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ORIGINAL ARTICLE

Deprivation and suicide mortality across 424 neighborhoods in Seoul, South Korea: a Bayesian spatial analysis

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Abstract

Objectives A neighborhood-level analysis of mortality from suicide would be informative in developing targeted approaches to reducing suicide. This study aims to examine the association of community characteristics with suicide in the 424 neighborhoods of Seoul, South Korea.

Methods Neighborhood-level mortality and population data (2005–2011) were obtained to calculate age-standardized suicide rates. Eight community characteristics and their associated deprivation index were employed as determinants of suicide rates. The Bayesian hierarchical model with mixed effects for neighborhoods was used to fit age-standardized suicide rates and other covariates with consideration of spatial correlations.

Results Suicide rates for 424 neighborhoods were between 7.32 and 71.09 per 100,000. Ninety-nine percent of 424 neighborhoods recorded greater suicide rates than the Organization for Economic Cooperation and Development member countries' average. A stepwise relationship between area deprivation and suicide was found. Neighborhood-level indicators for lack of social support (residents living alone and the divorced or separated) and socioeconomic disadvantages (low educational attainment) were positively associated with suicide mortality after controlling for other covariates.

Conclusions Finding from this study could be used to identify priority areas and to develop community-based programs for preventing suicide in Seoul, South Korea.

Keywords Neighborhood · Socioeconomic factor · Suicide · Mortality · Bayesian hierarchical model · Spatial analysis

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Introduction

The mortality rate from intentional self-harm has rapidly increased in South Korea during the past 15 years. The crude suicide mortality rate was 10.8 per 100,000 residents in 1995 but skyrocketed to 31.7 per 100,000 in 2011 (Statistics Korea 2014). According to the 2010 Global Burden of Disease study, suicide was the second leading cause of deaths following stroke in terms of years of life lost in South Korea (Institute for Health Metrics Evaluation

2014). Suicide is the only major leading cause of deaths in South Korea showing an increasing trend in age-standardized mortality rates during the most recent decade (Statistics Korea 2014). This rise in suicide deaths is known to be associated with the two economic crises in 1997 and 2008 and subsequent structural adjustment resulting in increased ‘flexibility’ of labor market and worsened income distributions (Khang et al. 2005; Khang and Lynch 2010), and to the underdevelopment of social welfare in South Korea (Chang et al. 2009; Kwon et al. 2009; Khang and Lynch 2010; Kim et al. 2010, 2011; Chan et al. 2014). Since 2003, South Korea has recorded the highest suicide mortality rate among Organization for Economic Cooperation and Development (OECD) member countries, showing a tenfold difference between Korea and Greece, which has the lowest suicide rate (OECD 2014).

Examining the absolute levels of and time trends in suicide mortality would be the first step toward developing effective policies. The absolute rise in suicide mortality has reportedly been concentrated in the male and elderly population in South Korea (Kwon et al. 2009; Kim et al. 2011). Several studies have reported substantially large and widening socioeconomic inequalities in suicide mortality (Khang et al. 2005; Lee et al. 2009, 2014; Kim et al. 2010). Geographical differences in suicide mortality according to district-level socioeconomic status have recently been an important research concern (Khang et al. 2005; Kim et al. 2010; Hong and Knapp 2013; Lee et al. 2014). Rural–urban differences in suicide have also been presented (Kim et al. 2010; Cheong et al. 2012; Park and Lester 2012).

A neighborhood-level analysis of suicide mortality would be informative in developing targeted approaches to reduce suicide mortality. Despite the recent increase in studies on socio-demographic characteristics of suicide mortality and its geographic patterns in South Korea, there is a paucity of information on suicide in small areas, partly due to limited access to the data. Although neighborhood-level analyses of major causes of death such as cardiovascular disease and cancer are now widely performed in many countries (Asaria et al. 2012; Di Cesare et al. 2013; Vigotti et al. 2014), neighborhood-level analysis of suicide is not readily available in most parts of the world due to the relatively small number of suicide deaths in such small geographical areas and limited access to suicide data. However, a few studies in Australia (Cheung et al. 2012), Canada (Ngamini Ngui et al. 2014), England and Wales (Congdon 2000; Middleton et al. 2008), Finland (Pirkola et al. 2009), and Taiwan (Chang et al. 2010) have provided findings from small area analysis of suicide.

In this paper, we presented neighborhood-level analysis results on suicide in Seoul, the capital city of South Korea, which has about 10 million people, and examined the association of community characteristics with suicide at the neighborhood level.

Methods

Units of analysis

The unit of neighborhood for our analysis was the dong, which is a Korean term referring to the smallest area-level administrative unit based on the classification of the Ministry of Public Administration and Security in South Korea. The average population of a dong in Seoul was 23,859 in 2011 and ranged between 1204 and 52,464 in the same year. The total number of dongs in Seoul was 522 in 2005 but has been reduced to 424 in 2011 via the annexation of neighboring dongs according to governmental administrative structural adjustment. To take into account this change in the number of dongs in Seoul, we grouped some dongs between 2005 and 2011 to use consistent administrative areas for our analysis. Therefore, 424 neighborhood units (dongs) of analysis were used over the study period.

Suicide mortality rates

Dong-level aggregate data for suicide deaths (the International Classification of Disease, Tenth Revision code: X60-X84) between 2005 and 2011 were obtained from Statistics Korea for the information on numerators in the calculation of suicide mortality rates. In this study, dong refers to the residential area of the deceased who committed suicide, not the place of suicide. For denominators, dong-level mid-year age-specific numbers of residents (5-year age groups from 0 to 84 years and over 85 years) of each year (2005–2011) were obtained from the residence registration data of the Ministry of Public Administration and Security. Total numbers of mid-year population during the study period was used.

Standardized mortality ratios (SMRs) from suicide, the ratio of the observed to expected numbers of suicide, were calculated for each of the 424 dongs between 2005 and 2011. The expected number of suicides in each dong was calculated by multiplying the 5-year age-specific suicide rates (from 0 to 84 years, and over 85 years) of Seoul by the corresponding age-specific numbers of the population in each dong. The SMRs from suicide were then converted into age-standardized suicide mortality rates through simple multiplication of the SMRs by the overall suicide rates of Seoul over the study period (2005–2011).

Neighborhood deprivation index

We calculated the dong-level deprivation index using 2010 Korean Census data. The method for calculating the area deprivation index is described in detail elsewhere (Choi et al. 2011). In brief, the deprivation index used information on eight indicators: residents living alone, female household head, no housing ownership, low educational attainment (less than high school graduation among those aged 35–64), low occupational social class (low social class among economically active household heads aged 15–64 according to occupation-based social class classification) (Yoon 2003), a divorced or separated marital status among those aged 15 or over, population aged 65 or over (elderly), and unemployment among males aged 15–64. The percentage of each indicator was calculated at the dong level and then standardized to a *Z*-score. The standardized *Z*-scores for the eight indicators were summed up to create the deprivation index.

Statistical analysis

We examined the geographic differences in the suicide mortality rates across dongs in Seoul by quintiles of the deprivation index.

Bayesian hierarchical models were used to estimate the 'smoothed' age-standardized suicide mortality rates for each dong and mitigate the effects of extreme outliers by borrowing strength across dongs. An adjacent matrix, containing adjacent neighborhood information of the areas, was compiled by Quantum Geographic Information System (QGIS) and then converted to WinBUGS format. The adjacent neighbors of a dong were defined as the dongs that shared common boundaries, or so-called "rook's case" neighbors.

The Bayesian hierarchical model with mixed effects for neighborhoods was used to fit the age-standardized suicide rates and other covariates, taking into consideration the spatial correlation. The built-in conditional autoregressive (CAR) distribution in WinBUGS 1.4 was used to incorporate spatially correlated components. Markov-Chain Monte Carlo (MCMC) simulations were implemented, and parameter means and associated 95 % confidence intervals (CIs) were estimated from a chain of 20,000 iterations after a burn-in of 20,000 iterations. To minimize the autocorrelation among the simulated MCMC samples, every 10th sample (thinning of 10 iterations, thus 20,000 samples in total) was used to infer all the posterior information. Convergence was assessed by examining the graphical histories of the simulated suicide rates and Gelman-Rubin convergence statistics (Gelman and Rubin 1992). All of the samples for the parameters of interest also converged well. Hierarchical models were also applied to examine the associations of area suicide mortality rate with covariates both before and after controlling for all other area characteristics which were used to created deprivation index.

The final models used in the statistical analysis have forms as follows:

$$\text{standardized suicide rates } \sim N(\mu, \tau),$$

$$\mu = \alpha + \beta \cdot X + u \tag{1.1}$$

$$\mu = \alpha + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \cdots + \beta_1 \cdot X_8 + u \tag{1.2}$$

$$u \sim \text{CAR}$$

As shown in (1.1), each of eight indicators that compose of the deprivation index can replace '*X*' for the univariate analysis. For the multiple regression analysis, all indicators (X_1, X_2, … , X_8) can be included in the model as shown in (1.2). The CAR model is used for the prior of the spatial effects and we used non-informative distributions for the other parameters such as a flat distribution or a normal distribution with large variance to ensure uncertainty of prior information. More details about the priors and their setting for the hyper parameters can be found in the WinBUGS model codes in the Appendix. In this study, we examined the correlations among the covariates to validate the multiple linear models. Statistics and graphics were done using Stata v13.0 and open source program R v3.1.1 and maps were produced using open source package QGIS v1.80.

Results

Table 1 shows summary statistics for the population number, number of suicides, and age-standardized suicide rates in the 424 dongs of Seoul, South Korea. The mean total population in each dong over the study period was 167,844, ranging between 7355 and 363,715. The total number of suicide deaths over the study period (2005–2011) was 16,305, and the mean number of suicides per dong for the 424 dongs was 37.82 (median 37) for those 7 years. The age-standardized suicide rate was 26.29 per 100,000 per year with a standard deviation of 7.28 per 100,000. Table 1 also presents wide variations in each component of the deprivation index. The mean deprivation index was 0.06 with an SD of 5.81 and a range between −18.67 and 14.01. Negative values in the deprivation index represented less deprived areas in Seoul. Less deprived areas are located in the southeast region while deprived areas are located in inner regions in Seoul (Supplementary Figure 1).

Figure 1 presents relationships between the neighborhood deprivation index and suicide mortality rates. Figure 1a employed raw ('unsmoothed') age-standardized suicide rates, and the Pearson's correlation coefficient was 0.48. When we used smoothed suicide rates, the correlation coefficient was 0.54. An increase of 1 SD in the deprivation index was associated with an increase of 3.46 (95 % CI 2.85–4.08) per 100,000 in suicide mortality and a one-point increase in the deprivation index was associated with 0.60 (95 % CI 0.49–0.70) suicides per 100,000. Figure 1b shows a cloud plot for the relationship between the deprivation index quintiles and smoothed age-standardized suicide mortality rates. The mean suicide rate in the least deprived quintile was 21.25 per 100,000, while the rate in the most deprived quintile was 30.17 per 100,000 (relative rates = 1.42) (see Supplementary Table 3). This cloud plot also shows wider variation within each deprivation quintile than differentials of the averages of each quintile. Supplementary Table 3 also shows the linear stepwise relationships of the deprivation index quintiles with the eight indicators used for the neighborhood deprivation index and two mortality measures for suicide (age-standardized rates and standardized mortality ratios).

Results showed significant correlations among covariates, notably between "low educational attainment" and "low social class" (see Supplementary Table 1). However, the variance inflation factor for each covariate was not greater than 5, which is the widely accepted threshold for significant multicollinearity (see Supplementary Table 2). Thus, we decided to include all the covariates that comprise the deprivation index in the Bayesian hierarchical model.

Table 2 presents the associations of the eight indicators for the neighborhood deprivation index with dong-level suicide mortality rates. When we examined regression models without considering the spatial term, the results were similar to the results by the Bayesian model. We found no changes in the direction of the associations (see Supplementary Table 4). Univariate analyses show a significant association between 1 SD changes in all eight indicators and suicide mortality. For example, a 1 SD difference (11.10 %) in the dong-level percentage of residents living alone was positively associated with 2.78 suicide deaths per 100,000 residents. These results also provide a comparative assessment of the magnitude of the association of 1 SD changes in indicators with suicide rates. Low educational attainment showed the largest magnitude of association (3.31 suicides per 100,000 by 1 SD in the percentage of low educational attainment), followed by low social class and no housing ownership, while 1 SD in the dong-level percentage of the elderly population was less strongly associated with suicide mortality rates (1.12 suicides per 100,000 by 1 SD in the percentage of the elderly population). Table 2 also presents unadjusted associations of 1 % changes in indicators with suicide rates. One percent changes in the dong-level indicator for the divorced or separated and male unemployment were associated with about 1 suicide death per 100,000. Considering the total number of Seoul citizens (10 million), the figures mean that 100 additional suicides would occur annually with an increase in the proportion with a disrupted marital status (divorced or separated) or male unemployment by 1 % in Seoul. Table 2 shows the analysis results when the eight indicators used for the area deprivation index were simultaneously adjusted for. Three of the area indicators—those for the percentage of residents living alone, low educational attainment, and divorced or separated marital status—were statistically positively associated with suicide rates, while the indicator for the elderly proportion of the population was negatively associated with suicide rates.

Figure 2 shows two maps indicating 424 dongs for (A) the raw age-standardized suicide rates and (B) the posterior means of the suicide rates based on the Bayesian spatial analysis with adjustment for all covariates which were used to build deprivation index. The map with Bayesian spatial analysis reveals that many dongs with relatively low rates of suicide death were located in the southeast part of Seoul, which includes the three most affluent districts (Gangnam, Seocho, and Songpa districts) in Seoul. Meanwhile, the dongs with high rates of suicide death were located in the northeast part and the west and southwest parts, where several districts with poor indicators for living standards can be found. The map also indicates the absolute levels of suicide rates in the 424 dongs using decile tones. The lowest decile was less than 18.50 suicides per 100,000.

Considering that the average suicide rate among OECD member countries was 12.68 per 100,000 in 2007 (OECD 2014), 419 dongs (98.9 %) recorded a greater suicide rate than the OECD average. In addition, 4 of the 5 dongs (1.1 % of 424 dongs) with a suicide rate equal to or less than the OECD average were located in the three affluent districts.

Discussion

The results of this study showed high absolute rates of suicide death in Seoul, South Korea. The suicide rates in the least deprived quintiles (the most affluent areas in Seoul) were 21.25 per 100,000, which is 1.68 times greater rates than the OECD average in 2007 (12.68 per 100,000) (OECD 2014). Of the 424 neighborhoods (dongs) in Seoul, 99 % recorded greater suicide rates than the OECD average. Although Seoul has recorded the lowest suicide rate among the 16 provincial regions in South Korea (Hong and Knapp 2013), the results of this study indicate that the absolute level of the suicide rate in Seoul is very high compared to the international figures on suicide rates. This shows that Seoul is under the broader national socioeconomic and cultural cloud of South Korea in spite of its prominent position in terms of suicide rates within the country.

Table 1 Summary statistics for population, age-standardized suicides, and the deprivation index in 424 dongs (the smallest administrative unit) in Seoul, South Korea, 2005–2011

Variables	Mean	SD	Min	Max
Total population between 2005 and 2011	167,844	61,661	7355	363,715
Number of suicides between 2005 and 2011	37.82	15.83	5.00	90.00
Age-standardized suicide rate (per 100,000)	26.29	7.28	7.32	71.09
Standardized mortality ratio from suicide	1.00	0.28	0.28	2.71
Eight indicators used for the deprivation index				
% of residents living alone	24.31	11.10	4.19	71.14
% with a female household head	27.88	6.45	12.89	55.68
% without housing ownership	58.86	11.97	26.74	87.85
% with low educational attainment	15.68	7.50	0.68	46.26
% of low social class	19.53	8.26	1.66	42.76
% divorced or separated	10.22	2.85	3.58	23.34
% of elderly	10.09	2.29	5.15	17.10
% of male unemployment	7.63	1.84	3.21	15.92
Deprivation index	0.06	5.81	−18.67	14.01
Residents living alone	0.01	1.00	−3.72	2.65
Female household head	0.00	1.00	−3.18	3.08
No housing ownership	0.00	1.00	−2.67	2.42
Low educational attainment	0.01	1.00	−2.00	3.98
Low social class	0.00	1.00	−2.16	2.80
The divorced or separated	0.01	1.00	−2.84	3.73
Elderly	0.01	1.00	−2.44	2.73
Male unemployment	0.00	1.00	−2.83	3.73

Eight indicators used for deprivation index were based on the 2010 Korea Census data

SD standard deviation

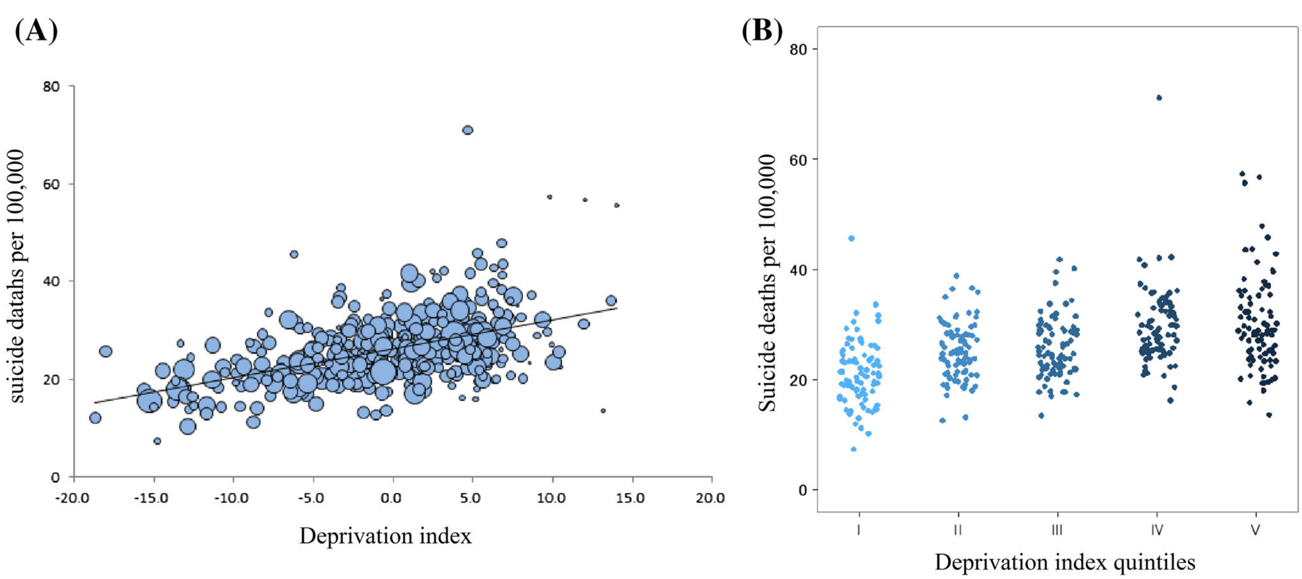

Fig. 1 Relationship between neighborhood deprivation index (2010) and suicide mortality rates in 424 dongs (the smallest administrative unit) of Seoul, South Korea, 2005–2011. **a** Raw (unsmoothed) age-standardized suicide mortality rates according to dong-level deprivation index (weighted by each dong's population size); **b** Smoothed age-standardized suicide mortality rates (2005–2011) by neighborhood deprivation index quintiles (*I* least deprived group, *V* most deprived group)

Table 2 Associations of eight indicators for the neighborhood deprivation index with age-standardized suicide mortality rates (suicide deaths per 100,000) in 424 dongs (the smallest administrative unit) of Seoul, South Korea, 2005–2011

	Unadjusted analysis, β (95 % CI)	Adjusted for all indicators simultaneously, β (95 % CI)
Association of 1 SD changes in indicators with suicide rates		
Residents living alone	2.78 (2.04 to 3.51)	1.65 (0.46 to 2.83)
Female household head	2.44 (1.75 to 3.12)	0.23 (−0.82 to 1.28)
No housing ownership	3.11 (2.41 to 3.80)	−0.07 (−1.17 to 1.28)
Low educational attainment	3.31 (2.68 to 3.93)	1.80 (0.53 to 3.09)
Low social class	3.16 (2.53 to 3.79)	0.59 (−0.61 to 1.78)
Divorced or separated	2.87 (2.22 to 3.54)	1.83 (0.60 to 3.04)
Elderly population	1.12 (0.32 to 1.87)	−1.17 (−2.00 to −0.35)
Male unemployment	1.84 (1.12 to 2.54)	−0.57 (−1.32 to 0.20)
Association of 1 % changes in indicators with suicide rates		
Residents living alone	0.25 (0.18 to 0.32)	0.15 (0.04 to 0.26)
Female household head	0.37 (0.26 to 0.47)	0.04 (−0.12 to 0.20)
No housing ownership	0.25 (0.19 to 0.32)	−0.01 (−0.10 to 0.09)
Low educational attainment	0.44 (0.36 to 0.53)	0.24 (0.07 to 0.41)
Low social class	0.38 (0.31 to 0.46)	0.07 (−0.07 to 0.22)
The divorced or separated	1.01 (0.78 to 1.24)	0.64 (0.21 to 1.06)
Elderly	0.49 (0.14 to 0.82)	−0.51 (−0.87 to −0.15)
Male unemployment	1.00 (0.61 to 1.38)	−0.31 (−0.72 to 0.11)

Bayesian hierarchical model: unadjusted and adjusted beta coefficients (95 % credible intervals, CIs) for the associations

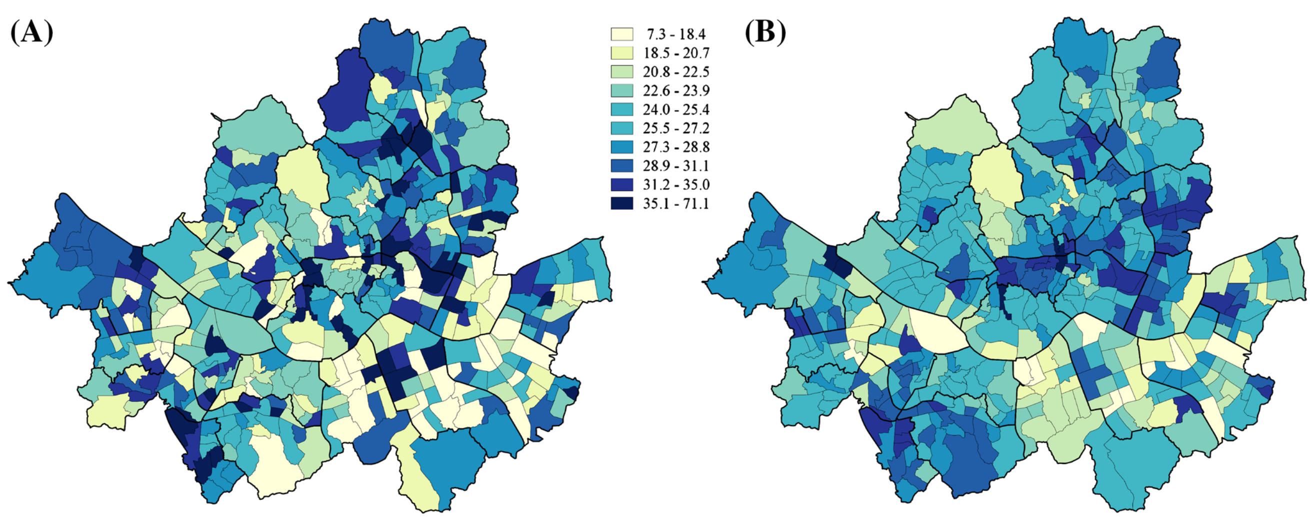

Fig. 2 Maps for **a** raw age-standardized suicide rates and **b** the posterior mean of the age-standardized suicide rates according to the Bayesian spatial model with adjustment for all covariates constituting deprivation index in 424 dongs (the smallest administrative unit) of Seoul, South Korea, 2005–2011. *Each tone* in the legend based on suicide rates (per 100,000) corresponds to a decile of dongs in the raw age-standardized rate panel. *Black bold lines* indicate boundaries of 25 local authorities in Seoul

This study provided the first evidence in South Korea on the relationship between deprivation and suicide in neighborhoods level. Prior Korean studies have presented neighborhood deprivation and suicide at the greater level of "area" (district or si-gun-gu) (Khang et al. 2005; Kim et al. 2010; Hong and Knapp 2013; Lee et al. 2014), but no studies have been conducted at the level of neighborhoods in South Korea. Stepwise associations and moderate levels of correlation between deprivation and suicide were found in this study (Fig. 1a and Supplementary Table 3). Results of analysis on the relationship between the eight indicators used for the deprivation index and suicide also provide information on the eco-social determinants of suicide in Seoul. In addition to low educational attainment, variables for residents living alone and the divorced or separated were significantly associated with suicide in the model where indicators were simultaneously adjusted for (Table 2). These two indicators represent a lack of social support, while low educational attainment represents socioeconomic disadvantages in South Korea (Khang et al. 2004; Son 2004). A recent Korean study showed that, at the district level, divorce rates were positively associated with suicide rates (Hong and Knapp 2013). Interestingly, the indicator for a high proportion of elderly in the population was positively associated with suicide in the univariate analysis but showed a significant negative association with suicide in the simultaneously adjusted model (Table 2). This may be due to close associations of the percentage of the elderly with other indicators such as the percentage of those with a disrupted marital status and low educational attainment (see Supplementary Table 1). Like low educational attainment, low social class and no housing ownership might represent socioeconomic disadvantages. However, these two indicators did not present significant association with suicide in the simultaneously adjusted model (Table 2), which might be due to close correlations with low educational attainment and strong effects of education on mortality in South Korea (Khang et al. 2004; Son 2004).

Identification of neighborhoods with high suicide rates may help to explore any potential determinants of high suicide rates in these communities. It should be noted that, despite the significant associations between area deprivation and suicide, the magnitude of variation in the suicide rate within each deprivation quintile was greater than the differences in the average suicide rates across deprivation quintiles (Fig. 1b). More explanatory factors need to be identified at the neighborhood level to explain such a wide variation within a deprivation quintile.

Small area analyses may also help policy makers to develop suicide prevention interventions at the neighborhood level. Means restriction (controls on pesticide access in South Korea) (Cha et al. 2014), gatekeeper training (training of those who contact with potentially vulnerable population in their daily work), and education of primary care clinicians have been listed as the most promising approaches to reduce suicide at the population level (Mann et al. 2005; Beautrais et al. 2007). In South Korea, a gatekeeper training program has now become available at the community level since the national government has started to establish suicide prevention centers to reduce suicide rates. Small area analysis results on suicide rates may contribute to more focused local initiatives to prevent suicide. Significant determinants identified in this study (e.g., indicators for lack of social support) could be used for developing approaches for reducing suicides.

This study has limitations. First, this study is prone to ecological fallacy and modifiable areal unit problem, since the analyses were based on aggregate and spatial data. The geographical definition of small areas is often determined by pragmatic considerations (Voigtländer et al. 2014). In this study, the spatial unit chosen is an administrative unit that has not been designed for research on health and mortality (suicide here). Thus, the use of different spatial units in terms of size and shape (e.g., small electoral unit) would be necessary in the future. Second, although we combined suicide data for 7 years between 2005 and 2011, the numbers of suicides in each dong ranged between 5 and 90, which might have resulted in relatively large chance variations in the suicide rates. Third, we used eight dong-level indicators and a deprivation index for predicting dong-level suicide rates. Despite the relatively constant nature of neighborhood characteristics, the neighborhood deprivation index used was based on the 2010 Korean Census while many suicides occurred before 2010. Since we only used the Census data, it was not possible to fully examine other potential neighborhood characteristics. Especially, variables for intervening mechanisms (e.g., social support or social network) between deprivation and suicide or policy relevant indicators (e.g., community activities to enhance social support) would be helpful to understand variations in suicide rates and to develop interventions to prevent suicide.

In conclusion, despite the wide variation in area-level suicide rates, 99 % of 424 small areas in Seoul recorded greater suicide mortality rates than OECD average suicide rates. A stepwise relationship between area deprivation and suicide was found. Small area-level indicators for lack of social support (residents living alone and the divorced or separated) and socioeconomic disadvantage (low educational attainment) were positively associated with suicide rates in the simultaneously adjusted model. Findings from small area analysis on suicide could be used to explore community-specific determinants of suicide and to identify priority areas for suicide prevention initiatives.

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