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Research report

# Suicide rates and the association with climate: A population-based study

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**Abstract**

*Background:* Seasonality of suicide has been noted in several studies. A spring peak of suicide was observed, and associations between various climatic parameters and suicide have been suggested. This study sets out to verify seasonal patterns of suicide rates and to explore the association with climate in Taiwan.
*Method:* The study used a nationwide mortality database in Taiwan from January 1997 to December 2003. An autoregressive integrated moving average model was applied to examine the presence of seasonality and the association of climate with suicidal death.
*Results:* Seasonality with a spring peak was evident in suicidal death regardless of gender or age. Ambient temperature was positively associated with suicide after adjustment for trend and seasonality.
*Limitations:* Misclassification and underreporting of suicidal death in the registry system might confound the results. Ecological fallacies might exist.
*Conclusions:* The seasonal effect on suicide is significant in Taiwan. Suicide rates may be influenced by ambient temperatures. The findings are of research interest for future studies regarding mechanisms of suicidal behavior, and also of practical interest for better timing of suicide interventions and effective preventive strategies.


*Keywords:* Suicide; Seasonality; Climate

## 1. Introduction

Suicide has ranked ninth among the ten leading causes of death since 1999 in Taiwan and has become one of the urgent issues needing to be addressed in public health. Better understanding of suicidal behaviors may shed light on effective strategies for suicide prevention.

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Suicide rates have long been observed to fluctuate in populations according to seasons (Lester, 1971). A spring peak in suicidal death was noted across studies mainly conducted in Western countries in temperate zones (Meares et al., 1981; Nayha, 1983; Partonena et al., 2004).

The seasonal recurrence of certain psychiatric disorders bearing higher suicidal risks may be related with the seasonality of suicide (Maes et al., 1993). Besides, some sociocultural and biological determinants have been proposed to explain seasonal variations in suicidal death. Yet, the mechanism underlying the seasonality of suicide rates is still unclear. Yip et al. (1998) suggested that lifestyle related to social contacts and activities might play a part in determining seasonal effects on suicide. Ajdacic-Gross et al. (2005) further indicated an association between specific seasonal cycles of social life and seasonal patterns of suicide. Other sociocultural determinants including marital status, employment, and the selection of a suicide method were also considered to contribute to seasonal variations in suicide rates (Nayha, 1982; Ajdacic-Gross et al., 2003; Yamasaki et al., 2004). These factors might not be universal and could only partially explain the seasonality of suicide within certain sociocultural contexts. For example, sociocultural determinants, marital status in particular, were noted to be strongly related to the autumn peak of suicide which has been repeatedly found among females in Western countries but was not apparent in other places (Nayha, 1983; Ho et al., 1997; Yip et al., 1998; Yamasaki et al., 2004).

Besides controversial findings regarding to the relationship between sociocultural factors and the seasonality of suicide, the influence of climate on suicide has been of interest and is consistently considered a very potential contributor to suicidal risk. Sunshine, for example, may affect brain serotonergic activity and is likely to trigger suicidal behaviors (Lambert et al., 2002; Petridou et al., 2002; Papadopoulos et al., 2005). However, the associations between climatic parameters and suicidal rates have been noted in various directions. A comprehensive review by Deisenhammer (2003) pointed out that methodological differences yielded equivocal results in climate–suicide relationships.

This study aimed to verify seasonal patterns of suicide rates among age- and gender-specific populations in Taiwan, where sociocultural contexts and weather conditions greatly differ from those of Western countries in temperate zones, and to explore the association with climate using a nationwide population-based database.

## 2. Methods

### 2.1. Setting

Being an island with a natural geographical boundary of the sea and having an extremely low immigration rate, Taiwan had a relatively fixed population at risk across the study period. Because 98% of residents in Taiwan are of Han Chinese ethnicity, the composition of the population is rather homogenous. These characteristics provided a less biased background to examine the seasonal patterns of suicide rates and their association with climate.

### 2.2. Suicide data

This study applied time-series analysis to a 7-year population-based mortality database to examine time trends of suicide rates in Taiwan. We used Taiwan Cause of Death data to study monthly suicide death rates per 100,000 population in the study, from January 1997 to December 2003. The Cause of Death Data File is put together by the Department of Health in Taiwan. Since it is mandatory to register all deaths, Taiwan's population and vital event statistics are highly accurate and complete.

### 2.3. Study sample

Between 1 January 1997 and 31 December 2003, there were 874,284 deaths in Taiwan. Among these deaths, 772,554, 71,938, 18,130, 2381, and 9281 cases were disease or natural deaths, accidental deaths, suicidal deaths, homicidal deaths, and others, respectively. We selected suicidal deaths as our study sample. Previous studies have demonstrated that different age groups have different seasonal patterns of suicide rates, so we classified suicidal cases into 3 age groups of < 15 (children and adolescents), 15∼64 (adults) and > 64 (elderly) years. Since the number of cases aged below 15 years was only 47, which accounted for 0.26% of the suicidal deaths, we excluded them to limit this study to the adult and elderly populations. Ultimately, our study sample was comprised of 18,083 suicidal deaths. The mean age of the cohort was 49.6 years with a standard deviation of 18.2 years.

### 2.4. Population data

Population data in Taiwan are released annually to the public by the Population Affairs Administration at the Ministry of the Interior in Taiwan. The suicide rate was defined in this study as the proportion (as a fraction) of the total monthly suicidal deaths for the entire island's population. This study used data on population registrations in the Taiwan area to calculate the suicide rates per 100,000 of the population for the period 1997~2003.

### 2.5. Meteorological data

Meteorological data, comprised of daily ambient temperature, relative humidity, atmospheric pressure, rainfall, and hours of sunshine, were obtained from 19 observation stations of the Central Weather Bureau (CWB) of Taiwan. Although the CWB has 26 observation stations spread out across the island, the meteorological data from 7 stations were discarded, since these stations are located in mountainous regions where few people live. The monthly mean values were then calculated by averaging the monthly data from the remaining 19 stations. Since Taiwan is a small island, with a total land mass slightly in excess of 36,188 $km^2$, we used only a monthly mean value for climatic data in order to explore the associations with suicide rates.

### 2.6. Seasons in Taiwan

Located between the northern latitudes of 21°45′ and 25°56′, Taiwan's weather is typically subtropical, and can be described as hot and humid year round, with the demarcation between the seasons being quite vague. According to the seasonal definitions provided by the CWB, spring in Taiwan occurs from March to May, summer from June to August, autumn from September to November, and winter from December to February.

### 2.7. Statistical analysis

Monthly suicide rates per 100,000 of the population were calculated across the 7-year study period, with seasonality being a general component of the time-series pattern; the seasonality of the data was therefore evaluated by the 'autoregressive integrated moving average' (ARIMA) regression method. This method, which describes a univariate time series as a function of its past values and other significant independent variables, has been used in many analogous studies as a means of testing for the presence of seasonality and the effects of environmental exposure. The ARIMA model uses autoregressive parameters, moving average parameters, and the number of differencing passes to describe the series in which a pattern is repeated seasonally over time.

To examine the associations between climatic factors and suicide rates, cross-correlations were used to compute a series of correlations. Thereafter, this study also adopted the ARIMA regression method as a means of evaluating the effects of climatic and monthly factors on suicide rates after adjusting for time-trend effects. The monthly factors included in the model were dummy variables, running from January to December, with a specific month being given a value of 1, while the remaining months were given a value of 0. Climatic factors included monthly mean ambient temperature, relative humidity, atmospheric pressure, rainfall, and hours of sunshine. In addition, the monthly unemployment rate was included in the regression model.

The time trend was a count variable numbered from 1 to 84 according to the time series. Considering the parsimony of the models, only statistically significant independent variables were included in the ARIMA regression models. The selection of the final model was based upon the lowest mean absolute percentage error, or mean absolute error, allowing the choice of the best model from the family of ARIMA regression models. All $p$ values of $< 0.05$ were considered statistically significant in this study.

## 3. Results

### 3.1. Suicide rates

Throughout the period of this study, from 1997 to 2003, the total number of suicide deaths in Taiwan was 18,083. Of the 18,083 suicide deaths, 67.6% were male and 74.7% were aged over 64 years. There were 2161 suicide deaths in 1997, 2173 in 1998, 2276 in 1999, 2463 in 2000, 2773 in 2001, 3049 in 2002, and 3188 in 2003, with their respective suicide rates of 12.8, 12.7, 13.1, 14.0, 15.6, 17.0, and 17.6 per 100,000 population. There was an upward trend in the suicide rates in Taiwan from 1997 to 2003. Across the entire study period, the monthly male suicide rates (per 100,000 of the population) ranged from a low of 1.12 in January 1999, to a high of 2.55 in May 2003, with a mean of 1.63 and a standard deviation of 0.31. The mean monthly female suicide rate was 0.81, while the respective mean rates for adults and elderly were 1.03 and 2.83.

### 3.2. Seasonal variations in ARIMA regression model

The ARIMA test for seasonality in suicide rates was found to be significant for each gender and age group and for all of the groups pooled ($p<0.05$ for all seasonal autoregressive parameters) (not shown in the table). We

Table 1
Cross-correlations coefficient between climatic factors and suicide rates in Taiwan from 1997 to 2003

| Suicide rate per 100,000 population | Temperature | Relative humidity | Rainfall | Sunshine hours | Pressure |
|---|---|---|---|---|---|
| Total | 0.376*** | 0.368*** | 0.056 | −0.014 | − 0.287** |
| Male | 0.336** | 0.350*** | 0.034 | − 0.023 | − 0.268* |
| Female | 0.382*** | 0.398*** | 0.095 | 0.007 | − 0.263* |
| Adult | 0.303*** | 0.320*** | 0.062 | − 0.081 | − 0.200 |
| Elderly | 0.436*** | 0.438*** | 0.023 | 0.218* | − 0.437*** |

*$p<0.05$; **$p<0.01$; ***$p<0.001$.

chose a multiplicative model for the ARIMA test for suicide rates with respective trend and seasonality parameters of (1,0,1) and (1,0,0). The (1,0,1) (1,0,0) model indicates that there was 1 autoregressive parameter, 1 moving average parameter, 1 seasonal autoregressive parameter, and no seasonal moving average parameters. These parameters were computed for the series without any differencing (such as seasonal differencing). There were some differences in monthly factors between gender and age groups. For the female group, as compared to other months throughout the study period, the death rates tended to be higher in March and April (early spring to mid spring, both $p<0.01$) and lower in June (early summer, $p<0.05$) and August to September (late summer to early fall, all $p<0.05$). However, for males, the suicide rates only tended to be lower in June ($p<0.001$) and August and September (both $p<0.01$). $R^2$ values within the ARIMA regression models for female and male suicide rates were as high as 0.732 and 0.743, respectively.

Regarding the suicide rates for the population aged 15~64 years, compared to other months throughout the study period, the rates tended to be higher in March and April (both $p<0.05$) and lower in June ($p<0.001$) and August and September (both $p<0.05$). When compared to other months, the rates for those aged > 64 years were lower in June ($p<0.001$) and August and September (both $p<0.001$). The $R^2$ values within the ARIMA regression model were 0.827 for the age group of 15~64 years and 0.457 for the group > 64 years.

### 3.3. Climatic influence

Across the 7-year study period, the mean monthly figures were an ambient temperature of 23.2 °C, relative humidity of 78.2%, atmospheric pressure of 999.62 hPa, rainfall of 173.9 mm, and monthly hours of sunshine of 158.2.

Table 1 shows the cross-correlation coefficients between climatic factors and suicide rates. Significant

Table 2
ARIMA regression model

| Dependent variable | Monthly suicide rate | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Independent variable | Female | | | Male | | | 15~64 years | | | ≥ 65 years | | |
| | $\beta$ | SE | *t*-value | $\beta$ | SE | *t*-value | $\beta$ | SE | *t*-value | $\beta$ | SE | *t*-value |
| Intercept | 0.130 | 0.071 | 1.82 | 0.200 | 0.149 | 1.35 | 0.161 | 0.085 | 1.90 | 0.415 | 0.323 | 1.29 |
| MA1 | 0.036 | 0.742 | 0.05 | − 0.241 | 0.809 | − 0.30 | 0.193 | 0.407 | 0.47 | − 0.790 | 0.196 | − 4.04*** |
| AR1 | 0.203 | 0.734 | 0.28 | − 0.098 | 0.833 | − 0.12 | 0.463 | 0.368 | 1.26 | − 0.535 | 0.251 | − 2.13* |
| SAR12 | − 0.075 | 0.143 | − 0.52 | − 0.124 | 0.135 | − 0.91 | − 0.231 | 0.135 | − 1.70 | − 0.285 | 0.130 | − 2.19* |
| Mean temperature | 0.020 | 0.003 | 7.30*** | 0.036 | 0.006 | 6.30*** | 0.020 | 0.003 | 6.51*** | 0.092 | 0.012 | 7.72*** |
| March | 0.158 | 0.029 | 5.48*** | 0.092 | 0.062 | 1.48 | 0.121 | 0.029 | 4.14*** | 0.065 | 0.130 | 0.50 |
| April | 0.085 | 0.029 | 2.96** | 0.081 | 0.061 | 1.33 | 0.061 | 0.029 | 2.09* | 0.213 | 0.128 | 1.66 |
| June | − 0.058 | 0.029 | − 2.00* | − 0.221 | 0.064 | − 3.48*** | − 0.107 | 0.029 | − 3.68*** | − 0.475 | 0.128 | − 3.72*** |
| August | − 0.084 | 0.032 | − 2.64* | − 0.207 | 0.068 | − 3.05** | − 0.076 | 0.032 | − 2.39* | − 0.712 | 0.141 | − 5.06*** |
| September | − 0.151 | 0.030 | − 5.02*** | − 0.277 | 0.065 | − 4.24*** | − 0.167 | 0.030 | − 5.52*** | − 0.530 | 0.142 | − 3.73*** |
| Unemployment rate | 0.041 | 0.020 | 2.02* | 0.129 | 0.041 | 3.11** | 0.076 | 0.027 | 2.78** | 0.146 | 0.100 | 1.46 |
| Trend | 0.002 | 0.001 | 1.94 | 0.004 | 0.002 | 2.07* | 0.003 | 0.001 | 2.64* | −0.003 | 0.005 | −0.73 |
| MAPE | 6.9166 | | | 7.4186 | | | 6.3706 | | | 10.5082 | | |
| MAE | 0.0540 | | | 0.1199 | | | 0.0653 | | | 0.2875 | | |
| $R^2$ | 0.732 | | | 0.743 | | | 0.827 | | | 0.457 | | |

*$p<0.05$; **$p<0.01$; ***$p<0.001$.
MA1, moving average, Lag 1; AR1, autoregressive, Lag 1; SAR1, seasonal autoregressive, Lag 12.

associations were found between ambient temperature and suicide death rates of the total ($r$=0.376, $p$<0.001), male ($r$=0.336, $p$<0.001), female ($r$=0.382, $p$<0.001), adult ($r$=0.303, $p$<0.001), and elderly ($r$=0.436, $p$<0.001) populations. Similarly, relative humidity was significantly associated with the suicide rates of the total ($r$=0.368, $p$<0.001), male ($r$=0.350, $p$<0.001), female ($r$=0.398, $p$<0.001), adult ($r$=0.320, $p$<0.001), and elderly ($r$=0.438, $p$<0.001) populations. Atmospheric pressure was significantly associated with the suicide rates of the total ($r$=− 0.287, $p$<0.01), male (r=− 0.268, $p$<0.05), female ($r$= − 0.263, $p$<0.05), and elderly ($r$=− 0.437, $p$<0.001) populations. However, hours of sunshine was only significantly associated with suicide rates of the elderly population ($r$=0.218, $p$<0.05).

After adjusting for seasonality, trend, and the unemployment rate, among climatic parameters, only ambient temperature was significantly associated with the monthly suicide rates of the total ($r$=0.036, $p$<0.001), male ($r$=0.036, $p$<0.001), female ($r$=0.020, $p$<0.001), adult ($r$=0.020, $p$<0.001), and elderly ($r$=0.092, $p$<0.001) populations (Table 2).

## 4. Discussion

The present study documents that significant seasonality was shown in suicidal deaths regardless of gender and age using a 7-year population-based dataset in Taiwan. In accordance with previous studies (Meares et al., 1981; Nayha, 1983; Micciolo et al., 1989; Flisher et al., 1997; Partonena et al., 2004), the spring suicide peak in Taiwan with a different, non-shared sociocultural context from Western countries may be better understood by factors other than sociocultural determinants.

Yip et al. (2000) has proposed that seasonal variations in suicide would smooth out because social contacts and activities were no longer relevant with seasons nowadays, partly through technological developments in telecommunications. The findings herein cast doubt on the above sociocultural hypothesis since our study was conducted in a subtropical area without obvious demarcation of seasons and therefore, lacking specific seasonal cycles of social life. As to the elderly population, their suicidal deaths were thought to be much more vulnerable to sociocultural factors, the seasonality of suicide, though in a less magnitude, was still significant as suggested by Salib (1997). Besides, a recent research in Australia also shows increasing, rather than decreasing, seasonality of suicide (Rock et al., 2003).

In our study, only a positive correlation between temperature and suicide rates was found in the ARIMA model after adjusting for trend and other seasonal factors. That is, temperature was the only climatic variable noted in the present study which had a primary influence on suicide and was not mere recurrence in line with the seasons. This finding is in accordance with previous studies conducted in European countries and Canada (Souetre et al., 1987; Preti, 1997; Marion et al., 1999).

Maes et al. (1995) demonstrated that higher ambient temperatures predict low L-tryptophan availability among healthy volunteers. This could possibly aggravate suicidal impulses in vulnerable people. Since the influence of ambient temperature noted in this study was adjusted for trend and seasonal factors including month of the year, the deviations of monthly mean temperatures from the expected mean temperature for that time of year, rather than absolute ambient temperature, might be much more important for suicidal death as suggested by Marion et al. (1999).

The findings of this study need to be interpreted within the context of three limitations. First of all, misclassification of cause of death and underreporting of suicides in the registry system might have confounded the results. Secondly, sociodemographic variables besides gender and age were not able to be examined due to the lack of available information. At last, ecological fallacies might exist in the investigation of relationships between climatic parameters and individual suicidal deaths.

In conclusion, this study clearly demonstrates the same spring peak of suicidal deaths in Taiwan. This universal pattern of suicide may imply a common scenario behind the seasonality of suicide and can give support for future studies regarding shared chronobiological risk factors for suicidal behaviors. Seasonal variations in suicide rates addresses the need for increased support by service agencies and public campaigns for heightening awareness of suicidal behaviors at times of high risk.

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