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Urban parks as a potential mitigator of suicide rates resulting from global pandemics: Empirical evidence from past experiences in Seoul, Korea

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ABSTRACT

Globally, the increased suicide rate of the general population has become a concern not only because of the COVID-19 pandemic, but also because of its associated socioeconomic insecurity, loss of jobs, and economic shocks. This study employed robust fixed-effects panel models to empirically identify the mitigating effects of infectious diseases, via urban parks, on the suicide rate, and to examine gender differences in this regard, based on previous experiences in Seoul, Korea. We found that the differentiating mitigating effect did not significantly affect suicide rates during the 2015 MERS epidemic. However, during the 2009 H1N1 pandemic, wherein the number of confirmed cases was very high and diffused nationwide, urban parks significantly reduced the suicide rates for both men and women. The role of parks as a mitigator was more enhanced in cities with a high number of confirmed cases if it was associated with economic shocks. However, this effect was significant only in the suicide rates of men, not women. During a pandemic, urban parks can help maintain social interaction and sustain physical activities (i.e., walking and exercise) while maintaining physical distance. National and local governments should develop urban parks to actively control the suicide rate influenced by movement restriction measures inevitably occurring during the spread of infectious diseases.

1. Introduction

The coronavirus disease 2019 (COVID-19) pandemic might have had serious effects on mental health, including fear of contagion, confusion, anxiety, depression, anger, and suicidal ideation in healthy people, as well as vulnerable demographic groups such as the elderly and unpaid adult caregivers (Abbas et al., 2020; al Mamun et al., 2021; Spano et al., 2021; Wasserman et al., 2020). In particularly, restriction measures such as physical distancing and mobility restrictions to prevent the spread of COVID-19 can effectively control the spread, but may unintentionally increase either the rate or ideation of suicide (Reger et al., 2019; Zortea et al., 2021). However, this occurrence may not be inevitable (Gunnell et al., 2020) and even must be dealt with in advance (Lennon, 2020). Some strategic approaches, such as providing transparent disclosure of information (Brooks et al., 2020) and psychological first aid to the survivors of COVID-19, have already been suggested to overcome the mental health challenges. However, they alone are not sufficient to prevent an increase in mental health problems, including suicide rates.

Greenery natural environments can be associated with reduced suicide mortality as several researchers have practically identified (i.e. Jiang et al., 2021). Greenery environments, including urban parks, can be one of the only sources to prevent suicide rate caused by movement restriction measures during the era of the COVID-19 pandemic (Geng et al., 2021). Recent research has reported that people had visited more green spaces, such as parks and urban forests, during the COVID-19 pandemic to reduce these negative effects on a global scale (Geng et al., 2021; Tyrovolas et al., 2021) as well as at city scale (Lu et al., 2021; Park et al., 2021; Soga et al., 2021; Volenec et al., 2021). This is due to the positive effects of psychological, physical, social cohesion, and mental wellness of natural environments, including parks (Alizadehtazi et al., 2021; Cheng et al., 2021; Helbich et al., 2018; Leberberger et al., 2021; Poortinga et al., 2021; Salama, 2020; Samuelsson et al., 2021). Exploring the association between natural environments and suicide rate in the Netherlands, Helbich et al. (2018) found that greenery natural environments played a positive role in reducing the suicide rate. In particular, urban parks may have more benefits than any other greenery environments, such as forests and grass, since they can be more easily accessed by citizens. Therefore, urban parks can play an important...
role in sustaining a healthy lifestyle despite the movement restriction measures during the COVID-19 pandemic (Jia et al., 2021; Poortinga et al., 2021; Samuelsson et al., 2021; Yoon et al., 2021).

Few studies have investigated the role of urban parks in mitigating suicide prevention during the COVID-19 pandemic beyond traditional and social media campaigns promoting mental health (Sher, 2020). In addition, as it was ongoing during the time of writing this paper, it is not yet possible to empirically identify the mitigating effects of urban parks on suicide rates unintentionally resulting from the COVID-19 pandemic. In addition, John et al. (2021) suggested that the likelihood of an increase in suicide rates during COVID-19 have been more concerning, but that there is no consistent evidence to date. Niederkrotenhaler et al. (2021) emphasized the need to investigate the impacts of previous either epidemic or pandemic diseases, as well as the current pandemic, on the suicide rate or ideation of suicide, because this rate can inevitably increase during a pandemic. However, few empirical studies have investigated the mitigating effects of natural environments, including urban parks, on the suicide rate during the influenza pandemic.

Therefore, this study focuses on empirically assessing the impact of previous influenza pandemic experiences on the suicide rate in South Korea, and then estimates the potential mitigating effects during the early COVID-19 pandemic, based on those findings. Also, this study demonstrates how the urban park mitigates the dampening effect of the COVID-19 on economic growth. Using the panel data from 2003 to 2018 in Seoul, South Korea, and its surrounding areas, that were aggregated and analyzed, this study empirically identifies how the increase in suicide rates had been caused by H1N1 (2009) and MERS, with gender differences, the mitigating effects of urban parks, and the combined effects of economic growth rates.

2. Literature review

The COVID-19 pandemic has been reported to result in potentially increasing public health challenges, such as lack of physical activity, social isolation, psychological anxiety, and depression (Abbas et al., 2020; Al Mamun et al., 2021; Spano et al., 2021; Wasserman et al., 2020). During the influenza pandemic, these potential mental disorders may consequently induce an increase in the suicide rate. For example, these mental health disorders have either increased or raised more concern in Western countries, such as the United States (US) (Czeisler et al., 2020), United Kingdom (Iob et al., 2020) and Canada (McIntyre, Lee, 2020a, 2020b; Samson & Sherry, 2020), as well as Asian countries, such as Taiwan (Li et al., 2020), China (Banerjee et al., 2021), Bangladesh (Auny et al., 2021; Mamun, 2021a, 2021b; Mamun et al., 2020), Pakistan (Mamun & Ullah, 2020), and India (Dsouza et al., 2021). This surge may be caused by various factors associated with the pandemic, including uncertainty of information, the threat of infection, and strenuous restriction measures (i.e., lockdown, control on movement, physical distance) (Chu et al., 2020), that lead to rapid changes in daily life (Halford et al., 2020), social isolation, loneliness, unemployment, and decreased income (Loades et al., 2020).

Moreover, a significant increase in suicide rates has been observed during past pandemics (Gunnell et al., 2020; John et al., 2020; Zoretta et al., 2021), specifically including the US (Wasserman, 1992) and Taiwan (Chang et al., 2020) during the 1918–1920 influenza pandemic (Spanish flu), in Hong Kong during the 2003 Severe Acute Respiratory Syndrome (SARS) outbreak (Cheung et al., 2008), and in Korea during the 2009 influenza (H1N1) pandemics (Jung et al., 2019; Park et al., 2016). Additionally, the COVID-19 pandemic is expected to yield a global unemployment rate beyond that seen during the Great Depression in the US. Therefore, the economic insecurity associated with the pandemic can significantly increase suicide rates (McIntyre, Lee, 2020a, 2020b).

An influenza pandemic, such as COVID-19, may be expected to increase suicide rates; however, this occurrence may not be inevitable (Gunnell et al., 2020). Therefore, the community must fervently prepare to mitigate the mental health challenges prevalent today (Lennon, 2020). Some strategic approaches to overcome these challenges caused by the COVID-19 pandemic have already been proposed. For example, the rationality and necessity of restriction measures during the pandemic period and transparent disclosure of information must be provided (Brooks et al., 2020), and psychological first aid to the survivors of COVID-19 should be made available (Shah et al., 2020). However, these measures alone are not sufficient to prevent an increase in suicide rates. Mental disorders can be influenced by environments as well as personal characteristics (Helbich et al., 2018), so that green natural environments can reduce the suicide rate (Helbich et al., 2018; Jiang et al., 2021). Mitchell and Popham (2008) indicates that green environments can lower health inequality. Conversely, based on the first longitudinal study, Helbich et al. (2021) found that the effectiveness of 20-year long-term exposure to the greenery environment is limited in mitigating suicide. However, the greenery natural environment may be effective in mitigating suicide rate during the unprecedented influenza pandemics. Geng et al. (2021) argue that the greenery environment has become one of the only sustainable and recovering sources of public lives during movement restriction measures in the era of the influenza pandemic.

More greenery environments, such as parks and green areas, are associated with lower suicide rate (Shen & Lung, 2018; Jiang et al., 2021), as well as a low level of both depression and suicidal ideation (Min et al., 2017). Besides, among many environments, urban parks can be easily accessible near the place of residence, while maintaining physical distance. They can also be a vital resource for physical activity and smooth social exchange (Geng et al., 2021; Xie et al., 2020). Many recent studies have reported that people visited urban parks to cope with the risks of mental health such as anxiety, depression, and stress caused by such non-pharmaceutical measures as movement restriction and social distancing due to the COVID-19 pandemic (Mayen Huerta & Cafagna, 2021; Venter et al., 2021; Volenc et al., 2021). Similarly, Astell-Burt & Burt (2021), who conducted an online and telephone survey of adults of 18 years of age and older in Australia, found that working from home, one of the movement restrictions during the COVID-19 pandemic, was associated with more frequent and longer visitation to green and/or blue spaces, as well as natural environments that had not been visited before. Empirically identifying how park visitation has been influenced by COVID-19 movement restriction measures, Volenc et al. (2021) also emphasize that parks have an important and consistent role in stressful times during the COVID-19 pandemic.

Influenza pandemics may not only cause financial difficulties such as unemployment and a decrease in income for many people (Dsouza et al., 2020; Mamun, 2021a, 2021b; Samson & Sherry, 2020), but also act as a factor hindering the economic growth of a country due to movement restrictions to control its diffusion (Buhiyan et al., 2021; Deady et al., 2020). Economic downturn including increasing unemployment can be a worse scenario to increase the suicide rate in a country during influenza pandemics. Deady et al. (2020) report that movement restriction measures have resulted in the extensive increase in job losses globally. The impacts of the suicide rate might have been of more serious concern to policy makers when mental disorders directly resulting from movement control measures caused by the COVID-19 pandemic are combined with an economic downturn. Arguing that the modeling results of the suicide rate due to unemployment during the influenza pandemic in Canada were underestimated, Samson and Sherry (2020) emphasize the importance of policy efforts to prevent suicide. Mamun and Ullah (2020) indicate that the increasing suicide rate during and after an influenza pandemic can be more aggravated when its situation is combined with unemployment caused by movement restriction measures such as lockdown.

Therefore, this study responds to the need to research the combined impacts of mental illness and economic depression on suicide rates during an influenza pandemic. In addition, our research is aimed at demonstrating how urban parks can mitigate the suicide rate under
these circumstances. However, the COVID-19 pandemic continued during the time of writing this report. It means that it is too early to empirically investigate the mitigating effects of urban parks on suicide rates unintentionally resulting from the COVID-19 pandemic (John et al., 2021). In this regard, this study focuses on the previous experiences during an influenza pandemic, since Niederkrotenthaler et al. (2021) suggest the need to investigate the impacts of previous pandemic diseases on suicide rate.

3. Study area, data and methodology

3.1. Study area and subjects

The study area was Seoul and Gyeonggi-do, and their surrounding regions, in South Korea. The area comprises 55 autonomous administrative city-county areas, including urban areas classified into districts, cities, and counties that correspond to rural areas. Fig. 1 depicts the spatial distribution of the mean suicide rate per thousand people over the past 16 years, from 2003 to 2018, in different city-county areas. The outcome indicates that the spatial distribution of the suicide rates is unevenly distributed according to city-county areas.

Notably, seven pandemic or epidemic infectious diseases during the 21st century, including COVID-19, occurred globally. Among them, three infectious diseases such as severe acute respiratory syndrome (SARS) in 2003, Influenza A virus subtype H7N9 in 2013, and Ebola Virus in 2014 were excluded from analysis in the study because there were no confirmed cases in Korea. The Zika virus (ZIKV) in 2016 was also excluded because there were only 33 confirmed cases in Korea, and the infection route was sexual relations rather than close contact between people. In addition, the COVID-19 pandemic could not be examined at this time as it was still in progress. Therefore, potential infectious diseases that enhanced the suicide rates due to fear of infection in Korea are Influenza A virus subtypes H1N1 in 2009 and Middle East Respiratory Syndrome (MERS) in 2015. The number of confirmed cases by city-county area per year for these two infectious diseases was based on the total surveillance infectious disease data provided by the Korea Centers for Disease Control and Prevention.

3.2. Data collection and statistics

For our analysis, the spatial and temporal range of data from 56 cities and counties over 16 years, from 2003 to 2018, were used. The data for the annual suicide rate in the city and county level can be downloaded from the Korean Statistical Information service (KOSIS, www.kosis.kr). Similar to the other data compiled by the government, the spatial and temporal data on the suicide rate were recorded up to 2018, and thus were the most recent data available at the time of this study. This is because aggregate data on suicide rates at the city and county level tend to mostly be released two years later. The other data related to this study were also obtained from various organizations such as Statistics Korea, the Ministry of Health and Welfare, the Ministry of Land, Infrastructure and Transport, and Korea Disease Control and Prevention Agency. All the study data were aggregated under secondary, public use, and de-identified datasets, that cannot link back to either subjects or specific places.

The dependent variable in the study was the total number of suicide deaths per 100,000 female and male populations. Gender differences are linked to socio-cultural differences, and it was considered that there would be discriminatory differences of effects in pandemic situations (Mamun et al., 2020). For example, unpaid women experience greater time spent at home due to social isolation, that leads to an extra burden on housework and childcare (Khan et al., 2020). Jiang et al. (2021) indicate that park density may have different impacts on the suicide rate by gender.

Statistics on the number of confirmed cases of new influenza and MERS per year were obtained from the Korea Disease Control and Prevention Agency (www.kdca.go.kr). Per capita park area (m²/person) was obtained from statistical data available on the open data portal (stat.molit.go.kr/portal) of the Ministry of Land, Infrastructure, and Transport. The data on the annual economic growth rate at national level were obtained from the KOSIS. Measures such as the suicide rate, urban parks, and confirmed infectious diseases cases were spatial and temporally variant, while the other one is as temporally variant but spatially invariant that is on national level so there is no spatial difference at the specific year.

The other independent variables such as female population ratio, the elderly ratio, population density, per capita gross regional domestic product (GRDP), basic living recipient ratio, divorce rate per thousand, and the number of beds per thousand were used as control variables. All of the data can be accessed from the KOSIS. These control variables were employed in the study since they are potential determinants based on the empirical studies on suicide. Thus, suicidal thoughts and behaviors may differ depending on the vulnerable population and the city-county area of residence during the COVID-19 pandemic. This notion led to higher suicide mortality among older adults during the past pandemic peak period (Leaune et al., 2020). Similarly, in Korea, the elderly and young women were at a particularly high risk of suicide mortality from 1992 to 2015 (Park et al., 2018). Mamun et al. (2020) demonstrate that personal characteristics such as being female, divorced, and having no child, have emerged as more sensitive indicators in suicidality during the COVID-19 pandemic in Bangladeshi. Furthermore, during the economic crisis of the late 1990s in Korea, the suicide rate among elderly and middle-aged men was higher (Hong & Knapp, 2014).

In this study, longitudinal or cross-sectional time-series data were used, being the balanced panel data with a total of 896 observations per each of the 16 years for each of the 56 city-county areas. Table 1 exhibits the overall statistics for the mean, standard deviation, minimum, and maximum values of the variables used in the model. The population and the elderly ratio are included in each model of the entire population suicide rate, the male population suicide rate, and the female population suicide rate. The results of the t-tests on the equality of means by gender are represented in the last right column. The suicide rate and the ratio of the elderly by gender were not equal, but the population by gender was equal. The outcome of interest was the suicide rate per 100,000 people.

![Fig. 1. Spatial distribution of suicide rates per 1000 people.](image-url)
In Table 1, the average suicide rate per 100,000 of the entire population, as well as the male and female populations, was 25.52, 34.44, and 16.51, respectively. The suicide rate of the male was almost twice as high as that of the female population. Also, the standard deviation in male and female populations was 11.17 and 5.81, respectively, that indicates that the former had a greater spatial imbalance.

Fig. 2 indicates that the suicide rate by city-county level gradually increased following the initial year of analysis, being 2003, and peaked from 2009 to 2011. The suicide rate had slightly decreased up to 2018 being the most recent data available at the time of our study. The range of suicides by city-county area in recent years had decreased compared to previous years, and it can be seen that the spatial variation in suicide rates was greater in the early and mid-half of the analysis period.

One of the main variables that influenced the suicide rate was the number of confirmed cases of infectious diseases. In Table 1, the mean number of confirmed cases of swine flu OR H1N1 and MERS was 370.8 and 0.132 per unit area, respectively. The distribution of the number of confirmed cases of H1N1 influenza and MERS by city-county level was spatially imbalanced, and the spread of these infectious diseases was more concentrated in a certain city-level area.

As of 2009, the number of confirmed cases of H1N1 flu was 2546.107, on average, with a range of at least 375 to at most 20,986 and a standard deviation of 375. Based on these statistics, the distribution of confirmed cases of the new flu is even across almost all regions. Conversely, the mean number of confirmed MERS cases in 2015 was 2.07, with a standard deviation of 4.75 and a range of at least 0 to at most 29. The standard deviation was larger than the average, which exemplifies a more biased pattern in a specific region, rather than an even distribution. There were no confirmed cases of MERS in 27 out of the 56 city-county areas in 2015. As the incidence and distribution of H1N1 flu and MERS were different, it can be expected that it would affect mental health differently, such as inducing anxiety, stress, or fear, that would ultimately lead to differences in suicide rates.

The main purpose of this study was to assess the role of parks as a mitigator for the increase in suicide rates per 100,000 people caused by major infectious diseases in Korea (i.e., H1N1 influenza in 2009 and MERS in 2015). Thus, it was imperative to observe the trend of per capita park area by city-county area and year (Fig. 3). It was evident that the area of parks was increasing in Seoul and the surrounding areas, the spiral imbalance was also increasing.

As shown in Table 1, the average economic growth rate of Korea was...
3.66%, with a minimum of 0.8% in 2009 and a maximum of 6.8% in 2010, that indicates considerable economic fluctuations. After recording the lowest economic growth rate (0.8%), it shows a V-shaped economic fluctuation that rebounded in 2010. This phenomenon could have been partially affected by the 2009 H1N1 flu pandemic. However, this rapid economic downturn could have been simultaneously affected by the spread of infectious diseases and the 2008 US subprime mortgage crisis. Alternatively, in the first quarter of the MERS outbreak period in 2015, it decreased by 0.7% from the previous quarter but recovered immediately, that indicates that the economic shock was not significant.

3.3. Method

The data for analysis in this study is panel ones with 56 city-county areas during 16 years from 2003 to 2018. The panel data had several advantages over cross-sectional or time series data: first, more accurate inference of model parameters; second, capturing the complexity of human behavior better than single cross-sectional or time series data; and third, simplifying calculations and statistical reasoning (Hsiao, 2007). The study utilized the aggregated data of individual-level attribute values of suicide at the city-county level. Aggregation of data in a specific spatial unit may lead to a cumbersome problem in the interpretation of spatial statistical analysis caused by the scale and zoning effects, namely the Modifiable Areal Unit Problems (MAUPs) (Helbich et al., 2021; Jelinski & Wu, 1996). Therefore, Wang and Di (2020) also highlighted the need to minimize problems due to MAUP by exploring the environmental determinants in the COVID-19 outbreak. The best way to solve these MAUPs was to use individual-level information in combination with spatial-level data (Helbich et al., 2021; Wakefield, 2008).

However, since suicide attribute information at the individual level is highly sensitive to privacy, it was not available for the study, because the government does not disclose it to the public. As an alternative approach, Cressie (1998) suggested that building a statistical model at the most suitable spatial level where interpretable parameters are defined was required. Since there is no agreement on spatial units for aggregation, Bixby et al. (2015) suggested that it may be more appropriate to explore the association between green space and mortality at the urban level. Similarly, Helbich et al. (2018) found that green natural environments reduced suicide mortality at the municipality level in the Netherlands. These studies were similar to our study at the spatial level where data were aggregated.

The study also examined both the spatial autocorrelation and heterogeneity of this panel data. The preliminary analysis for the former revealed that the spatial autocorrelation for the suicide rate was statistically significant. The study aimed to estimate the moderating effect between the number of confirmed cases of infectious diseases and the economic growth rate on the suicide rate. Calculated based on spatial contiguity, the value of Moran’s I was up to 0.608, indicating a rather high spatial autocorrelation. This suggested that it was necessary to also consider a spatial panel model. Accordingly, this study preliminarily tested the applicability of the spatial panel model to estimate it. However, the economic growth rate in the study was measured at the national level so that it had spatially invariant characteristics. In particular, the interaction term between the time-invariant variable, and the number of confirmed infectious diseases was not allowed if we built the panel models with spatial autocorrelation. Therefore, in this study, we ultimately did not build the panel model that took this spatial dependence into account.

Alternatively, the regression coefficients may be inconsistent when regressors are serially correlated if we ignored the heterogeneity for the panel data (Halunga et al., 2017). It was tested and panel data were found to be significantly heterogeneous. Therefore, we finally employed the panel models allowing heteroskedasticity to demonstrate the mitigating impacts of infectious diseases and economic growth on suicide rate by gender in Seoul and its suburban areas. The robust panel model employed in the study was a bias-correction one for heterogeneous panel data that was robust to serial correlation (Peng et al., 2021).

The study employed the panel models with heterogeneity to identify the role of urban parks as a mitigator for the suicide rate per 100,000 population for the entire population (Model A), the male one (Model B), and the female population (Model C). The potential models considered for our panel data analysis were the pooled linear regression model, random-effect panel model, and fixed-effect panel model. Table 2 provides four diagnostic statistics for the selection of a more suitable model: F-test, Breusch-Pagan Lagrange Multiplier (B–P LM) test, Hausman test, and Modified Wald test. The F-test is a test for the null hypothesis that all dummy variables included in the fixed-effect model are zero. The fact that the null hypothesis was rejected as a result of the F-test indicated that the fixed-effect was more suitable than the pooled regression model for all three models. The B–P LM test was used to test which model was more suitable between the pooled model and the random-effects model. If the null hypothesis could be rejected, the random-effect model would be more suitable. As a result of the B–P LM test, the null hypothesis was rejected, so the random-effect model was more suitable than the pooled model for all three models.

The Hausman test was used to test which model was more suitable between the fixed-effects model and the random-effects model. This is a test to determine whether there is a correlation between an explanatory variable and the effect of an individual (time) characteristic, or whether they are independent of each other. The Hausman test result indicated that the fixed-effect model was more suitable than the random-effect model for all three models. Another test is a modified Wald test, wherein groupwise heteroskedasticity in a fixed-effects regression model is assessed to be systematic or not. From the test results, we finally adopted a robust fixed-effects model allowing groupwise heteroskedasticity.

Based on the diagnostic statistics, the most suitable model for our analysis was the robust fixed-effect panel models for the entire population (Model A), the male one (Model B), and the female population (Model C). Compared to the other two alternative models, this model had the advantage of being able to control the bias of confounding effects caused by time-invariant factors (Hsiao, 2007). The main variables of interest, such as the per capita park area and the economic growth rate, were used as predictors to construct three different models (i.e., Model A-1, B-1, C-1). Furthermore, sub-models (i.e., Model A-2, B-2, C-2) were added to assess whether the spread of the infectious disease had significant effects on suicide rates by reflecting the outbreak and spread of infectious diseases in these models. These sub-models included variables for the number of confirmed cases of H1N1 flu and MERS by the

### Table 2

**Summary of results on model selection tests.**

| Test methods | Statistics | Model A: Suicide model of the entire population | Model B: Suicide model of men | Model C: Suicide model of women |
|--------------|------------|-----------------------------------------------|-----------------------------|-------------------------------|
| F-test       |            | 4.28                                          | 3.25                        | 3.45                          |
| (Fixed vs.  | Prob > F   | 0.000                                         | 0.000                       | 0.000                         |
| (Pooled)    |            |                                               |                             |                               |
| Breusch-Pagan LM test | chi2BAR2 | 39.08                                         | 24.23                       | 16.27                         |
| (Random vs. | Prob > chi2| 0.000                                         | 0.000                       | 0.000                         |
| Pooled)     | (OD1)      |                                               |                             |                               |
| Hausman test | chi2 (B)  | 96.25                                         | 64.62                       | 88.02                         |
| (Fixed vs.  | Prob > chi2| 0.000                                         | 0.000                       | 0.000                         |
| Random)     |            |                                               |                             |                               |
| Modified Wald test | chi2 (56) | 691.96                                        | 635.17                      | 1218.48                       |
| (Heterogeneity vs. Homogeneity) | Prob > chi2 | 0.000                                         | 0.000                       | 0.000                         |

Note: The F-test helps us identify that all individual effects are null (H0: all ui = 0).
city-county area. The final models were used to demonstrate the significant effects of parks as a mitigator on suicide rates associated with infectious diseases. Thus, final models (Model A-3, B-3, and C-3) were constructed by adding interactive variables, such as parks, confirmed cases per infectious disease, and economic growth rate.

4. Results

Table 3 summarizes the analysis results of the robust fixed-effect panel models to estimate factors that are associated with the suicide rate per 100,000 population. The adjusted R-squared statistics of the final models (i.e., Model A-3, B-3, and C-3) affecting the suicide rate per 100,000 of the total population, men, and women, are in the range of 0.122 to 0.131, respectively. The closer this statistical value is to 1, the greater the explanatory power of the regression model. Models with different numbers of predictors can be compared, as each of these models validated that the final models were more suitable because all the values were greater than the previous models (i.e., Models 1 and 2).

Among the predictors used as control factors in the model, statistically significant variables were the population numbers, the rate of the elderly, and the crude divorce rate per thousand people. However, conflicting results in separate models for men and women became apparent. For instance, population numbers highlighted that there was a significant and negative correlation with the suicide rates of the total and male populations with regression coefficients $-0.00002$ and $-0.00005$, respectively. However, this consequence was not observed with the suicide rates of women. In contrast, the crude divorce rate per thousand people showed a statistically significant negative relationship only with the suicide rates of the total and female populations with $-2.55505$ and $-4.09786$ values of coefficients, and the rate of the elderly was not significant in the total population model. Nonetheless, models that measured this aspect as the ratio of the elderly to men and women (i.e., models B and C) revealed conflicting associations in gender suicide rates. In other words, a higher rate of the elderly led to higher suicide rates in males, while the female suicide rate decreased.

Among the predictors, the only variable with statistically significant changes between sub-models (i.e., Models 1, 2, and 3) was the economic growth rate variable. In the models where the variables of interest, including per capita park area and economic growth rate variables, were added (i.e., Models A-1, B-1, and C-1), the suicide rate decreased as the economic growth rate of Korea increased. However, the economic growth rate was not significant in the models (i.e., Models A-2, B-2, and C-2), where unpredictable and irregular exogenous factors such as infectious diseases were included. These findings suggested that final models (i.e., Model A-3, Model B-3, and Model C-3) were required to control and confirm the effects of these interactions.

The following evidence can be derived from the last three models (i.e., Model A-3, Model B-3, and Model C-3), including the interaction terms of major variables of interest. First, urban parks function as a mitigator to prevent suicide rates. With every 1 m$^2$ per person increase in the park area, the suicide rate per 100,000 people decreased by 0.38. However, this function was more significant in women ($-0.62$) than in men.

Second, when the economic growth rate increased by 1%, the suicide rate per 100,000 people decreased by 0.218. However, this effect is larger and statistically more significant for men than for women. In the male suicide rate model (Model B-3), the corresponding regression coefficient was $-0.40109$, which was significantly greater than the total population model.

Third, if the spread of infectious diseases was global, the resulting suicide rate increased. The analysis results proved that unlike the MERS outbreak in 2015, the 2009 swine flu infection caused a significant increase.

Fourth, urban parks have a negative relationship with suicide rates during an infectious disease pandemic. The interaction term between the number of H1N1 confirmed patients and per capita park area showed a negative association in all models, that demonstrated that parks could have played a significant role in reducing the suicide rate during the spread of swine flu. In addition, parks may reduce the suicide rate of both men and women, where the relationship was relatively greater in the former (regression coefficient $= -0.00025$) than in the latter (regression coefficient $= -0.00021$).

Fifth, the mitigating roles of parks on the suicide rate were more significant in a situation where economic fluctuations were combined with a pandemic situation. The interaction terms of these three variables all showed negative associations; however, they were not significant for the female suicide rate. These results showed that parks acted as an important mitigator for both men and women under a pandemic situation. However, in situations where the pandemic was combined with economic fluctuations, its effects were more significant for men.

The suicide rate per 100,000 total population (Model A-3) during the H1N1 pandemic that occurred along with the economic shock in 2009, was estimated for our further discussion. Fig. 4 illustrates the estimation of the mitigating effects of urban parks during a record 0.8% economic downturn in 2009. The city-county variation in the number of H1N1 confirmed cases from 0 to 20,986 was considered, and areas with parks less than the mean area and with more than the mean per capita were divided. The suicide rate per 100,000 population by the number of confirmed cases in the year that experienced an economic growth rate of 0.8% was then estimated. As shown in Fig. 4, the overall difference in the suicide rates resulting from the 0.8% economic growth rate in the absence of any confirmed cases between low- and high-groups of park area is only 1.75. However, among the maximum number of confirmed patients, the difference in the suicide rates between low- and high-groups of park area is 26.37. This finding suggests that the greater scale of the economic crisis and the spread of pandemic the greater the control effects of parks.

This study did not investigate the impacts of the COVID-19 pandemic on suicide rate since the pandemic was ongoing, and data such as suicide rates were not available at the time. Therefore, this study estimated potential modulating impacts of urban parks on suicide rate with three different economic growth rate scenarios that might be caused by the COVID-19 pandemic. During this pandemic, the role of parks as a potential mitigator from each of the different scenarios on the economic growth rate could be estimated, as shown in Table 4. Scenario 1 estimated the modulating effects of parks on the suicide rate per 100,000 population in areas where there were no confirmed cases of COVID-19 while maintaining the same economic growth rate as in 2018 during the pandemic. In areas with a mean per capita park area (2.29 m$^2$/person), the suicide rate was reduced by 1.30 people per 100,000 people, and in areas with a park size of 95% percentile (12.92 m$^2$/person), a mitigating effect of $−5.31$ people was observed.

In another scenario, the mitigating effects of parks on the suicide rate caused by the H1N1 influenza pandemic could be used to estimate the COVID-19 pandemic situation. Scenarios 2 and 3 assumed an economic growth rate of 1% due to the COVID-19 pandemic, with varying numbers of confirmed cases by region. This was based on the OECD’s forecast of the economic growth rate per country for September 2020. Scenario 2 estimated the mitigating effects of parks in areas where the number of confirmed cases was 100 (the mean number of confirmed cases by city, county, and districts was 99.85 as of September 17, 2020). In this scenario, parks were effective in reducing the average suicide rate by 1.09 per 100,000 people. Scenario 3 estimated the suicide rates in the city-county area where the number of confirmed COVID-19 cases was 1600 (the maximum number of confirmed cases by city, district as of September 17, 2020, was 1671). In this scenario, the mitigating effects of parks on the mean suicide rate was $−0.55$.

In scenario 3, where the number of confirmed cases had increased significantly compared to scenario 2, the mitigating effects of the mean per capita park area on the suicide rate decreased two-fold. However, the negative values in scenario 3 still demonstrated that the mitigating effects of parks played an important role under such circumstances.
### Table 3
Analysis results on robust fixed-effects models.

|                           | Suicide Rate for Entire Population (Model A) | Suicide Rate for Male Population (Model B) | Suicide Rate for Female Population (Model C) |
|---------------------------|---------------------------------------------|-------------------------------------------|---------------------------------------------|
|                           | Model A-1 | Model A-2 | Model A-3 | Model B-1 | Model B-2 | Model B-3 | Model C-1 | Model C-2 | Model C-3 |
| Controlled independent variables |          |          |          |          |          |          |          |          |          |
| Population                | –0.00001* | –0.0001* | –0.0002* | –0.00005* | –0.00005* | –0.00005* | –0.00002 | –0.00002 | –0.00002 |
| Population density (person/km²) | 0.00032 | 0.00034 | 0.00028 | 0.00087 | 0.00088 | 0.00088 | –0.00036 | –0.00033 | –0.00038 |
| Female population ratio   | (0.59) | (0.64) | (0.54) | (1.46) | (1.49) | (1.38) | (1.64) | (0.88) | (0.97) |
| The elderly ratio         | –27.13308 | –11.59205 | –8.49661 | –93.92524 | –84.34533 | –84.83113 | 57.27478 | 80.84533 | 87.82364 |
| Crude divorce rate per 1000 | (0.26) | (0.11) | (0.08) | (0.62) | (0.55) | (0.56) | (0.61) | (0.88) | (0.97) |
| Number of beds per 1000   | 61.77 | 101.99 | 85.59 | 313.51* | 349.48* | 325.04* | –218.52* | –177.07 | –185.99* |
| Per capita GRDP           | 0.03223 | 0.06492 | 0.06677 | 0.28916 | 0.31632 | 0.31312 | –0.19311 | –0.15393 | –0.14833 |
| Main variables            |          |          |          |          |          |          |          |          |          |
| Per capita park area (m²/person) | –0.01742 | –0.01447 | –0.01451 | –0.00763 | –0.00546 | –0.00541 | –0.02780 | –0.02189 | –0.02402 |
| Economic growth rate (%)  | –0.32797*** | –0.04626*** | –0.21800** | –0.37987* | –0.14723 | –0.40109 | –0.29606** | 0.03111 | 0.06621 |
| Number of confirmed MERS cases | –0.04392 | –0.03260 | –0.05823 | –0.04518 | –0.03565 | –0.02569 |          |          |          |
| Number of confirmed swine flu cases | 0.00050*** | 0.00064*** | 0.00041*** | 0.00032** | 0.00058*** | 0.00094*** |          |          |          |
| Interaction (Mitigation) terms |          |          |          |          |          |          |          |          |          |
| Number of confirmed swine flu cases * per capita park area | –0.00023*** | –0.00021*** | –0.00025*** | –0.00023*** | –0.00021*** | –0.00025*** | –0.00023*** | –0.00021*** | –0.00025*** |
| Number of confirmed swine flu cases * economic growth rate | 0.00035*** | 0.00046* | 0.00024* | 2.57 | 2.55 | (2.56) |          |          |          |
| Number of confirmed swine flu cases * economic growth rate | –0.00003* | –0.00004 | –0.00002 | –0.00003* | –0.00004 | –0.00002 | –0.00003* | –0.00004 | –0.00002 |
| Constant                  | 49.73 | 38.02 | 38.32 | 78.21 | 70.32 | 70.31 | 17.96 | 1.54 | –0.76 |
| Model statistics          |          |          |          |          |          |          |          |          |          |
| No. observation           | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 | 896 |
| No. groups                | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| Log Likelihood            | –2597 | –2584 | –2571 | –2975 | –2971 | –2965 | –2633 | –2616 | –2604 |
| Adjusted R-squared        | 0.079 | 0.104 | 0.126 | 0.107 | 0.112 | 0.122 | 0.079 | 0.111 | 0.131 |
| Within R-squared          | 0.088 | 0.115 | 0.140 | 0.116 | 0.123 | 0.135 | 0.089 | 0.122 | 0.145 |
| Between R-squared         | 0.000 | 0.001 | 0.006 | 0.022 | 0.027 | 0.038 | 0.030 | 0.025 | 0.009 |
| Akaike Information Criterion (AIC) | 5211.8 | 5189.3 | 5169.4 | 5968.5 | 5964.7 | 5958.2 | 5283.2 | 5254.0 | 5236.6 |
| Bayesian Information Criterion (BIC) | 5254.9 | 5242.1 | 5236.6 | 6011.7 | 6017.5 | 6025.4 | 5326.4 | 5306.8 | 5303.8 |

Note: t statistics in parentheses.

*<p><0.10.
**<p><0.05.
***<p><0.01.
percentile) experienced increased suicide rates. These findings suggested that the role of parks was essential in pandemic situations. However, in scenario 3, areas with low groups of park areas (i.e., 5% average growth rate, average no. confirmed patients) experienced an increase in suicide rates during 2019. The number of confirmed MERS cases in Korea in 2015 and 2018 was 185 and 1, respectively, that were relatively small and spread locally. Contrariwise, at least 700,000 confirmed cases of swine flu A (H1N1), that was a novel infectious disease syndrome, were observed in Korea. Specifically, the mean number of infected people by district area in Seoul and the surrounding areas, being the target area of this analysis, was 374.62, with a maximum of 20,986, indicating that it was widely spread countrywide. Therefore, when the incidence and spread of infectious diseases are larger and nationwide, the pandemic situation may have more significant effects on suicide rates. This means that suicide rates increase when the spread of an influenza pandemic becomes more widespread. Mamun et al. (2021), in their systematic review, indicated that the suicide rate may further increase due to the higher risk exposure of infection during an influenza pandemic.

As per our findings, the mitigating effects of parks on the suicide rate were more significant in a situation combined with economic shock, while reducing the impact on suicide rates during an infectious disease pandemic. Urban parks are known to have direct effects on improving health levels through increased physical activity and exercise, and indirect effects such as air quality, biodiversity, water quality management, and cooling (Konijnendijk et al., 2012). Some studies argue that the greenery environments, including urban parks, can play an important role in modifying suicide rates during an unprecedented influenza pandemic (Geng et al., 2021; Helbich et al., 2018; Jiang et al., 2021; Tyrovolas et al., 2021). Auny et al. (2021) found that the anxiety level of people in Bangladesh increased when people had either no place for outdoor activity or did not perform more physical activities prior to the pandemic. This study, which empirically examined this association, demonstrated that in addition to these general effects, urban parks can also lower the suicide rates during a pandemic of unexpected infectious diseases. These findings suggested that mental health problems may be overcome or alleviated through the use of parks around the residence.

Most activities in parks are outdoor activities that can help to maintain social interactions during activities while maintaining physical distance, rather than social distance (Geng et al., 2021; Johnson et al., 2021; Volene et al., 2021). Therefore, during the COVID-19 pandemic, the national and local governments should seek ways to actively utilize the values of parks and maintain the measures to prevent the spread of unacknowledged sources to do it is the greenery natural environment (Geng et al., 2021). Many studies have already provided evidence on its potential impacts on mitigating mental disorders, including suicide behavior and ideation (Helbich et al., 2018; Jiang et al., 2021; Tyrovolas et al., 2021). Nonetheless, few studies have investigated the mitigating effects of urban parks on the suicide rate, especially combined with an economic downturn caused by a pandemic.

Therefore, this study identified the combined effects of previous pandemics and economic growth rates on suicide rates by gender in Seoul, South Korea, and its surrounding areas, and then estimated the potential mitigating effects during the COVID-19 pandemic, based on these findings. This study demonstrated that urban parks are integral in mitigating suicide rates, specifically for women. Mamun et al. (2020) indicated that women might be more vulnerable to suicidality during the COVID-19 pandemic. However, the mitigating role of urban park can be more effective for women in the association between suicidality and influenza pandemics. This fact may be justifiable because women tend to spend much time at home for housework and childcare, leading to more active park visits around women’s residences. We also discovered that although the rate of participation in economic activities by women have been increasing, that of men is still higher, and that the fluctuation of the suicide rate due to economic fluctuations is a factor that significantly affects only men, not women. It can be inferred that an increase in the suicide rate is closely related to unemployment and lower income level that might be influenced by an influenza pandemic (McIntyre, Lee, 2020a, 2020b; Samson & Sherry, 2020).

One of our findings was that the suicide rate significantly increased when the spread of an infectious disease becomes a pandemic. The number of confirmed MERS cases in Korea in 2015 and 2018 was 185 and 1, respectively, that were relatively small and spread locally. Contrariwise, at least 700,000 confirmed cases of swine flu A (H1N1), that was a novel infectious disease syndrome, were observed in Korea. Specifically, the mean number of infected people by district area in Seoul and the surrounding areas, being the target area of this analysis, was 374.62, with a maximum of 20,986, indicating that it was widely spread countrywide. Therefore, when the incidence and spread of infectious diseases are larger and nationwide, the pandemic situation may have more significant effects on suicide rates. This means that suicide rates increase when the spread of an influenza pandemic becomes more widespread. Mamun et al. (2021), in their systematic review, indicated that the suicide rate may further increase due to the higher risk exposure of infection during an influenza pandemic.

However, in scenario 3, areas with low groups of park areas (i.e., 5% percentile) experienced increased suicide rates. These findings suggested that the role of parks was essential in pandemic situations accompanied by economic shock waves.

The number of confirmed cases of influenza pandemic was 99.87% with a maximum number of 1671. Based on this statistic, the scenario for the number of confirmed patients by the city-county area was set to an average growth rate, and the economic growth rate as of September 2019, and the economic growth rate in 2020 was 2% in 2020. Moreover, the economic growth rate was 2% in 2019, and the economic growth rate in 2020 under the COVID-19 pandemic was projected to be 1% as of September 16, 2020. According to this scenario, the mitigating effects of parks were estimated.

### 5. Discussion

We investigated how urban parks can play a role in the suicide rate under unpredictable crises. The spread of infectious diseases and the economic shock might have influenced suicide rates. There were reports that the suicide rate had increased during the current and ongoing COVID-19 pandemic (McIntyre, Lee, 2020a, 2020b) at the time of this research, as well as the previous influenza pandemics (Cheung et al., 2008; Gunnell et al., 2020; John et al., 2020; Jung et al., 2019; Park et al., 2016; Wasserman, 1992; Zortea et al., 2021). However, it cannot be uncontrolled (Gunnell et al., 2020; Lennon, 2020). One of the
COVID-19 while improving the mitigating effects of parks to prevent suicide. This study empirically identified the mitigating role of urban parks, combined with economic downturns, in decreasing suicide rates, as well as its different associations by gender using the previous influenza pandemics. However, this study still has multiple limitations. First, it is necessary to mention limitations dealing with spatial dependence that were mentioned in the method section. Even if the spatial autocorrelation was significant in the models, we did not consider it in the panel models for this study since the national economic growth rate, one of the main variables of interest in this study, was a spatially invariant variable.

A second limitation is that we did not investigate the mitigating impacts of urban parks, combined to economic downturn, during the COVID-19 pandemic. The duration and shock of the COVID-19 spread widened unpredictably, globally, at the time of our study and thus its effects on the suicide rate could be even more unmanageable. Future studies need to empirically investigate the mitigating role of urban parks during COVID-19.

Third, this study only focused on urban parks, and assumed that they could be more effective in non-pharmaceutical intervention measures such as lockdown, working from home, stay-at-home, and restriction on social gatherings, because they had better physical accessibility, unlike other natural environments. However, it is undoubtedly true that the park is part of the green space. Therefore, the analysis results of this study on urban parks should be able to grasp the effect of controlling the suicide rate linked to the economic shock caused by an influenza pandemic as a part of the green natural environment. However, the mitigating effects of the suicide rate during an influenza pandemic may also be applied to the green natural environment (Geng et al., 2021; Helbich et al., 2018; Shen & Lung, 2018). Therefore, it is necessary to explore the role of the comprehensive greenery natural environment such as green areas, forests, and parks in near future.

6. Conclusion

The suicide rate of the general population has unintentionally become a concern, not only because of the ongoing pandemic (COVID-19) and related measures to contain its spread, such as travel restrictions and lockdowns, but also because of socioeconomic insecurity, loss of jobs, and economic shocks that occur as a result. Our study does not only empirically identify the mitigating role of urban parks in suicide rates attributed to pandemics and economic down-turns, but also uncovers its different impacts by gender. During the global pandemic, urban parks can effectively work to maintain social interaction, as well as sustain physical activities (i.e., walking and exercise) while maintaining physical distance, not social distance. The national and local governments should prepare for unintended negative effects. As one of the strategies, urban parks could be actively utilized in mitigating the suicide rate while controlling the spread of infectious diseases.

Data statement

Data used in this study are available from the authors upon reasonable request. The aggregated raw data analyzed including suicide rate per 100,000 population, population, population density, crude divorce rate, per capita GRDP, and economic growth rate are available to the public on the website (http://kosis.kr/). Park area data can be obtained from the MOLIT Statistics System website (http://stat.molit.go.kr), and data on number of MERS and H1N1 patients are available on the Infectious Diseases Portal (http://www.kdcga.go.kr/npt/biz/nnp/nppMain.do).

Declaration of competing interest

None.

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CRediT authorship contribution statement

Kim contributed to the literature search, data collection, and data analysis. Sung contributed to study design, data collection for economic and demographic measures, additional analysis, and writing of the report. All authors have read and approved the final report.
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