Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-024-04299-1 OPEN

Understanding online suicidal ideation in China: nationwide distribution, social determinants, and geographic variations

Yanji Zhang [1,4]✉, Liang Cai[2,4] & Chunwu Zhu [3]

Using novel Internet search data from Baidu Index, this study examines for the first time the nationwide distribution of city-level intensity of online suicidal ideation in China and the underlying social determinants and processes. We find that the intensity of suicidal ideation shows moderate spatial clustering, decreasing from east to west nationally and from developed to less developed areas within each province. Overall, socioeconomic inequality, social fragmentation as represented by single-generation households and religiosity, and the proportion of older adults are positively associated with suicidal ideation. Social deprivation, divorce rate, and male-to-female sex ratio have significant negative effects on suicidal ideation, while marriage rate has insignificant effects. Further analyses based on geographically weighted regression suggest that the direction, magnitude, and statistical significance of the set of risk factors relevant to suicidal ideation vary by contexts and that city-specific interventions for suicide prevention are needed.

[1] Department of Sociology, School of Humanities and Social Sciences, Fuzhou University, Fuzhou, China. [2] Department of Sociology, The University of Chicago, Chicago, IL, USA. [3] Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, TX, USA. [4] These authors contributed equally: Yanji Zhang, Liang Cai. ✉email: chairman7up@126.com

Introduction

Suicidal ideation and its measurement using big data. Suicidal ideation refers to thoughts of engaging in behaviors to end one's life, which is a manifestation of mental illness and is critical to individual and societal well-being (Li et al., 2012). Compared to the well-publicized suicide death, a more alarming fact is that a much larger number of individuals struggle with thoughts of attempting suicide. Globally, the lifetime prevalence of suicidal ideation has reached 9.2% (Nock et al., 2008). In China, one in six adolescents report suicidal ideation (Chang et al., 2023).

As the first step along the continuum of suicidal behavior, suicidal ideation shares risk factors with subsequent suicide attempts and suicide death (Liu et al., 2005; ten Have et al., 2009; Datta and Nakhaie, 2022). A common trend worldwide is that ~30% of individuals with suicidal ideation progress to suicide attempts (Nock et al., 2008). Most hotspot clusters of suicidal ideation and suicide rates are identical across the country (Taewan and Hee-Jung, 2021). Thus, elucidating suicidal ideation and its formation mechanisms is crucial to understanding not only this dangerous psychological state itself, but also subsequent suicidal acts. This is particularly important in China, which has the second highest number of suicides in the world (WHO, 2021), and where the suicide rate among middle-aged men and young urbanites has gone from declining to increasing (Jiang et al., 2018; Chang et al., 2023).

However, few studies have analyzed suicidal ideation and proposed suicide prevention strategies from a macro-level socio-spatial perspective (Wray et al., 2011). This is because most studies of suicidal ideation have taken a micro-level individual approach. They typically use non-random sample surveys and focus on specific population groups, schools, or districts (Li et al. 2012; Chang et al. 2017). The extent to which such findings can be generalized to the general population remains unclear (Allen and Goldman-Mellor, 2018; Peng et al., 2019). We know little about the nationwide distribution of the prevalence of suicidal ideation across Chinese cities.

Another major challenge with such self-reported data on suicidal ideation is recall bias and reliability issues (Allen and Goldman-Mellor, 2018; Peng et al., 2019; Uddin et al., 2019). Underreporting of suicidal ideation is quite common in retrospective surveys because of fear of invasion of privacy, avoidance of undue interference, fear of hostility due to stigma, and embarrassment in expressing mental health problems. Self-reporting is therefore susceptible to social desirability bias, which can lead to misleading conclusions (Klonsky et al., 2016; Richards et al., 2019).

The ubiquity of Internet products, such as social media and search engines, provides new opportunities for suicide research, especially in developing countries that lack high-quality suicide data (Klonsky et al., 2016; Wang et al., 2023). Suicidal thoughts expressed on the Internet and identified by Internet big data can be defined as online suicidal ideation. The Internet approach has two main advantages. First, due to the greater anonymity of the online world, people tend to express their emotions and feelings more directly than in offline interpersonal communications (Pourmand et al., 2019). Second, because of its broad coverage, real-time, low cost, and large sample size, big data from social media and search engines can monitor fluctuations in aggregate suicide risk and reveal the distribution of suicidal ideation at the macro level (Morese et al., 2022). For example, spatiotemporal patterns of online suicidal ideation captured by suicide-risk Twitter streams are highly consistent with actual suicide rates and suicide mortality in the U.S. and Japan (Jashinsky et al., 2014; Wang et al., 2023).

As of June 2023, the number of Chinese search engine users has reached 841 million, accounting for 78.0% of the total number of Internet users (CNNIC, 2023). Compared with social media, which typically requires account registration and does not automatically record geolocations, the use of Internet search engine has a higher degree of anonymity and is not subject to external monitoring and self-censoring, making it a more accurate reflection of individual thoughts across cities (Wang and Loo, 2019; Li et al., 2021), especially on sensitive topics such as suicide and disease (He et al., 2018). To our knowledge, no study has used big data from Internet searches to investigate online suicidal ideation in China.

Social determinants of suicidal ideation and behavior. The lack of suicidal ideation research at the macro-city level has also resulted in a limited understanding of the macro social processes that shape suicidal ideation. However, since the classic work of Emile Durkheim ([1897] 1951), suicidal behavior has been viewed as a social fact, influenced by the broader social milieu, rather than a purely individual matter. Several empirical studies have confirmed the contextual effects of a wide range of social determinants, including social deprivation, socioeconomic inequality, social fragmentation, and demographic characteristics, on suicidal ideation and suicide deaths (Denney et al., 2015; Jasilionis et al., 2020; Chang et al., 2023).

The influence of social deprivation on suicide is still debated. Some argue that social deprivation is a risk factor for suicidal behavior because of the economic vulnerability, instability, and lack of social resources of people living in poverty and with low levels of education (ten Have et al., 2009; Elbogen et al., 2020) and in deprived areas (Congdon, 2011; Chang et al., 2011; Graetz et al., 2020). In contrast, another strand of research postulates that highly educated individuals and residents of socioeconomically advanced areas tend to experience greater psychological distress and fiercer competition, and are therefore more likely to develop suicidal thoughts (Yan and Gai, 2022). The latter finding is in line with early work suggesting that poverty may act as a protective mechanism against suicide (Durkheim [1897] 1951).

The strain theory of suicide posits that socioeconomic inequality, accompanied by conflicting values, discrepancies between realities and aspirations, relative deprivation, and deficient coping, is central in stimulating psychological strain and motivating internalized violence to relieve pressure (Zhang et al., 2009; Zhang, 2010). The negative consequences of socioeconomic inequality can also be explained by Durkheim's ([1897] 1951) concept of anomie. Widening socioeconomic gaps create a stark contrast between the ideal of just societies and the reality of unequal distribution of opportunities, leading to resentment, alienation, and subsequent suicidal behavior. The relationship between income or ethnic inequality and suicide rates/mortality has been demonstrated in empirical studies (Miller et al., 2005; Wadsworth and Kubrin, 2007; Liu, 2017), but the impact on suicidal ideation is less addressed.

Social fragmentation implies that aspects of social capital such as the reinforcement of social norms, trust and reciprocity may be difficult to maintain (Fagg et al., 2008). In contrast to social integration and social connectedness, social fragmentation creates a sense of social alienation and emptiness in life and increases people's vulnerability to suicide (Durkheim [1897] 1951). The later three-step theory of suicide argues that when social connectedness or a sense of purpose outweighs an individual's pain and hopelessness, the person is unlikely to engage in active suicidal ideation (Klonsky et al., 2016). Marriage, family relationships and religious affiliation are important institutions for generating social capital and integration and reduce social fragmentation. The positive effect of social fragmentation on

suicidal behavior has been demonstrated in Western societies among single, divorced, solitary and non-religious individuals (ten Have et al., 2009; Li et al., 2012; Denney et al., 2015; Datta and Nakhaie, 2022) and in regions with high divorce rates, residential instability, fewer family members living together, and higher proportions of unmarried and non-religious populations (Wadsworth and Kubrin, 2007; Congdon, 2011; Denney et al., 2015; Jasilionis et al., 2020; Brantez and Houle, 2023). An alternative view sees the influence of social fragmentation as non-linear. When social integration is taken to extremes, leading to what Durkheim calls over-integration ([1897] 1951), the protective effect of social integration would be weakened or even reversed. However, this view has only been supported by a few case studies of Chinese women (Zhang, 2010).

In terms of demographic characteristics, suicidal ideation is most common in the 50+ age group due to declining physical health and shrinking social networks (Chang et al., 2017). Women are more likely to have suicidal ideation (Nock et al., 2008; Taewan and Hee-Jung, 2021; Yan and Gai, 2022; Chang et al., 2023).

In summary, suicidal behavior, including suicidal ideation, is a social fact that is strongly influenced by the social context beyond individual attributes. However, the impact of most social determinants remains a subject of ongoing debate. More importantly, while established studies have examined factors influencing suicide deaths at both the micro-individual and macro-city/regional levels, discussions of suicidal ideation have, with few exceptions (Wang et al., 2023), been limited to the individual level. The social determinants of suicidal ideation at the macro-city level remain unclear.

Geographic variation in the determinants of suicidal behaviors. So far, most existing studies at the macro level have relied on a single model for the whole study sample, assuming that the impact of social determinants on suicide risks is uniform across space (Brunsdon et al., 1996; Fotheringham et al., 2002). This neglect of spatial non-stationarity may have contributed to the inconsistent empirical results described above. More importantly, because culture, customs, policies, and other unmeasurable aspects vary from place to place, the influence of the same social-environmental factors on suicidal behavior may also differ by location (Tran and Morrison, 2020; Zhang and Monnat, 2024). Moreover, global estimates limit our ability to design place-based intervention strategies.

Empirical research on suicidal behavior has indeed shown evidence of spatial non-stationarity. For example, although socioeconomic inequality contributes to suicide in many regions of the U.S., it is negatively associated with suicide rates in California and Maryland, likely due to their higher levels of public welfare spending (Tran and Morrison, 2020). Moreover, in areas of greater gender inequality in rural China, the over-integration of women into marriage would be exacerbated, making the association between marriage and female suicidal ideation less negative and even positive, a pattern rarely observed in Western societies (Ji et al., 2001; Zhang, 2010).

Compared to global analytical methods such as Ordinary Least Square (OLS) regression, local modeling techniques such as Geographically Weighted Regression (GWR) have been introduced to disentangle the more nuanced spatial non-stationarity by allowing parameters to vary locally rather than assuming globally identical parameters (Brunsdon et al., 1996; Fotheringham et al., 2002). Several pioneering studies using GWR models have found that the direction, magnitude, and significance of the effects of social deprivation, socioeconomic inequality, social fragmentation, proportion of elderly, and proportion of African Americans on suicide rates vary across U.S. counties (Trgovac et al., 2015; Ha and Tu, 2018; Tran and Morrison, 2020; Zhang and Monnat, 2024). With region-specific determinants of suicidal behavior and their importance, research findings can inform geographically tailored suicide prevention strategies (Zhang and Monnat, 2024). However, the geographic variation of factors influencing suicidal ideation remains limited, particularly in the Chinese context.

Summary. To fill the gaps in understanding the intensity and social determinants of suicidal ideation and their geographic variations at the macro level, this study focuses on online suicidal ideation at the city level in China using novel real-time Internet search big data. Given the high penetration rate, wide geographic coverage, and anonymity of the Internet, keyword search volume on Baidu, the leading Internet search engine in China, provides a reliable proxy for suicidal ideation, a concept that is difficult to quantify accurately in the past.

We aim to answer three empirical questions. First, what is the nationwide spatial pattern of online suicidal ideation intensity in China? Second, overall, how are social processes such as social deprivation, socioeconomic inequality, social fragmentation, and demographic characteristics associated with online suicidal ideation at the city level? Third, do factors associated with online suicidal ideation vary geographically across cities? Our analysis not only provides a direct test of classic sociological theories related to suicide in a non-Western context, but also informs place-based suicide prevention policies.

Research design

Unit of analysis. Our study area covers mainland China, excluding Sansha City in the South China Sea. The unit of analysis consists of municipalities (‘直辖市’ in Chinese), prefecture-level cities (‘地级市’), leagues (‘盟’), autonomous prefectures (‘自治州’), prefectures (‘地区’), and sub-prefectural divisions (‘副地级行政区’). We refer to our analytical units as cities for brevity. A total of 360 cities are included in this study.

City-level online suicidal ideation. As mentioned above, Internet search engine query data can provide real-time insights into the intensity of online suicidal ideation at the city level. Baidu is the leading search engine in China with a market share of over 80% (Li et al., 2021). The Baidu Index, similar to Google Trends, standardizes the total volume of searches on Baidu.com for different keywords and has been widely used to reflect various public concerns and social sentiments (http://index.Baidu.com) (Wang and Loo, 2019; Chen et al., 2021).

We take three steps to construct the suicidal ideation index for each city. First, we measure the intensity of online suicidal ideation based on the number of searches for suicide and suicide methods. Pesticide ingestion, hanging/suffocation, gas poisoning, and jumping from tall buildings account for most suicide deaths in China (Ji et al., 2001; Chang et al., 2011). Therefore, we crawl the daily Baidu index in each city for the Chinese keyword ‘suicide’ (‘自杀’ in Chinese) and seven keywords related to suicide methods, namely ‘jumping from a building’ (‘跳楼’), ‘self-hanging’ (‘上吊’, ‘自缢’), ‘paraquat’ (‘百草枯’, a pesticide often used for suicide in China), ‘slitting wrists’ (‘割腕’), ‘suffocation’ (‘窒息’), and ‘charcoal burning suicide’ (‘烧炭自杀’). We then sum the daily index to obtain the annual index for each city from 2012 to 2020.

Next, we adjust for the influence of population size and Internet usage frequency of different cities on search volume. Similar to the common practice of using certain common word counts in social media as a proxy for the frequency of people

Table 1 KMO test and rotated component matrix of the per capita Baidu index for 'suicide' and seven suicide methods.

Year	KMO	Suicide	Jumping	Hanging	Self-hanging	Paraquat	Slitting wrists	Suffocation	Charcoal burning suicide
2012	0.92	0.94	0.91	0.89	0.89	0.84	0.85	0.94	0.84
2013	0.92	0.93	0.90	0.89	0.92	0.90	0.91	0.93	0.90
2014	0.93	0.92	0.89	0.90	0.90	0.85	0.85	0.93	0.84
2015	0.88	0.93	0.91	0.81	0.87	0.79	0.85	0.91	0.84
2016	0.89	0.93	0.91	0.91	0.88	0.73	0.87	0.93	0.86
2017	0.84	0.94	0.93	0.90	0.67	0.69	0.88	0.84	0.87
2018	0.85	0.92	0.94	0.90	0.85	0.64	0.90	0.92	0.89
2019	0.88	0.91	0.92	0.91	0.85	0.78	0.91	0.89	0.90
2020	0.88	0.93	0.94	0.89	0.84	0.84	0.92	0.91	0.91

using a social media product (Wang et al., 2023), we consider the search volume of Baidu products as the penetration rate of Baidu's search engine in each city, measured by the Baidu index of the keyword 'Baidu' ('百度'). Specifically, for each city and each year from 2012 to 2020, we divide the annual Baidu index of the eight suicide-related keywords by the annual Baidu index of the keyword 'Baidu' separately to estimate the annual per capita Baidu index of the eight keywords reflecting suicidal ideation.

Finally, given the correlation in the per capita Baidu index for the eight keywords reflecting suicidal ideation in each year, we perform factor analysis for the eight indices by year. We find that the per capita indices in each year have KMOs greater than 0.84 ($p < 0.001$). As shown in the rotated component matrix, the eight per capita indices have high loadings on one single factor, indicating that all eight overlap to reflect the same latent suicidal ideation (Table 1). Regression is used to estimate the factor score for suicidal ideation in each city each year. Correlation analyses show that these factor scores are also highly correlated between each year from 2012 to 2020, with Pearson's correlation coefficients all greater than 0.85. This suggests that the nation-wide spatial pattern of suicidal ideation intensity is stable over time and that the 9-year factor scores can be averaged to measure the final suicidal ideation index, which is our dependent variable.

Social determinants. To reflect the social milieu at the city level, we focus on four social factors associated with suicidal ideation, namely, social deprivation, socioeconomic inequality, social fragmentation, and demographic characteristics, which are the main factors identified by Durkheim in his classic work Suicide and recent development following this tradition.

To test Durkheim's thesis that poverty is a protective mechanism against suicidal behavior, we examine the role of social deprivation. Area social deprivation refers to geographical concentrations of material hardship and is usually represented by observed indicators of low social status such as poverty, unemployment, or welfare dependency (Congdon, 2011). We use the proportion of the population without a bachelor's degree (abbreviated as the less educated) in the total population over the age of 25 to measure social deprivation in each city. This is because education is a key variable that reflects social status, and in particular, whether one has attended university or not largely determines an individual's income level, occupational status, and social prestige in China (Hu and Hibel, 2014; Xiao and Bian, 2018). We use data on educational attainment from China's seventh national census.

To test the strain theory and Durkheim's concept of anomie (Zhang et al., 2009), we examine the effect of socioeconomic inequality. Socioeconomic inequality focuses on the differentiation in the distribution of social resources among individuals. We use the Gini coefficient of housing area per capita to measure the socioeconomic inequality in each city. This is because higher housing area per capita is a direct measure of wealth, larger and better-quality housing, and access to amenities and public resources (Zhang and He, 2024). In contrast, housing crowding has long been considered a key social disadvantage with important implications for individual well-being and living standards (Solari and Mare, 2012). The housing data come from the 2015 national 1% population sample survey, which covers all Chinese cities. The micro-individual data we use are randomly selected from all respondents in this survey, representing 1.5% of the total Chinese population. Some migrants are interviewed at both their current place of residence and their hukou registration place (hometown). We only keep their information at the current place of residence. In the end, we have housing information on 1,715,495 respondents.

To test the Durkheim's concepts of social integration and social connectedness (Durkheim [1897] 1951), we consider the impact of social fragmentation. Given that social fragmentation is primarily concerned with the loss of social capital and the breakdown of social networks (Fagg et al., 2008), we quantify social fragmentation in terms of living arrangements, marital status, and religiosity. For living arrangement, we use the proportion of single-generation households in total households. We see the disintegration of the extended family as a manifestation of social fragmentation because having more family members living together, especially with children or parents, provides emotional support, a stronger sense of social bonds and shared values, increased social solidarity and regulation, and more normative behavior (Denney, 2010; Denney et al., 2015; Calati et al., 2019). For marital status, we use the proportion of divorced persons and the proportion of married persons. These data come from the seventh national census.

Online search frequency has been proven to be a reliable ecological measure that reflects offline religious culture and practice, with search engine data aligning closely with religious adherence and religious service attendance (Scheitle, 2011; Yeung, 2019; Kuang and Liang, 2021). Due to the lack of official statistics on religiosity in China, we measure it in the same way as suicidal ideation. We scrape the daily Baidu index for keywords related to religion, including 'Jesus' ('耶稣' in Chinese), 'Bible' ('圣经'), 'Christianity' ('基督教'), 'Bodhisattva' ('菩萨'), 'Buddhist scriptures' ('佛经'), 'Buddhism' ('佛教'), 'Taoism' ('道教'), 'Allah' ('安拉'), 'Koran' ('可兰经'), and 'Islam' ('伊斯兰教'). Although these keyword searches do not capture the full range of religion and religious practice, they are representative of the main types of religion in China and the textual ways of expressing beliefs (Shelton et al. 2012). Then, we divide the annual value of these searches by the annual Baidu index of the keyword 'Baidu' to obtain the per capita value. According to the factor analysis, in each year the first seven per capita indices and the last three per capita indices have high loadings on the respective factors. Finally, the annual sum of these two-factor scores, weighted by each factor's contribution to the total variance explained, is taken to reflect the religiosity of each city.

Table 2 Descriptive statistics of variables.

Variable	Mean	Std. Dev.	Min.	Max.
Dependent variable				
Suicidal ideation index	0.01	0.89	−1.89	2.22
Independent variable				
Proportion of the less educated	0.83	0.07	0.51	0.94
Gini coefficient of housing area per capita	0.31	0.04	0.24	0.45
Proportion of single-generation households	0.48	0.09	0.26	0.95
Proportion of divorced persons	0.03	0.01	0.01	0.08
Proportion of married persons	0.73	0.04	0.49	0.81
Religiosity	0.01	1.98	−0.72	10.42
Sex ratio (female = 100)	105.68	8.69	96.37	241.58
Proportion of older adults	0.27	0.06	0.10	0.41

For robustness, we also count the number of Point of Interests (POIs) of religious sites such as nunneries ('庵'), Taoist temples ('观'), monasteries ('寺'), temples ('庙'), churches, etc. per capita in each city. The POI data are crawled from the Baidu Map website in 2015. We find that the religiosity indicator derived from the Baidu index has a high positive correlation with the number of religious POIs per capita (Pearson correlation coefficient = 0.701). This indicates that the religiosity indicator we use is reasonably reliable. To avoid multicollinearity, the number of religious POIs per capita is not included in our independent variables.

Because gender and age are recognized as the critical demographic characteristics influencing suicidal ideation, we introduce sex ratio and proportion of older adults as independent variables. Sex ratio refers to the ratio of males to females. The proportion of older adults is the ratio of the population over the legal retirement age (i.e., males over 60 and females over 50) to the total population. These data are also from the seventh population census. Table 2 shows the descriptive statistics of key variables used in the present study.

Analytical approach. We first examine the nationwide effect of social factors on the suicidal ideation index at the city level using an OLS model with robust standard errors to address heteroskedasticity. The mean value of the VIF for all independent variables is 1.8 and the maximum value does not exceed 3.5, indicating that there is no serious multicollinearity. To account for spatial non-stationarity and to identify city-specific determinants of online suicidal ideation, we use GWR models to provide local parameter estimates and significance tests for each city. Due to the uneven distribution of urban density, we use the adaptive kernel to allow for spatial patterning. To select the best-performing model, we use the Akaike Information Criterion (AICc) to select the optimal bandwidth (Ha and Tu, 2018). After the GWR model, we inspect the residual spatial autocorrelation. The residual Moran's I is not statistically significant at the 0.05 level, indicating that the GWR model effectively addresses spatial autocorrelation. To reflect the relative effect of the independent variables, we use their standardized Z-scores in all models. We perform standardization for each variable by subtracting its mean and dividing by its standard deviation across cities.

Results

Nationwide distribution of online suicidal ideation and its potential determinants. Figure 1 shows the nationwide spatial pattern of online suicidal ideation in China. There is a moderate degree of spatial clustering of suicidal ideation across cities (Moran's $I = 0.283$, $p < 0.001$) and clear heterogeneity in the intensity of suicidal ideation between regions and between cities within each province.

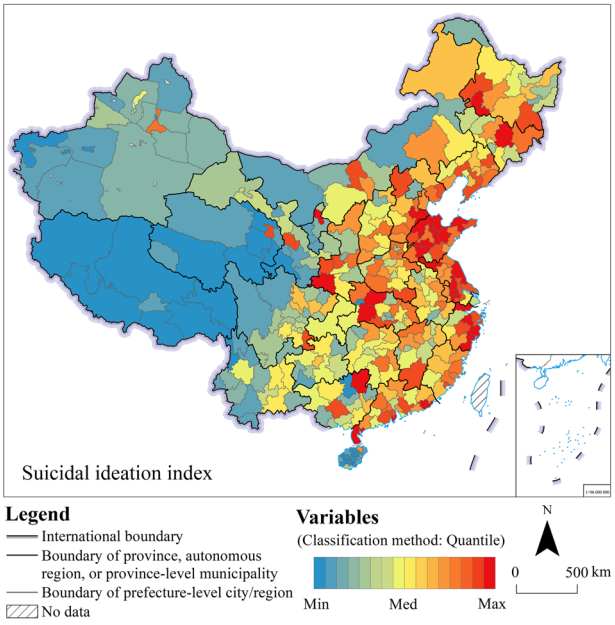

Fig. 1 Geographic distribution of online suicidal ideation. The suicidal ideation index (adjusted by the search volume of the neutral word 'Baidu') shows a decreasing trend from east to west in China.

In terms of regional differences in online suicidal ideation, the mean values of suicidal ideation index in the eastern, central, western, and northeastern regions are 0.420, 0.153, −0.487, and 0.320, respectively. Overall, suicidal ideation is strongest in the eastern and northeastern regions, intermediate in the central region, and weakest in the western region of China.

Regarding the differences in online suicidal ideation among cities within each province, the mean value of suicidal ideation index in provincial-level municipalities, provincial capitals, and sub-provincial cities is 0.339, while the mean value in remaining ordinary cities is −0.032. Moreover, 9 out of 27 provinces have their highest index in provincial capitals or sub-provincial cities, and almost all cities with the highest index in other provinces are those with the first or second highest GDP, GDP per capita, or population in the province. In general, residents of developed megacities are more likely to have suicidal thoughts, which is consistent with the pattern observed in Japan (Wang et al., 2023).

The value of the suicidal ideation index for each city is given in the Appendix.

Figure 2 shows the spatial pattern of potential determinants. Social deprivation is more prevalent in the ordinary cities (non-provincial capitals) in the Central and Western parts of the country, and housing inequality is pronounced in some megacities, developed Southeastern cities, and mountainous Southwestern cities. The proportion of single-generation households and the divorce rate are both highest in the Northeast. In contrast, marriage rates are higher in Shandong, Jiangsu, Inner Mongolia, Shaanxi, and Gansu. Religiosity is high in Northeastern, Western, and Southeastern cities. The imbalance in sex ratio, with more men than women, is greatest in some Southeastern and Western cities. The Northeast has the highest aging rate due to the strict implementation of the one-child policy in the past and the recent outflow of jobs and young people, while cities of the Pearl River Delta in the Southeast (represented by Shenzhen) have attracted many young migrants due to economic development, resulting in a low aging rate in the region.

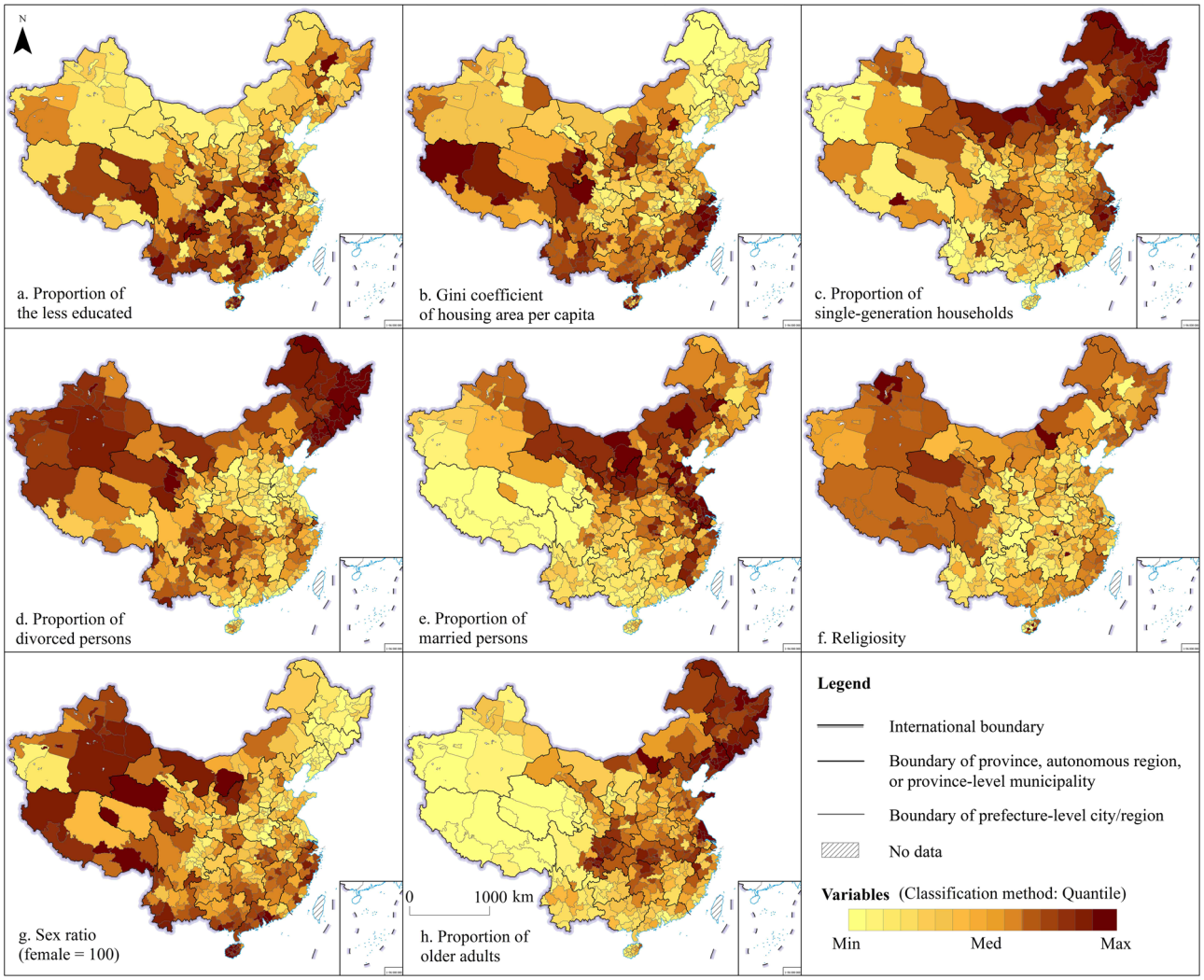

Fig. 2 Geographic distribution of potential determinants. Social deprivation is prevalent in some less-developed cities, and housing inequality is pronounced in advanced and mountainous cities. The proportion of single-generation households and the divorce rate are both highest in the Northeast. Marriage rates are higher in Shandong, Jiangsu, Inner Mongolia, Shaanxi, and Gansu. Religiosity is high in Northeastern, Western, and Southeastern cities. Gender imbalance, with more men than women, is greatest in some Southeastern and Western cities. The northeast has the highest aging rate.

National determinants of online suicidal ideation. In terms of the nationwide effect of social factors (Table 3), there is a significant negative association between social deprivation and suicidal ideation. In other words, there is a greater likelihood of individuals experiencing suicidal ideation in cities with less social deprivation, represented by a lower proportion of the population without a bachelor's degree. As predicted by the strain theory of suicide, the Gini coefficient of housing area per capita is positively correlated with the city-level prevalence of suicidal ideation.

Social fragmentation is also related to suicidal ideation. First, the higher the proportion of single-generation households, i.e., the weaker the interpersonal interaction and mutual care in intimate relationships, the greater the intensity of suicidal ideation. Second, in contrast to Western societies where marital disruption is predicted to be a risk for suicide, higher divorce rates in Chinese cities significantly reduce suicidal ideation; marriage rates are not significantly associated with suicidal ideation. Third, as expected, religiosity is negatively associated with suicidal ideation.

Consistent with empirical findings at the micro-individual level (Yan and Gai, 2022; Chang et al., 2023), suicidal ideation is significantly more common in cities with higher proportions of women and older adults.

City-specific determinants of online suicidal ideation. All parameters estimated in OLS models are assumed to be spatially stationary, which may mask local variation in the relationship between risk factors and the outcome (Brunsdon et al., 1996; Fotheringham et al., 2002). We therefore use the GWR model for more nuanced city-specific determinants of online suicidal ideation. The regression results show that the GWR models have a better model fit, with the adjusted R^2 of the GWR model increasing by 0.245 compared to the OLS model (Table 3). We set the 5% significance level as the criterion for identifying significant determinants in each city. Figure 3 visualizes the nationwide spatial distribution of the direction and magnitude of the determinants.

The associations between the proportion of the less educated and online suicidal ideation are significant and negative in all cities, with the strongest associations observed in eastern coastal cities and major southwestern cities (e.g., Chongqing). These are among the most developed cities in China, characterized by intense competition among residents for housing, education, and job opportunities.

Housing inequality is positively and significantly related to online suicidal ideation in about a quarter of Chinese cities, and this positive effect is strongest in southeastern cities. These cities have the highest Gini coefficient of housing area per capita in

Table 3 Results of regression analysis (OLS and GWR).

	OLS	GWR			
		% of cities with significant coefficients[a]		Significant coefficients[a]	
		>0	<0	Mean	Std. Dev.
Proportion of the less educated	−0.111*	0.0	100.0	−0.406	0.093
Gini coefficient of housing area per capita	0.121*	27.2	1.4	0.120	0.057
Proportion of single-generation households	0.261***	20.8	0.0	0.442	0.136
Proportion of divorced persons	−0.289***	0.0	56.1	−0.385	0.150
Proportion of married persons	0.076	20.0	0.0	0.378	0.071
Religiosity	−0.123**	0.0	55.6	−0.830	0.631
Sex ratio (female = 100)	−0.380***	0.0	36.4	−0.546	0.224
Proportion of older adults	0.237**	37.2	12.5	0.228	0.483
Intercept	−0.020	0.0	25.0	−0.415	0.117
ad R^2	0.395	0.640			
AIC	769.706	714.125			

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.
[a]The 5% significance level is used as the criterion for identifying the significant factors.

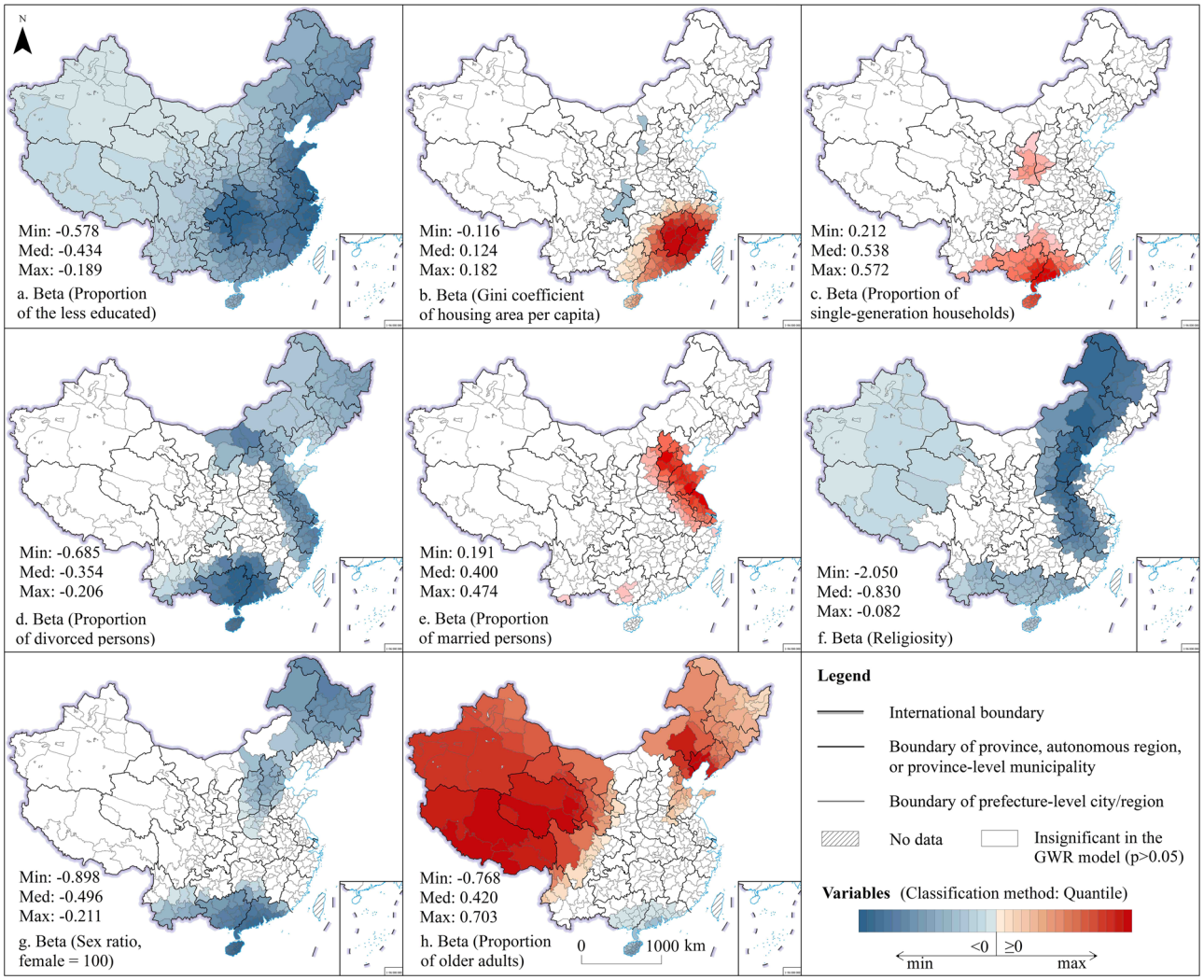

Fig. 3 Geographic distribution of beta coefficients and significance of determinants from the GWR model. Social deprivation shows a stronger negative relationship with suicidal ideation in developed cities. Housing inequality has a positive effect in southeastern cities. Proportion of single-generation households shows a strong positive effect in southern cities. The effect of divorce rate and marriage rate is negative and positive respectively in Shandong, Hebei, Jiangsu, and surrounding areas. There is a strong negative effect of religiosity in Northeastern cities. The effect of gender imbalance is negative in Northeastern, Northern, and Southern cities. Aging rate has a positive effect in Western and Northeastern cities, but a negative effect in Southern cities.

China. In contrast, in a few areas with relatively equal housing area per capita, the influence of housing inequality is not statistically significant, and a modest increase in housing inequality even discourages suicidal thoughts.

The effect of social fragmentation on online suicidal ideation is also characterized by spatial non-stationarity. Single-generation residence has a significant positive effect on suicidal ideation in southern China and Shaanxi province. Divorce rate has a significant negative effect and marriage rate has a significant positive effect on suicidal ideation in Southern China, Shandong, Hebei, Jiangsu, and surrounding areas, which may be due to the over-integration of marriage in those regions. Religiosity has a significant negative effect on suicidal ideation in more than half of the cities, with the effect being strongest in the northeastern region, the Rust Belt of China. This region has experienced an economic downturn and subsequent social anomie in recent decades (Xie, 2021).

Male-to-female sex ratio is significantly and negatively associated with suicidal ideation in some southern, northeastern, and northern cities. A higher proportion of females there is associated with greater online suicidal ideation. The proportion of older adults is a significant factor contributing to suicidal ideation in ~40% of cities, mainly in the Northeast and West. The level of institutional support for the elderly (e.g., social security and welfare, and nursing homes) is relatively low in these less developed cities. However, in Southern cities with low aging rates and high concentrations of young migrants, aging is negatively correlated with suicidal ideation.

Conclusion and discussion

Despite Durkheim's seminal work, the majority of existing studies of suicidal ideation rely heavily on individual cases that may not be generalizable. A nationwide picture of suicidal ideation remains elusive in China. Following previous research using Internet search data to study sensitive topics (He et al., 2018), this paper demonstrates the efficacy of this approach for understanding suicidal ideation, a topic that is highly sensitive and difficult to quantify. We use big data from Internet searches on Baidu.com to reveal, for the first time to our knowledge, the spatial pattern of online suicidal ideation across Chinese cities. Based on this, our study takes a sociological approach and pioneers the investigation of the city-level social mechanisms behind suicidal ideation and their geographic variations. We contribute to the literature by pioneering a macro-level exploration of a non-Western developing country that lacks national sample surveys and accurate statistics on suicide.

We find that the nationwide spatial pattern of online suicidal ideation is not random but shows moderate spatial clustering, with a gradual decline from the east and northeast to the west of the country, and from developed to less developed areas within each province. This confirms the basic finding of the early sociologist Durkheim ([1897] 1951) that suicidal behavior, including suicidal ideation, is a social fact influenced by macro-social factors rather than a purely individual matter. We show that social deprivation, socioeconomic inequality, social fragmentation, and demographic characteristics all play a role in shaping online suicidal ideation. Due to different cultural and institutional contexts, there is apparent spatial non-stationarity in these determinants, both in comparisons between Chinese and Western contexts and across cities within China.

Specifically, socially deprived areas have relatively lower, rather than higher, online suicidal ideation, particularly in some highly competitive megacities. This finding is consistent with empirical evidence from Japan (Wang et al., 2023) and with the pattern that suicide rates and social deprivation tend to be more negatively associated at the macro level (Rehkopf and Buka, 2006). There may be two reasons for this. For one, the recent success of China's comprehensive poverty alleviation projects has made it possible to extend social security systems such as pensions and medical care to rural areas. As a result, financial hardship is less likely to lead to suicide among people living in deprived areas, especially the elderly poor and the sick poor in rural areas, a trend that was common decades ago (Yang, 2017; Xu, 2017). For another, developed cities tend to have a concentration of highly educated people, a faster pace of life, heavier housing burdens, intense job competition, and more stressful lifestyles. As the logic of the modern marketplace replaces the logic of traditional societies, strong traditional interpersonal relationships between individuals can easily break down, leading to a greater likelihood of helplessness, despair, and serious mental health problems, and ultimately to more widespread suicidal ideation among individuals in developed regions (Liu and Wang, 2013).

Overall, it is the relative deprivation, rather than the absolute deprivation, resulting from housing inequality that significantly exacerbates online suicidal ideation. As the strain theory of suicide suggests, the relative deprivation caused by housing inequality may create conflicts between the expectation of fair and sufficient opportunities for upward social mobility and the reality of unfair and inadequate distribution of social resources, resulting in frustration, alienation, and the emergence of suicidal ideation (Zhang et al., 2009). Interestingly, the positive effect of housing inequality on suicidal ideation is strongest in southeastern cities where housing inequality is high; however, in a few cities where housing area is more equal, housing inequality instead serves to dampen suicidal ideation. This implies that there may be a U-shaped relationship between socioeconomic inequality and suicidal ideation. Strain theory applies to contexts of severe inequality, while excessive equality of outcome may have the potential for process inequality or inefficiency, which in turn also lead to frustration and psychological problems.

In contrast to findings in Western societies, in China, high divorce rates are associated with lower online suicidal ideation, and marriage rates do not reduce overall online suicidal ideation. This is because in China, which is heavily influenced by Confucianism, marriage has historically been seen as an institutional arrangement characterized by the over-integration of women. Especially in parts of rural China, marriage does not play a preventive role against suicide among women. Instead, compared to their single counterparts, some married women receive inadequate social support and must remain subordinate in their family roles, resulting in limited social networks and poorer relationships with family members (Zhang, 2010), leading to elevated suicide risk (Durkheim [1897] 1951). Therefore, the positive effect of marriage rates and the negative effect of divorce rates on suicidal ideation may be stronger and statistically significant in cities with high marital over-integration and greater gender inequality. In addition, based on fieldwork in rural China, Liu (2019) finds that defiant retaliation, impulsive outbursts of anger, emotional despair and release from pain caused by arranged marriages, and conflicts between mothers-in-law and daughters-in-law are the main causes of suicide among young women in rural China.

As expected, social fragmentation, embodied in single-generation living arrangements, increases suicidal ideation, with the effect being most pronounced in southern China, where traditional family values are particularly emphasized. Both the condemnation of suicidal behavior by religious doctrine and the sense of belonging and cohesion fostered by religious participation can promote social bonds and discourage suicidal ideation, especially in northeastern cities experiencing economic downturn and social anomie (Graetz et al., 2020).

The finding that women and the elderly are more susceptible to suicidal ideation is confirmed at the macro level in China. However, in some southern cities, where the aging rate is low and the welfare level is high, the aging rate shows a negative relationship with online suicidal ideation. One explanation is that when the overall aging rate

is low, seniors are supported by sufficient social, institutional, and familial resources and the risk of family conflict is lower (Ku et al., 2009; Dong et al., 2015), thus reducing their likelihood of suicide. Meanwhile, a moderate size of the elderly population may promote intergenerational support, thereby reducing the likelihood of suicide among other age groups (Denney et al., 2015).

Our findings have important implications for suicide prevention policies. Suicide intervention in China has long been considered a burden of individuals, and the role of larger social forces and social policies has been overlooked. This study confirms that social policies such as narrowing the gap between the rich and the poor, encouraging intergenerational cohabitation and communication, promoting equal rights for men and women, guaranteeing freedom of marriage and the right to divorce, and guaranteeing freedom of religion and religious activities can reduce the emergence of suicidal ideation and possible subsequent suicide injuries and deaths. Each city also needs to tailor prevention strategies based on the salient factors contributing to suicidal ideation in the local context. For example, developed regions could enhance mental health care by increasing the number of psychiatric facilities and counselors per capita; and in the northeast and west, more resources should be devoted to increasing the level of social welfare for the elderly.

Limitations of our study remain. First, the extent to which the intensity of online suicidal ideation inferred from Internet search data reflects actual suicidal ideation needs to be verified by representative social surveys. Coupled with the fact that not all people use Internet search tools, national sample surveys, and a more accurate nationwide cause-of-death statistics system are still urgently needed in China. However, given the lack of large-scale data on suicide in China, our novel approach using Internet search volume adjusted by neutral keywords offers valuable insights into the nationwide distribution of suicidal ideation and its determinants. Second, the associations identified in this study are correlational. The temporal dimension can be further disaggregated to conduct a longitudinal or quasi-experimental study to investigate the precise causes of fluctuations in suicidal ideation. Third, our selection of social determinants is informed by empirical work in the Chinese and particularly Western contexts. Additional research is needed to investigate factors specific to the Chinese context. Last, our study focuses on the aggregate online suicidal ideation of all individuals, whereas the intensity of suicidal ideation varies across populations. Although city-level sub-population Baidu index data are not yet publicly available, Internet companies (e.g., Baidu.com) have developed algorithm-based methods to accurately predict the characteristics of users through their Internet searches and routine behaviors, setting the stage for future macro-level research on suicidal ideation across people of different ages, genders, and classes.

Data availability

The dataset of suicidal ideation index for each city is included in the supplementary information file. Other datasets generated and/or analyzed during the current study are available on reasonable request from the corresponding author.

Received: 2 July 2024; Accepted: 12 December 2024;
Published online: 23 December 2024

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Author contributions

Yanji Zhang: conceptualization, formal analysis, model calculation, mapping, and writing. Liang Cai: conceptualization, writing, and reviewing. Chunwu Zhu: data collection, reviewing, and editing.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-024-04299-1.

Correspondence and requests for materials should be addressed to Yanji Zhang.

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