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Original article

Association between depression and green space before and after the COVID-19: Panel data evidence in South Korea

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Abstract

Green space potentially promotes positive mental health in people. Consequently, the role of green spaces has become increasingly important because of the new coronavirus disease (COVID-19). While the association between green space and depression was explored during the COVID-19 pandemic, population data on this relationship before and after the pandemic are lacking. Furthermore, how different types of green space impact depression needs clarification. Thus, this study investigated the association between two vegetation types of green spaces(forests and grass) and perceived depression in South Korea before and after COVID-19 using population data. The percentage of forest areas had a significant negative effect on perceived depression before and after COVID-19. However, the percentage of grass areas had no significant effect on the perceived depression. A 1% increase in forest area reduced perceived depression by 16 people per 100,000 people. These findings are expected to contribute towards advancing public mental health and natural environment domains, and forests should be prioritized to capture the mental health needs of citizens.

Keywords : GIS, COVID-19, Perceived Depression, Panel Regression, Green Space

1. Introduction

Green space is widely considered to promote positive mental health in people (Beyer *et al*., 2014; Kondo *et al*., 2018; Browning and Lee, 2019; Reece *et al*., 2021). In South Korea, the Ministry of Health and Welfare's epidemiological survey on mental illness showed that the lifetime prevalence of depression was 5.0% in 2016, which had risen compared to previous surveys (Ministry of Health and Welfare, 2019). Depression is accompanied by low mood, pessimism, and negative thoughts and motives, resulting in reduced physical and mental functions (Jeon and Kim, 2012). Depression in South Korea is expected to become a bigger social problem in the future; thus, it is urgent to identify the actual context, and take preventive measures. Consequently, green spaces could be a solution for combating depression. For instance, Browning and Lee (2019) showed that depressive symptoms in elderly residents living in nursing homes were negatively correlated with tree-covered green spaces. Furthermore, Gubbels *et al*. (2016) showed that greenery in neighborhoods was associated with a decrease in depressive symptoms among adults.

The role of green spaces to promote positive mental health became more important during the coronavirus pandemic

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(COVID-19). The government's social distancing policy altered the population's behavior to control the spread of COVID-19 (Park and Lee, 2021). Consequently, the pandemic strongly impacted people's mental health (Salari *et al*., 2020). Policies made to prevent the spread of COVID-19 increased stress levels, raising the prevalence of depressive symptoms compared to before the pandemic (Ettman, 2020). In addition, green space facilitates engagement in physical activity, which helped reduce negative mental health issues caused by social distancing and lockdown during COVID-19 (Slater *et al*., 2020). Thus, access to green space has become vital in preventing depression following COVID-19.

The association between green space and depression during the COVID-19 pandemic has been widely explored. People that visited green spaces less frequently during the pandemic were more likely to be at higher risk of major depression (Heo *et al*., 2021). Maintaining visits to green spaces during COVID-19 reduced the likelihood of reporting depressive symptoms (Pouso *et al*., 2021). Reid *et al*. (2022) showed that the NDVI(Normalized Difference Vegetation Index) around residences was negatively correlated with depressive symptoms during the COVID-19 pandemic. However, to the best of our knowledge, the association between green space and depression using population data before and after the COVID-19 pandemic remains unclarified. Moreover, knowledge on how different types of green spaces affect depression requires investigation, which could be used to enhance planning and management of green.

Thus, this study investigated the association between two vegetation types of green space(grass versus forests) and perceived depression in South Korea before and after the COVID-19 outbreak using population data. The hot or cold spots of perceived depression were explored to find out spatially different patterns that might exist during COVID-19. In other words, the hot spot analysis can reveal whether COVID-19 affects clustered patterns of perceived depression in South Korea. Panel regression was used to statistically analyze the association using four years of data from 2018 to 2021. The effect of COVID-19 on the perceived depression was also explored. This study will help understand health inequities associated with green space distribution in South Korea. Additionally, it will give insights into the association between green space and depression from a population-level perspective in urban and rural areas.

2. Methodology

2.1 Data description and variables

We used Community Health Survey data from Korea Disease Control and Prevention Agency (https://chs.kdca.go.kr) over 2018 to 2021 to calculate the prevalence of perceived depression on a national scale. The Community Health Survey has been conducted annually since 2008 by the Korea Centers for Disease Control and Prevention. This survey was initiated in response to demand for an index that represents the health level of local residents, to establish a health plan suitable for local conditions. The Community Health Survey is a sampling survey conducted in the 250 administrative districts across South Korea. The target population includes adults over the age of 19, and the results are analyzed using a complex sample design with predefined parameters. Using the data, the prevalence of perceived depression in all administrative districts was calculated per 100,000 population, and the prevalence of perceived depression in 2021 is shown in Fig. 1. The question in the survey focused on perceived depression over the previous year. For example, it states "During the past year, have you felt sad or hopeless enough to interfere with your daily life for more than 2 weeks in a row?"

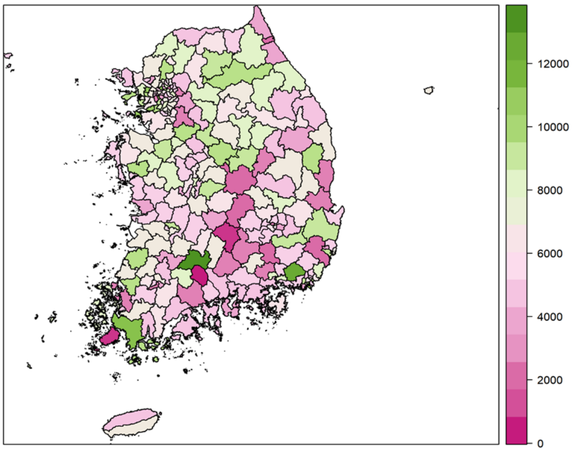

Fig. 1. Perceived depression in South Korea, 2021 (per 100,000)

The smokers in the population were also recorded, as an independent variable when using these data. For the other independent variables, including age, sex, and population density, we used the Korean Population and Housing Census data from 2018 to 2020 provided by Statistics Korea (https://sgis.kostat.go.kr/). Since Korean Population and Housing Census data were not available for 2021, we substituted it using the data from 2020.

For green space, we calculated and tested two different vegetation types. These were the percentage of forest and grass cover in each administrative district. These two vegetation types were calculated using land cover data from the late 2010s provided by Ministry of Environment (https://egis.me.go.kr). Because the available years of the land cover data were the late 2010s, 2000s, 1990s, etc., we chose the late 2010s, which was the recent year and the closest year to the years 2018 through 2021 in this study. Land cover data had a 30-m spatial resolution, with seven land cover types and cover the entire South Korea. The administrative districts layer was overlaid with the land cover layer using the same coordinate reference system, and the area of forest or grass pixels within each administrative districts was divided by the area of each administrative district to calculate the percentage.

To understand the impact of the COVID-19 on the association between green space and perceived depression, the COVID-19 pandemic was used as an independent variable in this study. As a dummy variable, 2020 and 2021 after COVID-19 were coded as one, whereas 2018 and 2019 before COVID-19 were coded as zero.

2.2 Hotspot analysis

The hot spot analysis allows one to identify the administrative districts where there are high (i.e., hot spots) or low (i.e., cold spots) levels of perceived depression. After the identification of the locations of hot or cold spots, this study compares the patterns from 2018 to 2021 to see whether there is any difference in the hot or cold spots of perceived depression before and after COVID-19. Getis-Ord G_i^* based on G_i^* spatial statistic (Getis & Ord, 2010; Ord & Getis, 2010) is used to identify the clustering of perceived depression. The equation of the G_i^* statistic is shown below (Eqs. (1), (2), and (3)).

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \overline{X}\sum_{j=1}^{n} w_{ij}}{S\sqrt{\frac{[n\sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} w_{ij})^2]}{n-1}}}, \quad (1)$$

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}, \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\overline{X})^2} \quad (3)$$

where G_i^* statistic that describes the spatial dependency of location i over all n locations, w_{ij} is a symmetric spatial weight between location i and j, and x_j is the value of the variable x of location j. For spatial weights, queen contiguity was used. In this study, each location indicates an administrative district, and the variable is the prevalence of perceived depression. The Getis-Ord G_i^* analysis was conducted using ArcMap 10.8.

2.3 Statistical analysis

To examine the association between perceived depression and green space from 2018 to 2021, we used a panel data regression. Panel data are a combination of cross-section and time series data. In panel data models, both space and time dimensions are considered simultaneously (Gujarati and Porter 2009).

Out of the fixed and random effects models in the panel model, we used the random effects model based on Hausman test outputs ($p > 0.05$). The Hausman test helps choose the best model from two possible models. In this test, if the p-value is lower than 0.05, the null hypothesis is rejected, with no significant difference in the estimator of the fixed-effects and random-effects models; thus, the fixed effects model is appropriate for use. If not, the random-effects model is appropriate.

In random effects models, it is assumed that variables that are not observed are not correlated with any observed variables, i.e., they have strong statistical independence (Allison, 2009). One advantage of the random-effects model is that time-invariant variables (i.e., percentage of green space in this study) can be evaluated. Since the fixed-effects model

Table 1. Dependent and independent variables in this study

Type of variable	Variable	Variable code	Data	Provider	Year
Dependent	Perceived depression (per 100,000)	PD	Community Health Survey	Korea Disease Control and Prevention Agency	2018 - 2021
Independent	Percentage of forest or grass	FOR or GRA	Land cover	Ministry of Environment	Late 2010s
	Percentage of smoking population	SMOK	Community Health Survey	Korea Disease Control and Prevention Agency	2018 - 2021
	Average age	AGE	Korean Population and Housing Census	Statistics Korea	2018 - 2020
	Percentage of male	MALE	Korean Population and Housing Census	Statistics Korea	2018 - 2020
	Population density (population/km^2)	PO	Korean Population and Housing Census	Statistics Korea	2018 - 2020
	Time before (0) or after (1) COVID-19	TI			

assumes that time-invariant variables have a constant effect over time, time-invariant variables are not generally considered in the fixed-effects model. Thus, the random-effects model considered to be the most appropriate for this study.

We used a one-way model that only considered temporal effects and a two-way random-effects model that captured individual and temporal effects simultaneously. The dependent and independent variables are provided in Table 1. The dependent variable is the prelvalence of PD (Perceived Depression). The independent variables are the percentage of FOR(Forest) or GRA(Grass), percentage of SMOK(Smoking population), AGE(Average age), MALE(percengtage of male), PO (Population density), and a time dummy variable (TI). The formula for the two-way model is shown in Eq. (4).

$$y_{i,t} = x'_{i,t}\beta + \alpha_i + \theta_t + \epsilon_{i,t}, \tag{4}$$

where i indicates individuals, which are the national administrative districts in this study; t represents time; $x_{i,t}$ is the i,tth observation of K independent variables; β is a Kx1 vector of coefficients; α_i denotes the unobservable individual effects; θ_t is the unobservable temporal effects; and $\varepsilon_{i,t}$ are idiosyncratic errors. In the two-way model, both α_i and θ_t were considered. In contrast, only θ_t was considered in the one-way model, which considered the temporal effects in different years in this study. All the data processing and statistical analyses were conducted using R.

3. Results and Discussion

3.1 Descriptive statistics

Out of the 250 administrative districts, 208 were used. That is because land cover data were only available for 210 administrative districts in South Korea, and two other administrative districts were also excluded because data on perceived depression were missing. Those 40 excluded districts due to the land cover data were located on the north side of South Korea including 14 districts in Seoul, 18 districts in Gyeonggi Province, and 8 districts in Gangwon Province. The two distircts with missing data were included in South Gyeongsang Province. Table 2 presents the descriptive statistics for the 208 administrative districts in

Table 2. Descriptive statistics of the 208 administrative districts in South Korea in 2020

n = 208 administrative districts	Mean ± standard deviation
PD	5,094.6 ± 1,980.1
FOR	54.8 ± 24.1
GRA	3.4 ± 2.6
SMOK	24.5 ± 32.2
AGE	46.0 ± 5.2
MALE	49.8 ± 1.3
PO	3,060.8 ± 4,817.0

2020. The mean and standard deviation of the prevalence of perceived depression are 5,094.6 and 1,980.1. The mean and standard deviation of the forest or grass are 54.8 ± 24.1 or 3.4 ± 2.6, respectively. The mean and standard deviation of the percentage of smoking population and male, average age, and population density are 24.5 ± 32.2, 49.8 ± 1.3, 46.0 ± 5.2, and 3,060.8 ± 4,817.0, respectively.

3.2 Perceived depression in 2018 through 2021

Before the analyses using the random-effects model, perceived depression in different years and the association between perceived depression and green space were examined using a boxplot. Perceived depression in 2018 to 2020 varied minimally, whereas that in 2021 was higher compared to all other years (Fig. 1). Of interest, perceived depression did not increase immediately after the COVID-19 outbreak in 2020, but increased in 2021. Thus, the time dummy variable with one for only 2021 and zero for the other three years was also tested.

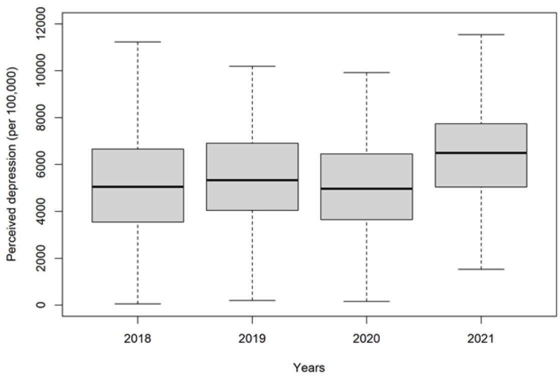

Fig. 2. Perceived depression in 2018 through 2021

3.3 Hot or cold spots of perceived depression in 2018 through 2021

Our analysis results using the Getis-Ord Gi* indicated that there were some common characteristics in hot or cold spots in different years (Fig. 3). The high levels of perceived depression were clustered in the Seoul metropolitan area where population density is very high and many urban opportunities exist, while the low levels of perceived depression were clustered in the south and east sides of South Korea.

In 2021, there were more administrative districts with high levels of perceived depression clustered near the south side of the Seoul metropolitan area when compared to other years. However, it was not a very noticeable difference. The cold spots also did not have any big difference before and after COVID-19. These results mean that the spatial patterns of hot or cold spots were not significantly changed before and after COVID-19 although the level of perceived depression increased overall across administrative districts in 2021 as shown in Fig. 2.

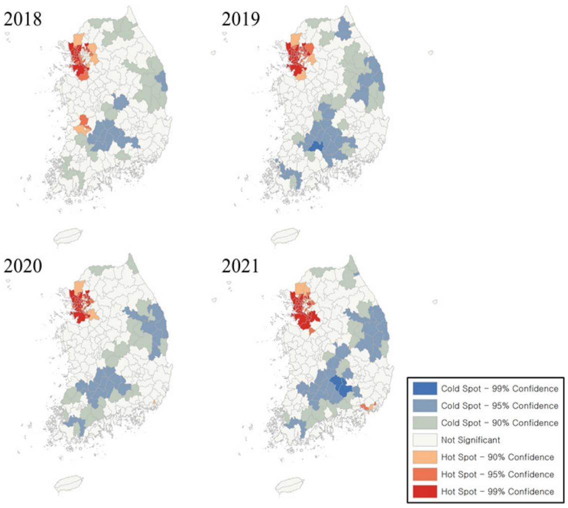

Fig. 3. Hot (red) or cold (blue) spots of perceived depression in 2018 through 2021

3.4 Random-effects model

The one-way and two-way random-effects models showed that the percentage of forest area had a significant negative effect on perceived depression before and after COVID-19 (Table 3). This effect was more significant in the one-way model than the two-way model. *R*-squared was higher when only the time effect was considered in the one-way model compared to the two-way model, which considered other effects too. As a vegetation type of green space, grass was not associated with perceived depression. A 1% increase in forest area reduced perceived depression by 16 people per 100,000 people. In contrast, the percentage of grass area before and after COVID-19 had no significant effect in either the one-way or two-way models. This result contrasted to the findings of previous studies, which obtained non-significant associations for both forest and grass (Akpinar *et al*., 2016; Astell-Burt and Feng, 2019).

The smokers in the population also exhibited a significantly negative association with perceived depression in both one-way (-12.611 and -14.259) and two-way (-11.976 and –13.479) models. A systematic literature review by Fluharty *et al*. (2017) obtained inconsistent results on the association between smoking and depressive symptoms. Nevertheless, the findings of the current study support the self-medication model, suggesting that people smoke to relieve psychiatric symptoms (Boden *et al*., 2010).

In contrast, the average age had a significantly positive association with the perceived depression in both one-way (97.811 and 91.602) and two-way (92.354 and 85.207) random effects models. Depression reaches its highest level in late life because of physical dysfunction and a low sense of personal control (Mirowsky and Ross, 1992). The percentage of male also had a significantly positive association with the perceived depression in both one-way (263.026 and 288.893) and two-way (262.600 and 286.147) random effects models despite of the fact that women are twice as likely as men to develop depression (Nolen-Hoeksema, 2001). This may be closely related to the highest suicide rate of South Korea among OECD member countries, which is a big issue in Korean society (Lee and Kim, 2018), and the gender difference in committing suicide. In South Korea, men are twice as likely as women to commit suicide (Kim, 2016). The difference in the suicide rate between men and women is in stark contrast to the number of women who visit hospitals for treatment for depression more than twice as many as men. It can be presumed that it is not because men actually experience less depression, but because the expression pattern is different from the diagnostic criteria so that they are being diagnosed less (Cho and Joo, 2020). In addition, this is because men underreport symptoms, and when women experience depression, it is interpreted as being more easily diagnosed and identified more quickly than men (Cho and Joo, 2020). In this regard, there is a possibility that the prevalence of depression in men is lower than that in women. Thus, the perceived depression, which helped to understand the relationship between the depression and suicide rate, needs to be taken seriously in the health research domain as well as the number of visits to hospitals for treatment for depression.

Population density had a significantly positive association with the perceived depression when the percentage of grass was used as a vegetation types of green space measure. The time dummy variable had a significantly positive effect on perceived depression in both one-way (1028.850 and 1029.731) and two-way (1033.000 and 1034.750) models. Perceived depression clearly increased during the COVID-19 pandemic since 2021.

The R-squared and adjusted R-squared values of one-way random effects models were higher than two-way random effects models. Especially, when the forest was used as a vegetation type of green space, the R-squared and adjusted R-squared values were higher than grass.

Table 3. Coefficients and standard errors of random effects models when a time dummy variable is defined as one for 2021 during COVID-19

	One-way random effects		Two-way random effects	
FOR	-16.337*** (4.360)		-16.034* (6.291)	
GRA		32.168 (31.450)		29.859 (45.728)
SMOK	-12.611*** (3.362)	-14.259*** (3.358)	-11.976* (4.687)	-13.479** (4.707)
AGE	97.811*** (22.388)	91.602*** (23.175)	92.354** (31.434)	85.207** (32.723)
MALE	263.026*** (74.909)	288.893*** (75.142)	262.600* (105.018)	286.147** (106.001)
PO	0.037 (0.023)	0.084*** (0.019)	0.038 (0.032)	0.084** (0.027)
TI	1028.850*** (194.980)	1029.731*** (193.974)	1033.000*** (195.960)	1034.750*** (195.017)
R^2	0.092	0.079	0.065	0.059
Adj. R^2	0.086	0.072	0.058	0.052
σ_ε	2137.150	2154.030	1703.200	1702.900
σ_α			1286.500	1314.500
σ_θ	77.750	73.440	118.600	117.300

***p < 0.001; **p < 0.01; *p < 0.05

However, when the time dummy variable was defined as one for 2020 and 2021 during COVID-19, no significant association with perceived depression was obtained in the one-way and two-way models (Table 4). This outcome was somewhat expected based on Fig. 1, which showed that perceived depression only rose in 2021. The *R*-squared and adjusted *R*-squared values were also slightly lower when the time dummy variable was defined as one for 2020 and 2021. Thus, the COVID-19 pandemic made people more depressed after a prolonged period (one to two years), which needs to be considered accurately in statistical models when evaluating the effects of COVID-19.

Table 4. Coefficients and standard errors of random effects models when a time dummy variable is defined as one for 2020 and 2021 during COVID-19

	One-way random effects	Two-way random effects
FOR	-16.414*** (4.360)	-16.207** (6.292)
SMOK	-13.186*** (3.381)	-13.070** (4.737)
AGE	102.795*** (22.618)	102.079** (32.068)
MALE	274.290*** (75.304)	283.994** (106.063)
PO	0.039 (0.023)	0.041 (0.032)
TI	240.357 (462.272)	240.374 (463.337)
R^2	0.060	0.031
Adj. R^2	0.054	0.024
σ_ε	2137.000	1703.200
σ_α		1286.300
σ_θ	435.000	444.100

***p < 0.001; **p < 0.01; *p < 0.05

4. Conclusions

This study investigated the association between two vegetation types of green space(forests versus grass) and perceived depression before and after COVID-19. The percentage of forest area had a significantly negative effect on perceived depression, whereas that of grass did not. This study demonstrated that depressive symptoms only rose in 2021. However, COVID-19 did not significantly change the spatial patterns of hot or cold spots of perceived depression in South Korea. The time dummy variable had a significantly positive association only when it regarded 2021 after COVID-19. These findings are expected to contribute towards advancing research linking public mental health and natural environment domains, and forests should be prioritized to capture the mental health needs of citizens.

However, this study had some limitations. First, certain variables were not available for 2021, including the percentage of green space, average age, percentage of males, and population density. The explanatory power of the variables might be better if they were calculated based on the data for all years. Second, socioeconomic variables were not considered because there were no available open data to calculate them. Therefore, income and education should be considered in future studies. Finally, spatial dependence was not considered in this study. Perceived depression which might have spatial dependence with neighboring administrative districts, with spatial regression models being required to evaluate this. In future work, a geographically and temporally weighted model could be used for panel data.

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