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Associations between social fragmentation, socioeconomic deprivation and suicide risk across 1887 municipalities in Japan, 2009–2017: a spatial analysis using the Bayesian hierarchical model

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ABSTRACT

Objective Previous studies have indicated that spatial variation in suicide mortality is associated with area-specific socioeconomic characteristics, such as socioeconomic deprivation and social fragmentation. However, most of these studies have been conducted in the West and findings from Asian countries are limited. This study aims to investigate associations between socioeconomic characteristics and suicide mortality rates across 1887 municipalities in Japan between 2009 and 2017. We also assessed these associations by gender and age group.

Methods Suicide data were obtained from the suicide statistics of the Ministry of Health, Labour and Welfare in Japan and included information on the number of suicides by gender, age and municipality location. Social fragmentation, socioeconomic deprivation and urbanicity were used as socioeconomic characteristics in this study and were created from survey data obtained from the 2010 census. Bayesian hierarchical models were used to examine associations between socioeconomic characteristics and suicide risk.

Results Suicide rates were significantly higher in municipalities with higher levels of deprivation, with a rate ratio of 1.13 (95% credible interval: 1.10 to 1.17) in the highest quartile compared with the lowest. Higher levels of urbanicity had significantly lower suicide rates, with a rate ratio of 0.79 (95% credible interval: 0.77 to 0.82) in the highest quartile compared with the lowest. However, associations between exposures and suicide varied considerably by gender and age. Among both men and women aged 0–39 years, fragmentation was significantly associated with suicide, with rate ratios of 1.07 and 1.15 for men and women, respectively, in the highest quartile compared with the lowest.

Conclusion Suicide prevention in Japan should particularly focus on areas with high levels of deprivation or low levels of urbanicity. Furthermore, young Japanese people residing in the most fragmented municipalities were also at high risk of suicide, and appropriate measures need to be taken.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ In this study, spatial analysis is conducted using data on the number of suicides in municipalities, which are relatively small geographic units.
⇒ The results of spatial analysis for small geographic units can be unstable and unreliable, and this study used a Bayesian hierarchical Poisson regression model to address this problem.
⇒ This study considers social fragmentation, socioeconomic deprivation and urbanicity as area-specific socioeconomic characteristics.
⇒ Since this is an ecological study, associations identified cannot be directly inferred at the individual level.

INTRODUCTION

Suicide is a leading cause of premature mortality worldwide. In addition, there are notable geographic variations in the incidence of suicide globally. According to one WHO report,[1] national global suicide rates range from 0.4 to 44.2 per 100 000 people. Within the same country, suicide incidence also varies between regions and distinct features exist with regard to geographic distribution.[2–4]

Previous studies have indicated that spatial variation in suicide mortality is associated with area-specific socioeconomic characteristics.[2 5 6] One such characteristic is socioeconomic deprivation, which refers to geographical concentrations of material hardship.[7–9] It is also considered to be multidimensional, composed of poverty, housing, employment, education, racial composition and occupational domains.[10] Systematic reviews, largely based on studies conducted in the West, indicate that areas characterised

by high levels of socioeconomic deprivation tend to have increased suicide rates.[5][6] In addition, social fragmentation is another factor possibly associated with area-specific suicide risk.[11][12] This is derived from Durkheim's theory of social integration,[13] and refers to low levels of community integration linked to above-average numbers of non-family households (eg, one-person households), high residential turnover and concentrations of particular household tenure, such as short-stay private rented households.[9][12][14] Recently, there is growing evidence that areas characterised by high levels of social fragmentation have increased suicide rates.[3][9][11][15]

So far, studies investigating the association between area-specific suicide rates and socioeconomic characteristics have been mainly conducted in European countries, the USA and Australia.[5][6] In comparison, reports from Asian countries are limited. Regarding socioeconomic factors associated with area-specific suicide risk, it has been pointed out that findings from Asian countries may be different from those of Western countries.[16] The results from the UK tended to show that area-specific suicide risk was more strongly associated with social fragmentation than socioeconomic deprivation.[11][12][15][17][18] In contrast, studies from Taiwan and Hong Kong have shown that indicators of socioeconomic deprivation appear to affect area-specific suicide risk as strong or stronger than those of social fragmentation.[3][16][19] For South Korea, two spatial analyses reported a positive association between area-specific suicide rates and socioeconomic deprivation, but these studies did not examine the association between social fragmentation and suicide.[20][21] It has been previously reported that there were significant associations between area-specific suicide rates and social environment characteristics such as socioeconomic status and isolation.[22] Although it is not clear why the findings of Asian countries are different from those of the UK, Lin *et al* suggested that one of the reasons may be the differences in social protection measures between the UK and Asian countries.[16] That is, social protection measures might be relatively more comprehensive in the UK than in Asian countries and offset some of the suicide risk in deprived areas. Japan can provide a unique setting to investigate the spatial patterning and determinants of suicide since Japan has developed a more comprehensive social security system compared with most other Asian countries.[23] Identifying socioeconomic characteristics that are strongly associated with area-specific suicide risk in Japan may provide important insights into the differences between Western countries and Asia.

In addition, studies have indicated that associations between suicide rate and area-specific characteristics might vary by gender/age group.[6][15][19] One review article from Europe showed that a positive association between area-level deprivation and suicidal behaviour was consistent across different countries, all age groups and both genders, but was particularly the case for men.[6] Also in South Korea, results of one spatial analysis revealed a clear positive association between suicide rates and area

deprivation among men, but this association was less clear for women.[20] However, there are still limited findings as to whether the differential associations by demographic group observed in Western countries could also be found in non-Western settings. Furthermore, previous studies have shown no consistent pattern of gender/age difference in the association of suicide with social fragmentation.[3][15][19]

Our previous study investigated the geographic distribution of suicide risk by gender and age group using data on the number of suicides for municipalities in Japan from 2009 to 2017. We found that the geographic distribution of suicide mortality in Japan varied considerably by gender and age.[24] In the current study, we conducted analyses to investigate the association between a variety of socioeconomic characteristics, including socioeconomic deprivation and social fragmentation, and suicide mortality across 1887 municipalities in Japan between 2009 and 2017. We also assessed these associations by gender and age group.

METHODS
Suicide and population data
Suicide data between 2009 and 2017 were obtained from the suicide statistics of the Ministry of Health, Labour and Welfare in Japan,[25] and included information on the number of suicides by gender, age and municipality location. Each suicide is assigned to a municipality based on residential address before death. In this study, units of analyses were municipalities. The category of municipality in Japan consists of special wards of the Tokyo Metropolis: cities; towns and villages. In addition, 20 large cities (cities designated by ordinance) consist of several wards. These wards were also classifies as municipalities in this study. Because three of the cities designated by ordinance (Kumamoto, Okayama and Sagamihara) were subdivided into wards after January 2009, these cities were aggregated in this study. Therefore, although there were 1896 municipalities in Japan in 2017, suicide data were grouped into 1887 aggregated municipalities. Population data for each of the municipalities in Japan by year were obtained from demographic surveys based on the nation's domiciliary registration system.[26]

Area-specific socioeconomic characteristics
Previous studies in the UK, Finland, the Netherlands and Sweden calculated the indices of social fragmentation and socioeconomic deprivation by using data from the census.[12][15][27–29] Our study also calculated the indices of social fragmentation and socioeconomic deprivation for each municipality in Japan based on the computational procedures of these previous studies, using data from the 2010 census.[30] The social fragmentation index, reflecting low levels of community integration, was based on single-person households (% of single-person households), unmarried adults (% of unmarried adults) and population mobility (% of those who moved to the address in the

last 5 years). The socioeconomic deprivation index was calculated by unemployment rate (% of people aged 15+ years who were neither in paid employment nor in school or higher education), educational level (% of those aged 35–64 years with less than college education) and non-owner-occupied households (% of households where the occupants did not own their house). To construct both indices, each input variable was z-scored and summed, with higher scores referring to higher levels of social fragmentation and socioeconomic deprivation. These area-specific socioeconomic characteristics were selected based on findings from previous studies.[5 10 12 15] Large proportions of single-person households, unmarried adults and population mobility were significantly associated with an increased risk of area-specific suicide mortality.[15] And they are among the variables included in Congdon's index of social fragmentation.[12] Large proportions of unemployment and non-owner-occupied households were significantly associated with an increased risk of suicide,[5 15] and they are among the variables included in the Townsend's deprivation index.[15] A low level of educational attainment was significantly associated with an increased risk of suicide,[5] and educational attainment is considered to be one of the domains of area-specific deprivation.[10] And thus, in this study, we used single-person households, unmarried adults and population mobility as indicators of social fragmentation, and unemployment rate, educational attainment and non-owner-occupied households as indicators of socioeconomic deprivation. In addition to social fragmentation and socioeconomic deprivation, population density was used as an indicator of urbanicity.[31] Population density (people per square kilometre (km^2)) for each area was calculated using the 2010 census population data. For the indicators of social fragmentation, socioeconomic deprivation and urbanicity, we used the quartiles as exposure variables in the primary analyses and continuous quantities in the secondary analyses. The continuous quantities of fragmentation and deprivation were z-scored, and population density was transformed to a logarithm and then z-scored. None of these area-specific characteristics was gender-specific/age-specific.

Statistical analysis

For each municipality, we calculated 'raw' (unsmoothed) standardised mortality ratios (SMRs: the ratio of the observed to the expected number of suicides) for inhabitants during the period 2009–2017. Expected suicides were calculated by multiplying the national gender-specific and age-specific suicide rates (in 10-year age bands) by the corresponding gender-specific and age-specific population in each municipality. SMRs for males and females under the age of 40 years, 40–59 years and 60 years or above were also calculated separately. Geographic variations in suicide rates were presented using differences over the middle 90% of SMRs (ie, the ratios between values at 95% and 5%), as extreme values at both ends of the distribution are likely to be unreliable estimates.

Bayesian hierarchical models were used to estimate the 'smoothed' SMR for each municipality. These were based on Poisson regression models with random effects allowing for both non-structural variability (heterogeneity across all areas in the study region) and structural variability (autocorrelation between neighbouring areas).[32–34] In the models used, an intrinsic conditional autoregressive prior distribution was assigned to the random effect for structural variability, while the random effect for non-structural variability was represented using independent normal distributions. The default prior distributions were specified for the model hyperparameters.[35] By default, prior distributions for the log transformation of both the unstructured effect precision and the structure effect precision are given in logGamma(1, 0.0005), which is a minimally informative prior. We changed the prior distribution for the precisions to logGamma(1, 0.01) or logGamma(2, 0.1) and conducted sensitivity analyses, but the results remained much the same, confirming the robustness of our results. Sets of municipalities that share a border were defined as neighbouring areas. Concerning island areas, sets of municipalities that have a regular sea route were defined as neighbouring areas, therefore all municipalities had some neighbouring areas. Associations with area-specific socioeconomic characteristics were examined before and after controlling for all other variables in multivariable models. 'Residual' SMRs after controlling for the effects of all investigated socioeconomic variables were estimated and mapped, to investigate the spatial patterning of residual variation which could not be accounted for by studied variables. The models were estimated with integrated nested Laplace approximation.[36 37] Statistical analyses of the models were carried out using the R-INLA library (21.11.22) in R-4.1.2. All other statistical analyses were performed using Stata statistical software, V.15.1, for Macintosh (StataCorp, College Station, Texas, USA).

When testing for evidence of interactions between each area's socioeconomic characteristics and gender or age group, the complex correlations between different gender/age groups (ie, an area's rate is correlated with values in its neighbours within the same gender/age group and those in other gender/age groups) could not be readily specified in the R-INLA library. Therefore, referring to the approach taken by the previous study of Chang *et al*, negative binomial regression models were used to test interactions between area-specific socioeconomic characteristics and gender or age group, ignoring any spatial autocorrelations.[3] Continuous quantities of the area characteristics were used in the analyses of the interactions.

SMRs were mapped using seven categories that are symmetrical on the logarithmic scale (<0.50, 0.50 to <0.67, 0.67 to <0.90, 0.90 to <1.10, 1.10 to <1.50, 1.50 to <2.00 and ≥2.00). Red, blue and pale yellow with varying degrees of lightness were used to present those higher (red) and lower (blue) than the middle category (pale

Table 1 Summary statistics of the number of suicides in 2009–2017, as well as population and area-specific socioeconomic characteristics from the 2010 census, across 1887 municipalities in Japan

	Mean	SD	Minimum	25%	Median	75%	Maximum
Number of suicides in 2009–2017	126.1	176.8	0	5	60	468	1440
Population size	67 862.9	99 233.4	201	9842	30 534	82 866	877 138
Single-person households (%)	27.0	8.9	8.8	20.8	25.8	31.2	73.5
Unmarried adult population (%)	39.4	3.3	28.5	37.3	39.0	40.8	56.5
Population mobility (%)	18.2	5.8	5.4	13.7	17.9	22.0	49.1
Unemployment rate (%)	6.3	2.1	0	5.1	6.2	7.3	22.7
Non-owner-occupied households (%)	26.2	13.4	2.3	16.0	24.6	34.4	84.3
Percentage (%) of population with less than a college degree	85.4	6.8	53.8	82.1	86.7	90.3	97.5
Population density (people/km^2)	1516.9	3138.6	1.6	69.8	248.2	1107.2	21 898.3

yellow), respectively. All maps were produced using QGIS V.2.18.15 for Macintosh.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

Table 1 summarises the number of suicides, population and area-specific socioeconomic characteristics of the 1887 municipalities in Japan used in this study. There were 240 673 suicides in Japan between 2009 and 2017. Of these, 2699 (1.1%) suicides were excluded from the analysis because address or age data were unavailable, and thus 237 974 suicides (males: 164 432 (69.1%)) were included in the study. Across municipalities, total number of suicide deaths ranged from 0 to 1440. Total number of suicides was zero in 15 of the 1887 municipalities. For males aged 0–39 years, 158 municipalities (8.4%) had zero suicides. Corresponding figures were 80 (4.2%) for males aged 40–59 years, 57 (3.0%) for males aged

60+ years, 439 (23.3%) for females aged 0–39 years, 271 (14.4%) for females aged 40–59 years and 120 (6.4%) for females aged 60+ years.

Table 2 shows estimates of suicide rate ratios among the overall Japanese population according to levels of each of the area-specific socioeconomic characteristics before and after adjustment. Compared with the quartile 1 group, there were no statistical differences in the associations between social fragmentation and area-specific suicide risk in the other groups. Regarding socioeconomic deprivation, the rate ratios of suicide were significantly higher in quartile 2, quartile 3 and quartile 4 compared with quartile 1. And as the level of deprivation increased, so did the suicide risk. With regard to the level of urbanicity, the rate ratios of suicide were significantly lower in quartile 2, quartile 3 and quartile 4 compared with quartile 1. And as the level of urbanicity increased, the suicide risk became smaller. For neither fragmentation, deprivation nor urbanisation did the rate ratios of suicide change much before or after the adjustment. Online supplemental appendix table 1 presents the results of the analysis of the associations with suicide rates

Table 2 Rate ratios (and 95% CIs) of suicide among the Japanese population according to quartile levels of each of the area-specific characteristics

	Quartile 1	Quartile 2		Quartile 3		Quartile 4	
Social fragmentation							
Unadjusted	Ref.	0.98	(0.95 to 1.01)	0.98	(0.95 to 1.00)	1.02	(0.99 to 1.05)
Adjusted†	Ref.	0.98	(0.95 to 1.00)	0.97	(0.95 to 1.00)	1.00	(0.97 to 1.04)
Socioeconomic deprivation							
Unadjusted	Ref.	1.04*	(1.01 to 1.06)	1.07*	(1.05 to 1.10)	1.12*	(1.09 to 1.15)
Adjusted†	Ref.	1.05*	(1.03 to 1.07)	1.09*	(1.06 to 1.12)	1.13*	(1.10 to 1.17)
Urbanicity							
Unadjusted	Ref.	0.93*	(0.90 to 0.96)	0.85*	(0.83 to 0.88)	0.80*	(0.78 to 0.83)
Adjusted†	Ref.	0.93*	(0.90 to 0.95)	0.84*	(0.82 to 0.87)	0.79*	(0.77 to 0.82)

Quartile 1 refers to the lowest levels of fragmentation, deprivation and urbanicity, and quartile 4 refers to the highest levels.
*P<0.05.
†Adjustments for the other two area-specific characteristics.
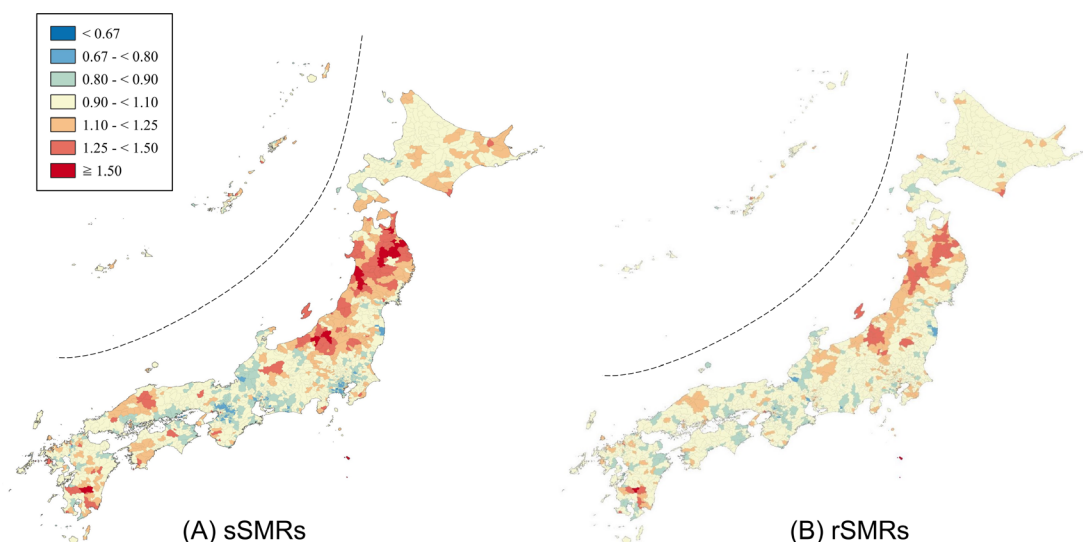CIs, credible intervals; Ref., reference.

Figure 1 Maps of (A) smoothed standardised mortality ratios (sSMRs) and (B) residual standardised mortality ratios (rSMRs) after adjusting for social fragmentation, socioeconomic deprivation and urbanity, for suicide among total Japanese population across 1887 municipalities, 2009–2017.

when area-specific socioeconomic characteristics are continuous quantities. Concerning deprivation and urbanicity, the results for continuous quantities and quartiles were similar. For fragmentation, the results of the analysis of continuous quantity showed that suicide rates were significantly higher in more fragmented municipalities, although rate ratios were not large.

Figure 1 shows the maps of smoothed SMRs (sSMRs) and residual SMRs (rSMRs) after taking into account all studied area-specific characteristics for suicide among the overall Japanese population. Compared with the map of sSMRs, the spatial concentration of high-risk and low-risk areas was attenuated or disappeared in the map of rSMRs. This suggests that the spatial patterning of suicide can be explained to some extent by the area-specific characteristics investigated in the current study. The 90% range of sSMRs was 0.81 to 1.31 (a 1.6-fold difference), while the corresponding rSMRs values were 0.86 to 1.21 (a 1.4-fold difference).

Table 3 shows gender-specific/age-specific estimates of suicide rate ratios according to levels of each of the area-specific socioeconomic characteristics after adjusting for all other variables. Regarding social fragmentation, the rate ratios of suicide were significantly larger in quartile 4 compared with quartile 1 for males aged 0–39 years and females aged 0–39 and 40–59 years. However, the rate ratios were significantly smaller in quartile 2, quartile 3 and quartile 4 for males aged 60 years and older, and in quartile 3 and quartile 4 for females aged 60 years and older, compared with quartile 1. Concerning socioeconomic deprivation, the rate ratios were significantly larger in quartile 2, quartile 3 and quartile 4 than in quartile 1 for males aged 40–59 years and 60+ years and females aged 40–59 years and 60+ years. For males aged 40–59 years and 60+ years and females aged 40–59 years, the rate ratios of suicide tended to increase as the level of deprivation increased. And the values of the rate ratios

were greater for men than for women, suggesting that the associations between deprivation and suicide are stronger for men. Regarding urbanicity, the rate ratios were significantly smaller in quartile 2, quartile 3 and quartile 4 compared with quartile 1 among males aged 0–39 years, 40–59 years and 60+ years and females aged 60+ years. And for these gender-age groups, the rate ratios of suicide tended to decrease as the level of urbanicity increased. Among women aged 40–59 years, the rate ratio of suicide was significantly smaller only in quartile 2 compared with quartile 1. The values of the rate ratios were smaller for men than for women, suggesting that the association between urbanicity and suicide is stronger for men. Online supplemental appendix table 2 presents the results of the analysis of the associations with suicide rates where area-specific socioeconomic characteristics are continuous quantities, by gender and age group. Comparing the results of this analysis with those for quartiles, the results were roughly similar, although there were some differences. Online supplemental appendix table 3 presents the results of an analysis examining interactions between gender or age and socioeconomic characteristics. The results indicated that all the interaction terms were statistically significant. That is, there were stronger associations between a higher level of fragmentation and higher suicide rates for women than for men, and for young people than for older people. In contrast, a weaker association with deprivation was observed among women and young people. The associations between a higher level of urbanicity and lower suicide rates were stronger for men and older people.

DISCUSSION
Main findings
In our previous study, we examined the geographical distribution of and rural-urban differences in suicide

Table 3 Rate ratios (and 95% CIs) of suicide in males and females aged 0–39 years, 40–59 years and 60+ years according to quartile levels of each of the area-specific socioeconomic characteristics after adjusting for other characteristics

	Quartile 1	Quartile 2		Quartile 3		Quartile 4	
Males aged 0–39 years							
Social fragmentation	Ref.	1.01	(0.96 to 1.06)	1.01	(0.96 to 1.06)	1.07*	(1.01 to 1.13)
Socioeconomic deprivation	Ref.	1.02	(0.98 to 1.06)	1.04	(1.00 to 1.08)	1.02	(0.98 to 1.07)
Urbanicity	Ref.	0.92*	(0.86 to 0.98)	0.85*	(0.80 to 0.91)	0.79*	(0.74 to 0.84)
Males aged 40–59 years							
Fragmentation	Ref.	1.01	(0.97 to 1.05)	1.01	(0.97 to 1.05)	1.04	(0.99 to 1.08)
Deprivation	Ref.	1.07*	(1.04 to 1.10)	1.13*	(1.09 to 1.17)	1.22*	(1.17 to 1.26)
Urbanicity	Ref.	0.93*	(0.89 to 0.98)	0.83*	(0.79 to 0.87)	0.72*	(0.68 to 0.76)
Males aged 60+ years							
Fragmentation	Ref.	0.94*	(0.90 to 0.98)	0.94*	(0.90 to 0.98)	0.95*	(0.90 to 1.00)
Deprivation	Ref.	1.07*	(1.03 to 1.11)	1.14*	(1.09 to 1.18)	1.26*	(1.20 to 1.31)
Urbanicity	Ref.	0.93*	(0.88 to 0.97)	0.8*	(0.76 to 0.84)	0.75*	(0.71 to 0.79)
Females aged 0–39 years							
Fragmentation	Ref.	0.99	(0.91 to 1.07)	1.05	(0.97 to 1.14)	1.15*	(1.06 to 1.25)
Deprivation	Ref.	1.03	(0.97 to 1.09)	1.05	(0.99 to 1.12)	1.06	(1.00 to 1.14)
Urbanicity	Ref.	1.00	(0.90 to 1.13)	1.01	(0.91 to 1.13)	1.09	(0.98 to 1.22)
Females aged 40–59 years							
Fragmentation	Ref.	1.03	(0.96 to 1.10)	1.07	(1.00 to 1.14)	1.13*	(1.05 to 1.21)
Deprivation	Ref.	1.06*	(1.01 to 1.11)	1.08*	(1.03 to 1.14)	1.15*	(1.09 to 1.21)
Urbanicity	Ref.	0.91*	(0.84 to 1.00)	0.93	(0.86 to 1.01)	0.96	(0.88 to 1.05)
Females aged 60+ years							
Fragmentation	Ref.	0.96	(0.91 to 1.01)	0.91*	(0.86 to 0.96)	0.88*	(0.83 to 0.93)
Deprivation	Ref.	1.08*	(1.04 to 1.13)	1.08*	(1.03 to 1.13)	1.07*	(1.01 to 1.12)
Urbanicity	Ref.	0.94*	(0.88 to 0.99)	0.87*	(0.82 to 0.92)	0.85*	(0.80 to 0.91)

Quartile 1 refers to the lowest levels of fragmentation, deprivation and urbanicity, and quartile 4 refers to the highest levels.
*P<0.05.
CIs, credible intervals; Ref., reference.

mortality in Japan from 2009 to 2017.[24] Results showed that, overall, suicide rates in Japan tended to be higher in rural municipalities than in urban ones, but the geographical distribution of and rural-urban differences in suicide mortality varied considerably by gender and age. In the current study, we used a spatial analysis approach to investigate associations between suicide rates and area-specific socioeconomic characteristics across 1877 municipalities in Japan during the period 2009–2017. This study considered social fragmentation, socioeconomic deprivation and urbanicity as area-specific socioeconomic characteristics. Among the overall Japanese population, municipalities with higher levels of socioeconomic deprivation were associated with greater suicide risk, and those with higher levels of urbanicity were associated with smaller suicide risk. As for social fragmentation, however, there was no association with area-specific suicide risk. Gender-specific/age-specific analyses revealed that the associations between area-specific socioeconomic characteristics and area-specific suicide risk varied considerably by gender and age in Japan. Municipalities in the highest quartile level for social fragmentation were

associated with significantly larger suicide risk than those in the lowest quartile among males aged 0–39 years and females aged 0–39 years and 40–59 years. Higher levels of socioeconomic deprivation were associated with greater suicide risk among males aged 40–59 years and 60+ years, and among females aged 40–59 years, with the association appearing to be stronger for males than for females. Higher levels of urbanicity were associated with smaller suicide risk among males of all the age groups and among females aged 60+ years, with the association appearing to be stronger for males than for females.

Socioeconomic correlates of overall suicides

Findings from the UK indicated that associations of area-specific suicide risk were stronger with social fragmentation rather than socioeconomic deprivation.[11 15] There are several possible reasons why the results of our study differed from the findings of the UK in that social fragmentation was not associated with suicide risk, while socioeconomic deprivation was associated with risk. First, this result may be influenced by the fact that Japan started suicide prevention measures at the national level much

later than the UK. The UK government launched the Health of the Nation strategy in 1992, which included suicide reduction as a key target area.[38] On the other hand, in Japan, the Basic Law for Suicide Countermeasures was finally enacted in 2009, and from then, suicide countermeasures at the national level started in earnest.[39] Second, differences in social and cultural circumstances between Japan and the UK may have influenced the results. Japanese society is considered to be more cohesive than that of many Western countries, including the UK.[40 41] The cohesiveness of society may have mitigated the effect of social fragmentation on area-specific suicide risk in Japan.

Studies in Taiwan and Hong Kong have shown that both social fragmentation and socioeconomic deprivation were associated with area-specific suicide risk, but deprivation tended to be more strongly associated with suicide risk compared with fragmentation.[3 16 19] It is possible that Taiwan and Hong Kong, like Japan, are also more cohesive societies than the UK, which has resulted in deprivation having a stronger impact, as found in the current study. However, the findings in Taiwan and Hong Kong were somewhat different from the current study. In Japan, no significant association was found between fragmentation and suicide, but in the former two countries, a significant association was indicated. The difference in the results may be due to the different indicators used. That is, unlike our study, the studies of Taiwan and Hong Kong did not use composite measures of fragmentation or deprivation, and rather used indicators directly from the census and other sources, such as unemployment rates, unmarried adults and educational attainment, without compositing them.

Socioeconomic correlates of gender-specific/age-specific suicides

A review article in Europe indicated that the associations between area-level socioeconomic disadvantage and suicidal behaviours were more pronounced among men,[6] and the results of our Japanese study were similar, with a stronger association found in men. However, our study did not find any significant association for males aged 0–39 years. As for the associations of suicide with social fragmentation, previous studies showed no consistent pattern with respect to gender or age.[3 15 16 19] Our results indicated that, only among males aged 0–39 years and females aged 0–39 years and 40–59 years, suicide risk was significantly larger for municipalities in the highest quartile category of social fragmentation. Jang et al reported that in South Korea, the associations between indices of isolation (% divorce and % detached houses) and suicide rates were stronger for men than for women and for younger age groups than older.[22] Future research is needed to clarify why area-specific suicide risk among young Japanese population is not associated with socioeconomic deprivation, but social fragmentation. Concerning males and females aged 60+ years, suicide risk appeared to be lower in municipalities with higher level of social fragmentation.

These results were difficult to interpret appropriately. We think that these unexpected results are due to the failure of this study to consider some important factors in the area-specific risk of suicide among elderly people, such as social capital and neighbourhood-specific features. Previous studies in Taipei have shown that election participation, a proxy indicator of linking social capital, was associated with reduced suicide rates in females aged 65+ years after adjusting for a variety of area-specific socioeconomic characteristics.[16] An ecological study in Hong Kong indicated that neighbourhood-specific features, such as recreational services, daily necessity resources and community centres, were significantly associated with suicide rates in older adults.[42]

As for the associations of suicide with urbanicity, previous studies have shown no consistent pattern with respect to gender or age.[3 4 15 28] In our study, higher levels of urbanicity assessed by population density were associated with a decreased risk of suicide in males but not necessarily in females. One previous review article on suicide in rural areas reported that geographic and interpersonal isolation, agricultural or otherwise hazardous vocational demands, environmental and governmental policies, availability of means, lack of access to care and rural ideologies appeared to contribute to suicide risk among people residing in rural areas.[43] Therefore, since Japanese men can be vulnerable to rural characteristics such as those mentioned above, suicide prevention measures in Japan should take this into account.

LIMITATIONS

Our study had several methodological issues which must be acknowledged. First, since this is an ecological study, the associations identified cannot be directly inferred at the individual level. Furthermore, as indicators of area-specific characteristics in this study were used to describe the overall social and economic environment of each area, these exposure measures are not gender-specific/age-specific. And thus, this may limit the interpretability of findings from subgroup analyses. Second, the indices of fragmentation and deprivation used in our study were calculated based on those used in the previous European studies.[12 15 27–29] However, it is possible that the indices did not sufficiently reflect the circumstances in Japan. The indicators of fragmentation and deprivation in our study were calculated using six variables reported in the national census. In Japan, other than in the census, there is a paucity of data on the socioeconomic status of inhabitant in each municipality. For this reason, we had no choice but to select those variables from the census data that we considered appropriate for this study. Therefore, future studies are needed to investigate what indicators can adequately assess social fragmentation and socioeconomic deprivation in Japan. Third, area-specific socioeconomic characteristics investigated in the study did not include other variables of potential importance such as alcohol consumption and the prevalence of mental

disorders, for which data were unavailable. Considering the geographical distribution of rSMRs, it appears that the socioeconomic characteristics taken into account in our study alone do not fully explain the geographical distribution of suicide rates in Japan from 2009 to 2017 and that some other factors may indeed affect it. Future studies will therefore be needed to elucidate such factors. Fourth, different municipalities might have experienced different secular trends in suicide during the 9-year study period. During the study period from 2009 to 2017, suicide rates decreased in Japan for all gender and age groups, except for males under 20 years of age (online supplemental appendix table 4). However, the extent of the decrease varies considerably according to gender and age. Therefore, trends in suicide rates in each municipality over the 9-year period may also have varied considerably, but our study did not take this into account in the analysis. Fifth, we used municipalities as the unit of analysis. Although municipalities are not large geographical units, they vary greatly in both geographical and population size in Japan. Finally, congruent with most previous studies,[3 15] we assumed that people are only exposed to their actual place of residence. As suicide risk develops over a lifetime, future studies should be longitudinal and include people's residential history over their life course.

CONCLUSION

Our results, along with findings from other countries and regions, show that there were marked geographic and socioeconomic inequalities in suicide, which varied considerably by gender and age. This suggests that appropriate attention should be paid to social policies addressing social fragmentation, socioeconomic deprivation and urbanicity underlying the spatial variations in suicide in countries. Concerning Asian countries and regions, including Japan, it seems that suicide prevention needs to focus on areas with high level of socioeconomic deprivation rather than social fragmentation. However, among younger Japanese populations, suicide risk is larger in municipalities with high level of social fragmentation, and appropriate measures for this are needed to be taken. And to construct effective place-based interventions, more research is needed into underlying mechanisms in order to identify specific area characteristics that exacerbate or protect against suicide.

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REFERENCES

1 WHO. Preventing suicide: a global imperative, 2014. Available: https://www.who.int/publications/i/item/9789241564779 [Accessed 7 Feb 2022].
2 Middleton N, Sterne JAC, Gunnell DJ. An atlas of suicide mortality: England and Wales, 1988-1994. *Health Place* 2008;14:492–506.
3 Chang S-S, Sterne JAC, Wheeler BW, *et al*. Geography of suicide in Taiwan: spatial patterning and socioeconomic correlates. *Health Place* 2011;17:641–50.
4 Santana P, Costa C, Cardoso G, *et al*. Suicide in Portugal: spatial determinants in a context of economic crisis. *Health Place* 2015;35:85–94.
5 Rehkopf DH, Buka SL. The association between suicide and the socio-economic characteristics of geographical areas: a systematic review. *Psychol Med* 2006;36:145–57.
6 Cairns J-M, Graham E, Bambra C. Area-level socioeconomic disadvantage and suicidal behaviour in Europe: a systematic review. *Soc Sci Med* 2017;192:102–11.
7 Townsend P. Deprivation. *J Soc Policy* 1987;16:125–46.
8 Gunnell DJ, Peters TJ, Kammerling RM, *et al*. Relation between parasuicide, suicide, psychiatric admissions, and socioeconomic deprivation. *BMJ* 1995;311:226–30.
9 Congdon P. The spatial pattern of suicide in the US in relation to deprivation, fragmentation and rurality. *Urban Stud* 2011;48:2101–22.
10 Messer LC, Kaufman J. Using Census Data to Approximate Neighborhood Effects. In: Oakes JM, SKaufman J, eds. *Methods in social epidemiology*. John Wiley and Sons, 2006: 209–36.
11 Whitley E, Gunnell D, Dorling D, *et al*. Ecological study of social fragmentation, poverty, and suicide. *BMJ* 1999;319:1034–7.
12 Congdon P. Suicide and parasuicide in London: a Small-area study. *Urban Stud* 1996;33:137–58.
13 Durkheim Émile. *Suicide: a study in sociology*, 2005.
14 Congdon P. Assessing the impact of socioeconomic variables on small area variations in suicide outcomes in England. *Int J Environ Res Public Health* 2013;10:158–77.
15 Middleton N, Whitley E, Frankel S, *et al*. Suicide risk in small areas in England and Wales, 1991-1993. *Soc Psychiatry Psychiatr Epidemiol* 2004;39:45–52.

16 Lin C-Y, Hsu C-Y, Gunnell D, *et al*. Spatial patterning, correlates, and inequality in suicide across 432 neighborhoods in Taipei City, Taiwan. *Soc Sci Med* 2019;222:20–34.

17 Evans J, Middleton N, Gunnell D. Social fragmentation, severe mental illness and suicide. *Soc Psychiatry Psychiatr Epidemiol* 2004;39:165–70.

18 Smith GD, Whitley E, Dorling D, *et al*. Area based measures of social and economic circumstances: cause specific mortality patterns depend on the choice of index. *J Epidemiol Community Health* 2001;55:149–50.

19 Hsu C-Y, Chang S-S, Lee EST, *et al*. "Geography of suicide in Hong Kong: spatial patterning, and socioeconomic correlates and inequalities". *Soc Sci Med* 2015;130:190–203.

20 Hong J, Knapp M. Geographical inequalities in suicide rates and area deprivation in South Korea. *J Ment Health Policy Econ* 2013;16:109–19.

21 Yoon T-H, Noh M, Han J, *et al*. Deprivation and suicide mortality across 424 neighborhoods in Seoul, South Korea: a Bayesian spatial analysis. *Int J Public Health* 2015;60:969–76.

22 Jang H, Lee W, Kim Y-O, *et al*. Suicide rate and social environment characteristics in South Korea: the roles of socioeconomic, demographic, urbanicity, general health behaviors, and other environmental factors on suicide rate. *BMC Public Health* 2022;22:410.

23 Jacobs D. Social welfare systems in East Asia: a comparative analysis including private welfare. LSE STICERD research paper No. CASE010, 1998. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1158901 [Accessed 7 Feb 2022].

24 Yoshioka E, Hanley SJB, Sato Y, *et al*. Geography of suicide in Japan: spatial patterning and rural-urban differences. *Soc Psychiatry Psychiatr Epidemiol* 2021;56:731–46.

25 Ministry of Health, Labor and Welfare. Suicide statistics [in Japanese], 2022. Available: https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/0000140901.html [Accessed 8 Apr 2022].

26 Ministry of Internal Affairs and Communications. Demographic survey based on the nation's domiciliary registration system, 2021. Available: https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00200241&tstat=000001039591 [Accessed 7 Feb 2022].

27 Martikainen P, Mäki N, Blomgren J. The effects of area and individual social characteristics on suicide risk: a multilevel study of relative contribution and effect modification. *Eur J Population* 2004;20:323–50.

28 Hagedoorn P, Groenewegen PP, Roberts H, *et al*. Is suicide mortality associated with neighbourhood social fragmentation and deprivation? A Dutch register-based case-control study using individualised neighbourhoods. *J Epidemiol Community Health* 2020;74:197–202.

29 Stjärne MK, Ponce de Leon A, Hallqvist J. Contextual effects of social fragmentation and material deprivation on risk of myocardial infarction--results from the Stockholm Heart Epidemiology Program (SHEEP). *Int J Epidemiol* 2004;33:732–41.

30 Ministry of Internal Affairs and Communications. Census in 2010, 2014. Available: https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00200521&tstat=000001039448 [Accessed 7 Feb 2022].

31 Helbich M, Blüml V, de Jong T, *et al*. Urban-Rural inequalities in suicide mortality: a comparison of urbanicity indicators. *Int J Health Geogr* 2017;16:39.

32 Besag J, York J, Mollié A. Bayesian image restoration, with two applications in spatial statistics. *Ann Inst Stat Math* 1991;43:1–20.

33 Congdon P. Bayesian models for spatial incidence: a case study of suicide using the bugs program. *Health Place* 1997;3:229–47.

34 Lawson AB, Biggeri AB, Boehning D. Disease mapping models: an empirical evaluation. *Statistics in Medicine* 2000;14:35–59.

35 Blangiardo M, Cameletti M, Baio G, *et al*. Spatial and spatio-temporal models with R-INLA. *Spat Spatiotemporal Epidemiol* 2013;7:39–55.

36 Rue H, Martino S, Chopin N. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *Journal of the Royal Statistical Society Series B: Statistical Methodology* 2009;71:319–92.

37 Rue H, Riebler A, Sørbye SH, *et al*. Bayesian computing with INLA: a review. *Annual Review of Statistics and Its Application* 2017;4:395–421.

38 Gunnell D, Frankel S. Prevention of suicide: aspirations and evidence. *BMJ* 1994;308:1227–33.

39 Cabinet Office of Japan. White paper on suicide prevention in Japan, 2015, 2015. Available: https://dl.ndl.go.jp/info:ndljp/pid/10226219 [Accessed 7 Feb 2022].

40 Takao S. Research on social capital and health in Japan. A commentary on Ichida and on Fujisawa. *Soc Sci Med* 2009;69:509–11.

41 Marmot MG, Smith GD. Why are the Japanese living longer? *BMJ* 1989;299:1547–51.

42 Guo Y, Chau PPH, Chang Q, *et al*. The geography of suicide in older adults in Hong Kong: an ecological study. *Int J Geriatr Psychiatry* 2020;35:99–112.

43 Hirsch JK, Cukrowicz KC. Suicide in rural areas: an updated review of the literature. *Journal of Rural Mental Health* 2014;38:65–78.