitudinal studies and other appropriate designs to examine causal linkages and consider the more risk factors. Furthermore, the future studies should examine green space structures and health using a stratified approach. In addition, no study has examined the relationship between green space structure and mental disorder incidence in Asia at a national scale.

Therefore, this study analysed the association of green space structure and the mental health illness (Mental disorder, Neurotic disorders, Affective psychoses, and Schizophrenia) in Taiwan from 2000 to 2010 based on the Longitudinal Health Insurance Database (LHID) developed by the National Health Insurance (NHI) system. This is the first study to investigate the linkage between green space structure and mental health in Asia using a retrospective cohort study design with a considerable number of participants (one million).

## 2. Method and Material

### *2.1. Study Area*

Taiwan is an island located on the Tropic of Cancer; its climate regions consist of the northern and central subtropical and southern tropical regions. Because of the variety of its climate regions, Taiwan is the habitat for numerous species. Taiwan also lies in the circum-Pacific seismic zone at the intersection of the Yangtze Plate, Okinawa Plate, and Philippine Mobile Belt. This location causes the height above sea level to increase continuously and produces earthquakes. The total area of Taiwan is 36,197 $km^2$ (Ministry Of the Interior 2018), and the geography is characterized by rugged mountains running from north to south in the eastern two-thirds of the island and flat plains in the western third. The western region is also home to most of Taiwan's population. In Taiwan, the second half of the 20th century is called "Taiwan's economic miracle" because of the rapid economic growth and industrialization (Clough 1991). Between 1952 and 1982, the economic growth was on average 8.7% per year; between 1983 and 1986, it was 6.9% per year. The gross national product increased by 360% between 1965 and 1986. However, accompanying the economic development, the prevalence of common mental disorders doubled from 11.5% in 1990 to 23.8% in 2010 (Fu et al. 2013).

### *2.2. Databases*

#### *2.2.1 Greenness Databases*

In this study, two databases were used to calculate the green space exposure indices. One is the Remotely Sensing Greenness Database and the other is the National Land Surveying database. The Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), green biomass density indicator, were used as surrogates for surrounding greenness belonged in the Remotely Sensing Greenness Database. The forest and recreational green space were selected from the National Land Surveying database and Green Space Density and Quantified Green Space Structures were generated for each green space type at the township level by FRAGSRATS 4 (Computer Software Program, University of Massachusetts, Amherst, MA, USA).

*2.2.2 LHID*

We used the LHID, a subset of the NHI, as our main data source to assess the association between green space structures and mental health. The NHI database was established in 1995 and covered more than 99.6% of the Taiwanese population and is a single-payer and compulsory social insurance system that regulates the disbursement of health care funds and guarantees equal access to health care for all citizens. In the end of 2014, 99.9% of the citizens in Taiwan (approximately 23,340,000 citizens) were enrolled in this program. The LHID contains the medical information of two million randomly sampled individuals from the NHI database. One million subjects are collected using stratified random sampling by age, sex, and the registry of regions from the full database population. The original claims and a registry of the beneficiaries that includes demographic characteristics, inpatient and ambulatory care, diagnose, catastrophic illness certificates, medical expenditures, operations, prescriptions, investigation items, examinations, procedures, treatments, hospital levels, and medical divisions are recorded in this database for research purposes (Lin et al. 2018; National Health Insurance Administration Ministy of Health and Welfare 2017; National Health Research Institutes 2003). After validation, the individuals included in the LHID and those enrolled in the original Taiwan NHI did not differ particularly in terms of age, sex, mean health insurance rate, or distribution in townships (National Health Research Institutes 2003). The identification of mental disorder incidence from 2000 to 2010 in the LHID was based on the International Classification of Diseases, Ninth Revision (ICD-9) codes 290-319. We adopted the 1996 to 1999 period as a wash-out period; patients who had mental disorder during this period were masked out from the analysis. Participants residing in off-shore islands such as Kinmen and Matsu were excluded. In total, the number of individuals without a history of Mental disorder, was recruited 813,045 for our analysis. The LHID provides the hospital details for each participant's medical claim, instead of providing their residential address for confidentiality reasons. We assumed all patients lived near the hospital they most often visited for a common cold (ICD-9 code: 460 or 465) during the study period. The township-scale incidence rate during study period is displayed in Figure 1a. Demographic and socioeconomic data, namely age, sex, health insurance rate (proxy for personal financial status), and classification of the insured were acquired from the LHID. Six categories were used to classify the insured. The first category included civil servants, volunteer military personnel, public office holders, private school teachers, employees of public or private owned enterprises and organizations, employers self-employed, independent professionals, and technical specialists. The second category included trade union members and foreign crew members. The third category included members of farming, fishing, and irrigation associations. The fourth category included military conscripts, alternative military service personnel, military school students on scholarships, widows or widowers of deceased military personnel on pensions, and inmates. The fifth category included low-income households. The sixth category included veterans and their dependents and other individuals. The NHI premiums for the individuals in category 1, 2, and 3 are calculated based on the monthly income they report to the NHI administration. The premiums for the individuals in category 4, 5, and 6 are based on the average premium of the people enrolled in category 1, 2, and 3 (National Health Research Institutes 2003). The study protocol was reviewed and approved by the National Cheng Kung University Governance Framework for Human Research Ethics (A-EX-108-009), and the research had been conducted according to principles of Declaration of Helsinki

### *2.2.3. Adjusted variable database*

According to previous studies in totally, three databases would have employed for model adjustment, including meteorological, air pollution, and social-economic status databases. Monthly weather records were acquired from 333 monitoring stations of the Central Weather Bureau located in Taiwan. The spatial average of monthly mean temperature and total precipitation at a township resolution was estimated using an ordinary kriging interpolation method with a spherical model. The obtained cross-validated $R^2$ value ranges for temperature and precipitation were 0.62–0.76, 0.45–0.82, respectively. The air pollution records, such as Nitrogen dioxide ($NO_2$), Particulate Matter 10 micrometers or less in diameter ($PM_{10}$), Ozone ($O_3$), and Sulfur dioxide ($SO_2$) were acquired from 76 air quality monitoring stations of the Environmental Protection Administration, Executive Yuan, Republic of China (Taiwan). The spatial average of air pollutions was also estimated using an ordinary kriging interpolation method with a spherical model. Social-economic data derived from both the 2000 census and 2004 population statistics for stratification. A total of 358 boroughs and townships were regrouped into seven strata. The” Taiwan Social Change Survey” has first adopted this new typology as the stratification for sampling design in 2005. For the management of field work, the sixth and the seventh stratum were finally combined, resulting in six strata as the sampling scheme. These six embedded strata are substantial and as expected as well from the statistical analysis, indicating that social-economic status can be classified six categories in Taiwan, such as Metropolis, Industrial and commercial district, Emerging town and city, Traditional industrial town and city, Less developed town and city, and Aging and remote town and city (Hou et al. 2008).

## *2.3. Quantification of green space structures*

Three green space structures (Area, Contiguity index, and Proximity Index) were generated by using FRAGSRATS 4 (Computer Software Program, University of Massachusetts, Amherst, MA, USA)(UMass Landscape Ecology Lab 2000). These selected indices were chosen to characterize the patterns of green space based on existing theory and empirical studies that describe how the green space attributes potentially mental health effect. For instance, more green space (Green Space Density and Area) was found to associate with less stress, depression, and better mental health (Min et al. 2017; Thompson et al. 2012; Triguero-Mas et al. 2015; Tsai et al. 2018b). Contiguity index is the index describing that the complexity of the green space. More complex means the green space more natural; on the contrary, more ordered means more artificial. Proximity Index means the adjacent level among the green space. More proximity represents that the green space was fewer artificial intervention. The related theories which reveal the mental health beneficial effect on contacting with the green space were SRT (Ulrich 1983; Ulrich et al. 1991), ART (Kaplan and Kaplan 1989; Kaplan and Talbot 1983; Kaplan 1995), and Prospect and refuge theory (Appleton 1996). Table 1 provides definitions and formula for each of three green space structures.

**Table 1** The formula and descriptions of three green space structures.

| Variables | Formula | Description |
|---|---|---|
| **Area-edge** | | |
| Area | $\text{AREA} = \sum_{j=1}^{n} a_{ij} \times (\frac{1}{10{,}000})$<br>$a_{ij}$ = area ($m^2$) of patch ij | Mean of the total area of vegetative patches. |
| **Shape** | | |
| Contiguity Index (CONTIG) | $\text{CONTIG} = \frac{\left[\frac{\sum_{r=1}^{z} C_{ijr}}{a_{ij}}\right]}{v-1}$<br>$c_{ijr}$ = contiguity value for pixel r in patch ij<br>v = sum of the values in a 3-by-3 cell template<br>$a_{ij}$ = area of patch ij in terms of number of cells | CONTIG equals the average contiguity value (see comments) for the cells in a patch (i.e., sum of the cell values divided by the total number of pixels in the patch) minus 1, divided by the sum of the template values (13 in this case) minus 1. Note, 1 is subtracted from both the numerator and denominator to confine the index to a range of 1. The value **increase** as the patch type become more fragmentation. |
| **Proximity** | | |
| Proximity Index (PROX) | $\text{PROX} = \sum_{g=1}^{n} \frac{a_{ijs}}{h_{ijs}^2}$<br>$a_{ijs}$ = area ($m^2$) of patch ijs within specified neighborhood (m) of patch ij.<br>$h_{ijs}$ = distance (m) between patch ijs and patch ijs, based on patch edge-to-edge distance, computed from cell center to cell center. | The physical connectedness of vegetative cover. The value **increase** as the patch type become more physically connected. |

### 2.3. Statistical Analysis

We hypothesized that exposure to green space structures has a positive effect on mental health. With the retrospective cohort study design, the Cox proportional hazards model was used to estimate the association of green space structures with the risk of mental disorder (Cox 2018). The variables in the model were considered because research has proven them correlated with the green space structures, and collinearity was avoided by employing the Spearman correlation analysis. The inclusion criteria for the variables selection were a correlation greater than 0.7 between independent variables and references proving that one of the variables correlates with the green space structures. To examine the relationship between green space structures and mental disorder, we analyzed the hazard ratio (HR) of mental disorder incidence within different degrees of green space structures in comparison with the lowest green space structures. The categorical method was based on previous research (Sung et al. 2013). Adjustments were made using the representations of a range of well-established factors obtained from the LHID, including age (0 to 15, 15 to 30, older than 30 years), sex, health insurance rate (stratifying the data into two groups based on a previous study (IC Chien et al. 2004): Less than NT$20,000 and more than NT$20,000), and classification of the insured. Metrological factors such as mean temperature, and total precipitation were also considered for model adjustment because previous studies have suggested that weather conditions affect mental status (Brandl et al. 2018; Padhy et al. 2015). A P value of 0.05 was selected for statistical significance. ArcGIS (version 10.4.1; Environmental Systems Research Institute Inc., Redlands, CA) and SAS 9.4 (Cary, NC, U.S.A.) were used for the analyses.

### 2.4. Sensitivity Test

To examine the nonlinear relationship between green space structures and mental disorder, we used two approaches to conduct the sensitivity test. The first approach was to use continue value of green space structure to verify the robust of result.

## 3. Results

### 3.1. Descriptive Statistics

In Table 1, participants are stratified by their NDVI values into 10 stratifications to observe the demographic distribution in the assorted greenness levels. The mean NDVI values for the greenness stratifications from lowest to highest were 0.14, 0.18, 0.19, 0.24, 0.35, 0.43, 0.52, 0.57, 0.62, and 0.69. The highest mean health insurance rate was NT$13,408.54 in the fourth stratification (10th–24th percentile of NDVI [NDVI from 0.20 to 0.29]), and the lowest was NT$11,926.05 in the tenth stratification (>99th percentile of NDVI (NDVI from 0.60 to 0.68)). A higher proportion of men lived in greener places. The highest proportion of the age classification was 15 to 30 years old, the peak age of onset for mental disorder, in the 25th–

49th percentile (26.40%), and the lowest was in stratification below the first percentile (23.74%). The highest proportion of people with health insurance rates of less than NT$20,000 was in the 50th–74th percentile (80.48%), and the lowest was in the stratification in the 25th-49th percentile (74.15%). The tenth stratification (>99th percentile of NDVI (NDVI from 0.60 to 0.68)) included the lowest sociodemographic characteristics, but it did not include the highest mental disorder incidence rate (32.12%), implying that environmental factors play a role in the incidence of mental disorder.

**Table 2.** Baseline characteristics of study population stratified by greenness exposure (N = 813,045)

| Greenness Exposure | <1$^{st}$ (N = 6,243) | 1$^{st}$–4$^{th}$ (N = 33,328) | 5$^{th}$–9$^{th}$ (N = 34,470) | 10$^{th}$–24$^{th}$ (N = 128,276) | 25$^{th}$–49$^{th}$ (N = 204,090) | 50$^{th}$–74$^{th}$ (N = 200,733) | 75$^{th}$–89$^{th}$ (N = 124,549) | 90$^{th}$–94$^{th}$ (N = 39,703) | 95$^{th}$–99$^{th}$ (N = 33,356) | > 99$^{th}$ (N = 8,297) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | **P*** |
| **NDVI** | 0.14 (0.01) | 0.18 (0.01) | 0.19 (0.01) | 0.24 (0.03) | 0.35 (0.03) | 0.43 (0.03) | 0.52 (0.01) | 0.57 (0.02) | 0.62 (0.02) | 0.69 (0.02) | |
| **Health insurance rate** | 12,497.42 (15074.09) | 13,108.81 (15360.79) | 12,319.21 (15426.28) | 13,408.54 (16294.75) | 12,876.25 (15168.61) | 12,406.03 (14162.14) | 13,066.86 (15543.99) | 12,509.17 (14373.07) | 12,758.25 (14082.15) | 11,926.05 (13386.91) | < 0.001 |
| | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **No. (%)** | **P*** |
| **Sex** | | | | | | | | | | | |
| **Male** | 3,152 (50.49) | 16,885 (50.66) | 16,919 (49.08) | 63,330 (49.37) | 103,666 (50.79) | 104,665 (52.14) | 63,680 (51.13) | 20,870 (52.57) | 17,444 (52.30) | 4,540 (54.72) | < 0.001 |
| **Female** | 3,091 (49.51) | 16,443 (49.34) | 17,551 (50.92) | 64,946 (50.63) | 100,424 (49.21) | 96,068 (47.86) | 60,869 (48.87) | 18,833 (47.43) | 15,912 (47.70) | 3,757 (45.28) | |
| **Age (years)** | | | | | | | | | | | |
| **0–15** | 357 (5.72) | 2,207 (6.62) | 2,725 (7.91) | 9,765 (7.61) | 17,347 (8.50) | 18,382 (9.16) | 10,242 (8.22) | 3,468 (8.73) | 2,724 (8.17) | 802 (9.67) | < 0.001 |
| **15–30** | 1,482 (23.74) | 8,159 (24.48) | 8,513 (24.70) | 32,012 (24.96) | 53,877 (26.40) | 52,927 (26.37) | 31,717 (25.47) | 10,238 (25.79) | 7,975 (23.91) | 1,971 (23.76) | |
| **30 +** | 4,404 (70.54) | 22,962 (68.90) | 23,232 (67.40) | 86,499 (67.43) | 132,866 (65.10) | 129,424 (64.48) | 82,590 (66.31) | 25,997 (65.48) | 22,657 (67.92) | 5,524 (66.58) | |
| **Health insurance rate** | | | | | | | | | | | |
| **NTD 0–20,000** | 4,956 (79.38) | 24,847 (74.55) | 26,678 (77.39) | 95,114 (74.15) | 156,974 (76.91) | 161,550 (80.48) | 95,084 (76.34) | 31,521 (79.39) | 27,285 (81.80) | 6,988 (84.22) | < 0.001 |
| **NTD 20,000 +** | 1,287 (20.62) | 8,481 (25.45) | 7,792 (22.61) | 33,162 (25.85) | 47,116 (23.09) | 39,183 (19.52) | 29,465 (23.66) | 8,182 (20.61) | 6,071 (18.20) | 1,309 (15.78) | |
| **Psychological status** | | | | | | | | | | | |
| **Incidence cases of schizophrenia** | 2,303 (36.89) | 10,533 (31.60) | 10,659 (30.92) | 38,784 (30.23) | 59,626 (29.22) | 61,357 (30.57) | 38,183 (30.66) | 12,485 (31.45) | 10,341 (31.00) | 2,665 (32.12) | < 0.001 |

* *P* values were based on the Wilcoxon rank-sum test for no classified NDVI and health insurance rate or Pearson's chi-squared for sex, age, health insurance rate, psychological status incidence cases of schizophrenia. All statistical tests were two-sided. NDVI = Normalized Difference Vegetation Index, NTD = New Taiwan dollars.

*3.2. Descriptive statistics of green space structures*

The description of green space structures is displayed in table 3. Due to the fact that the proportion of forest space in green space is over than 90 %, the descriptive results are similar between overall green space and forest space. Comparing with the recreational green space, the area and edge indices of forest is bigger, such as Patch Area (4922.36 ha versus 9.02 ha). The Contiguity Index in forest is more complex than in recreational green space (0.87 versus 0.79). The Proximity Index in forest is much more than in recreational green space (44,233.20 versus 13.68). In general, comparing with the recreational green space, there are bigger area, more complex shape, more proximate green space in the type of overall green space and forest space. The visual results of table 3 were shown in Figure 1c. In this study, we classified the greenness indices and mean green space structures into 10 classifications in order to fit the hypothesis of cox proportional hazard model. The Cut-off values of each index were showed in Table 4.

**Table 3.** Descriptive statistics of green space structures

| | | Mean (SD) | Min | Median | Max |
|---|---|---|---|---|---|
| **Overall green space** | | | | | |
| **Area-edge** | Area (ha) | 4886.82 (15986.67) | 0.08 | 225.83 | 146268.53 |
| **Shape** | Contiguity index | 0.89 (0.09) | 0.30 | 0.91 | 0.99 |
| **Proximity** | Proximity Index | 41060.13 (145057.07) | 0.31 | 505.07 | 1195499.39 |
| **Forest** | | | | | |
| **Area-edge** | Area (ha) | 4922.36 (16028.31) | 0.02 | 254.40 | 146286.05 |
| **Shape** | Contiguity index | 0.87 (0.12) | 0.17 | 0.91 | 0.99 |
| **Proximity** | Proximity Index | 44233.20 (151435.91) | 0.00 | 623.81 | 1282877.45 |
| **Recreational green space** | | | | | |
| **Area-edge** | Area (ha) | 9.02 (20.44) | 0.04 | 2.97 | 201.73 |
| **Shape** | Contiguity index | 0.79 (0.11) | 0.25 | 0.81 | 0.98 |
| **Proximity** | Proximity Index | 13.68 (80.79) | 0.00 | 2.27 | 1436.78 |

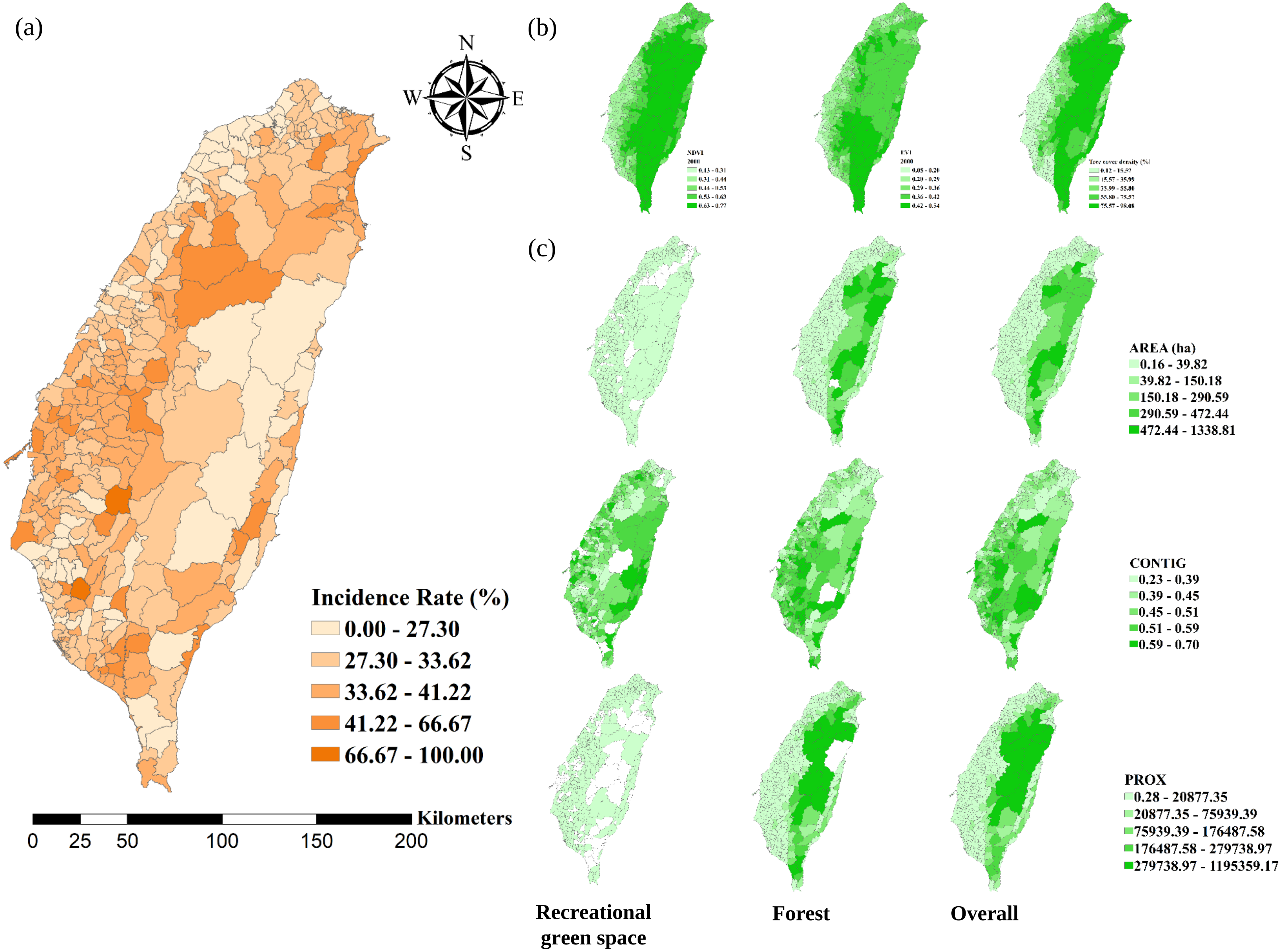


**Figure 1.** Databases displayed in the location of Taiwan. (a) The township scale of incidence rate from 2000 to 2010. (b) The township scale of greenness indices. (c) The township scale of green space structures.

**Table 4.** Cut-off values of greenness indices and mean green space structures

| | 1st | 5th | 10th | 25th | 50th | 75th | 90th | 95th | 99th |
|---|---|---|---|---|---|---|---|---|---|
| NDVI | 0.16 | 0.18 | 0.20 | 0.29 | 0.39 | 0.49 | 0.54 | 0.60 | 0.68 |
| EVI | 0.09 | 0.11 | 0.12 | 0.18 | 0.26 | 0.31 | 0.36 | 0.39 | 0.42 |
| Tree cover density | 1.00 | 2.51 | 4.16 | 6.42 | 14.77 | 32.90 | 52.53 | 60.65 | 78.94 |
| The area of overall green space | 0.25 | 0.37 | 0.44 | 0.63 | 1.61 | 3.46 | 7.30 | 11.96 | 28.43 |
| The area of forest space | 0.03 | 0.09 | 0.22 | 0.55 | 1.71 | 5.26 | 11.03 | 15.03 | 30.74 |
| The area of recreational green space | 0.14 | 0.19 | 0.27 | 0.44 | 0.74 | 1.31 | 1.80 | 2.51 | 4.48 |
| The contiguity index of overall green space | 0.66 | 0.75 | 0.78 | 0.83 | 0.89 | 0.93 | 0.94 | 0.95 | 0.97 |
| The contiguity index of forest space | 0.33 | 0.60 | 0.69 | 0.79 | 0.88 | 0.93 | 0.94 | 0.96 | 0.97 |
| The contiguity index of recreational green space | 0.61 | 0.68 | 0.74 | 0.79 | 0.85 | 0.89 | 0.92 | 0.94 | 0.95 |
| The proximity index of overall green space | 1.64 | 7.06 | 8.76 | 17.35 | 67.68 | 1075.15 | 6108.00 | 15058.14 | 62737.71 |
| The proximity index of forest space | 0.01 | 0.32 | 3.34 | 13.11 | 102.50 | 1890.97 | 8798.69 | 21595.33 | 74266.46 |
| The proximity index of recreational green space | 0.03 | 0.33 | 0.77 | 4.17 | 9.87 | 20.92 | 50.59 | 58.70 | 102.81 |

### 3.3. Model Analysis and Sensitivity Test

Table 3 depicts the association between green space exposure and mental disorders; especially, including the green space structures exposure indices in three types of green space and the mental disorders in Taiwan. An HR less than 1 indicates that the population received beneficial effects from green space exposure. An HR of more than 1 signified a higher hazard of mental disorder from green space exposure. After adjustments were made for demographic, socioeconomic, metrological, and air pollution factors, the coefficients of surrounding greenness revealed protective effects of every classification comparing the reference level (set the lowest decile), such as NDVI, EVI, and tree cover density. In addition, almost association between green space structures and mental health supported our hypothesis. The more proportion of green space, the more benefit for mental health, for example the HRs (95% CI) of area were about 0.77 (0.73, 0.81), 0.86 (0.82, 0.91), and 0.78 (0.74, 0.83) from overall, forest, recreational green space in class of 10 relatives to the reference level. The more complex shape of green space can lead to mental healthy profits. The HRs (95% CI) of Contiguity Index from overall, forest, recreational green space were 0.80 (0.76, 0.85), 0.86 (0.81, 0.91), and 0.80 (0.76, 0.84) in class of 10 relatives to the reference level. The more proximate green space may avail to improve mental health. The HRs (95% CI) of Proximity Index were 0.76 (0.71, 0.81), 0.91 (0.85, 0.96), and 0.83 (0.79, 0.88) form three types of green space in class of 10 relatives to the reference level. In addition, in the sensitivity analysis (Table 5), the HRs obtained from almost of the models were smaller than the one, namely the NDVI, EVI, Area, Contiguity Index, and Proximity Index. This result indicated that exposure to surrounding greenness had a protective effect on individuals, thus reducing the risk of mental disorder. Specifically, it appeared that more proportion (HR = 0.99, 95% CI = (0.99–0.99)), more complex (HR = 0.95, 95% CI = (0.90–1.01)), and more proximate (HR = 0.99, 95% CI = (0.99–0.99)) green space reveal protective effect for getting mental disorder.

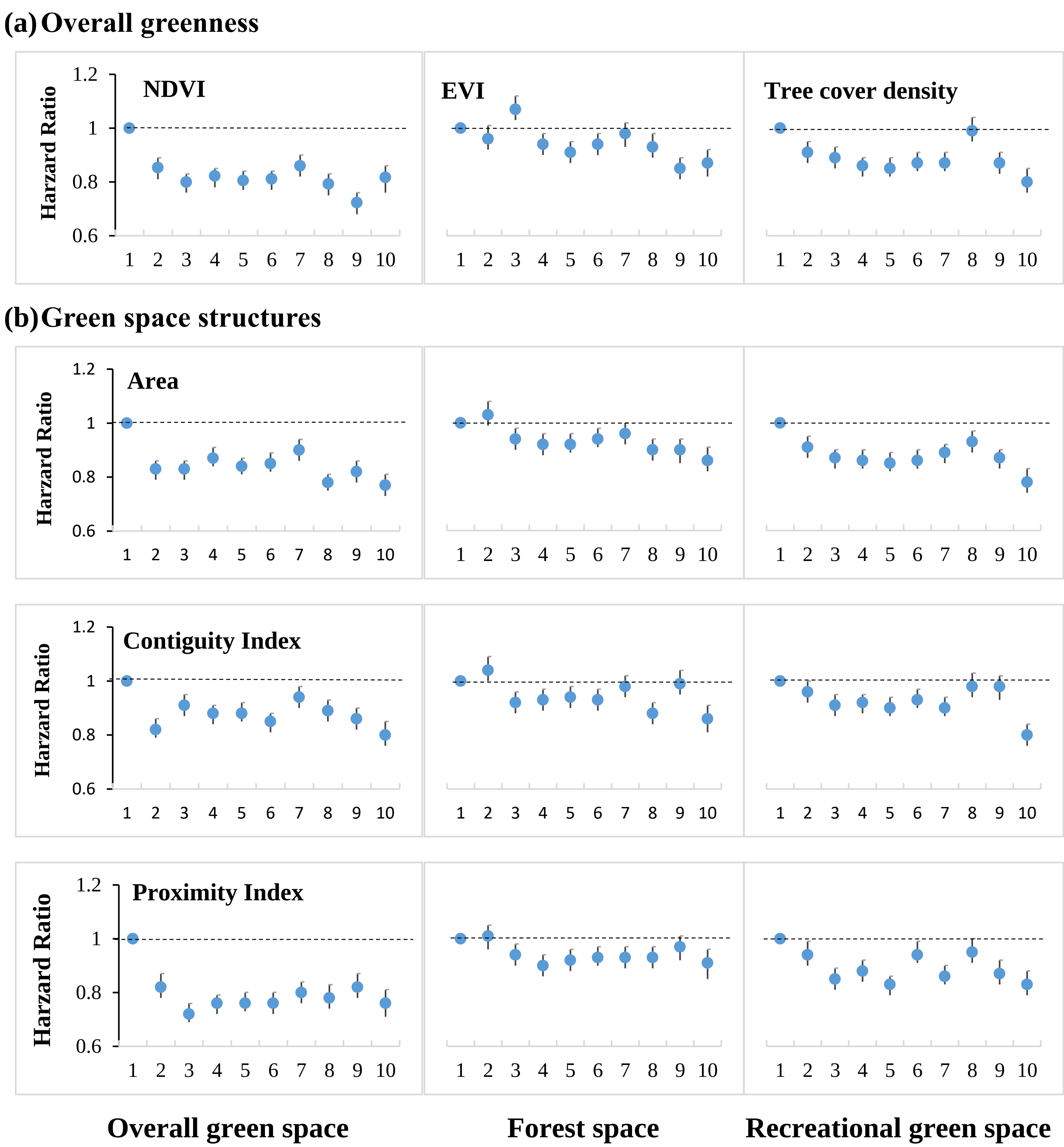


**Figure 2.** The association between the relative risk of developing a mental disorder. (a) The hazard ratio of greenness indices. (b) The hazard ratio of green space structures. All models were adjusted for age, sex, health insurance rate, classification of the insured, temperature, precipitation, $NO_2$, $PM_{10}$, $O_3$, and $SO_2$.

**Table 5.** Hazard ratios (HR) and confidence interval (C.I.) for continuous greenness and green space structures in cox model in sensitivity

| | | HR | (95% C.I.) |
|---|---|---|---|
| NDVI | 0.93 | (0.88 , 0.99) | <0.05 |
| EVI | 0.91 | (0.83 , 0.98) | <0.05 |
| Tree cover density | 1.00 | (1.00 , 1.00) | <0.05 |
| The area of overall green space | 0.99 | (0.99 , 0.99) | <0.001 |
| The contiguity index of overall green space | 0.95 | (0.90 , 1.01) | 0.17 |
| The proximity index of overall green space | 0.99 | (0.99 , 0.99) | <0.001 |

All models were adjusted for age, sex, health insurance rate, classification of the insured, temperature, precipitation, $NO_2$, $PM_{10}$, $O_3$, and $SO_2$.

**4. Discussion**

The lowest sociodemographic characteristic was observed in the tenth greenness exposure category (the proportion of the health insurance rate less than NT$20,000 = 84.22%, Table 2). Although various factors affect the risk of developing or triggering mental disorder and personal financial status is one of the dominant factors (Agerbo et al. 2015), no highest mental disorder incidence rate (32.12%) was found in that stratification. Therefore, the environmental factors of greenness might play a crucial role in incidence. This hypothesis was demonstrated through the main model (Figure 2), the sensitivity model (Table 5). There is a proactive effect in greenness indices against mental disorder incidence. Consistent findings were reported in recent studies (Chang et al. 2019; Engemann et al. 2018, 2019).

Three characteristic metrics of the green space structures, such as area-edge, shape and proximity were selected to investigate the health effect between green space structures and mental disorder incidence. The results were revealed the more proportion of green space, the more complex shape, and the more proximate green space may avail to improve mental health. It was consistent the theories and hypothesis, Stress Recovery Theory (SRT) (Ulrich 1983; Ulrich et al. 1991), Attention Restoration Theory (ART) (Kaplan and Kaplan 1989; Kaplan and Talbot 1983; Kaplan 1995), and Prospect and refuge theory (Appleton 1996).

This is the first retrospective cohort study to examine the health benefits from green space structures exposure to combat mental disorder. Physician-diagnosed information recorded in the NHI system for more than 800,000 individuals was employed for model analysis. Moreover, a National Land Surveying database established by NLSC and a remotely sensed greenness database established by NASA representing not only the spatial distribution and quality of greenness and green space structures exposure for each individual.

Furthermore, the gene information and family history of participants were unknown. In 2013, research suggested the effects of single-nucleotide polymorphisms are much less relevant than environmental factors (Lencz et al. 2013). According to this finding, missing gene information and family history should not limit our conclusions regarding surrounding greenness and mental disorder. We encourage further investigation to duplicate these analyses after the aforementioned limitations have been resolved.

## 5. Conclusions

This study used a national scale cohort database to examine the association between green space structures and mental disorder. The results revealed that people with more proportion of green space, the more complex shape, and the more proximate green spaceexperience lower mental disorder. Given the economic aspects of the social and medical burden of mental disorder and the quality of long-term care, green space structure is a crucial element to consider in the planning of future urban areas and policy. For example, treatments at psychiatric hospitals could be designed according to scientific evidence provided by environmental psychology and neuroscience, such as encouraging walks and exercise in green spaces. Further research is required in additional locations to determine the effects of greenness on different ethnic groups. We suggest that future studies duplicate these analyses in different countries to assess the effects of geographical differences on the benefits of green spaces.

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