Associations Between Air Temperature and Daily Suicide Counts in Astana, Kazakhstan

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Key Words: suicides; temperature; apparent temperature; Central Asia; Kazakhstan.

Summary. Background and Objective. Seasonal variations in suicide mortality and its association with ambient air temperature have been observed in many countries. However, the evidence from Central Asia is scarce. The aim of the study was to assess the relationship between 4 indicators of air temperature and daily suicide counts in Astana, Kazakhstan.

Material and Methods. The daily counts of suicides (ICD-10 codes, X60–X84) for the population of Astana in 2005–2010 were collected using death certificates and medical records at the Municipal Bureau of Forensic Medicine. Associations between the number of cases and mean, maximum, mean apparent, and maximum apparent temperatures were studied using negative binomial regression models controlling for the effects of month, year, weekends, holidays, wind velocity, barometric pressure, and relative humidity.

Results. Altogether, there were 685 suicides in Astana in 2005–2010. A clear seasonal pattern with the peak in summer was observed. In crude analyses, significant associations between suicide counts and all 4 temperatures were found. After adjustment for other variables, only apparent temperatures remained significantly associated with the outcome. An increase in the mean apparent temperature by 1°C was associated with an increase in suicide counts by 2.1% (95% CI, 0.4–3.8). Similar results were obtained for the maximum apparent temperature (1.2%, 95% CI, 0.1–2.3).

Conclusions. The results suggest a linear relationship between apparent temperatures and daily suicide counts across the whole spectrum of temperatures. Factors behind this association need further research with a further going aim to develop mitigation strategies in the period of climate change.

Introduction
Suicide is among the top 10 causes of death accounting for more than 1 million lives lost each year worldwide (1). Moreover, the incidence of suicide is increasing making it a considerable public health problem. According to the World Health Organization (WHO) estimates, 1.8% of all the global deaths were attributed to suicide in 1998, and this proportion is expected to increase to 2.4% by 2020 (2).

Various socioeconomic, demographic, and psychological factors have been studied in relation to suicide during the last decades, although seasonal variations in suicide rates have been documented already in the 19th century. Morselli collected data on suicide from 28 European countries and found that suicides were more common during summer and less frequent during winter months suggesting that air temperature could increase the risk of suicide through the alterations of brain functions (3). Durkheim, however, in his famous book on suicides reported that suicides occur more frequently in spring with social interactions but not weather factors being the most important factors behind this pattern (4). Although most of the frequently cited studies have reported seasonal variations in suicide rates with peaks during spring or summer months (5–7), several other studies failed to reveal a seasonal pattern (8–10). This heterogeneity in the results could be partly explained by the latitude of study sites. While seasonal variations were found in temperate climates, no associations were reported from the equatorial regions (11). Moreover, studies from England and Wales (12) and Switzerland (13) using the data for the periods of more than 100 years have shown a decrease in the effect of seasons on the incidence of suicide. Thus, the results of the associations between suicide and seasons are still contradictory warranting further research (14).

Air temperature has been the most studied climatic variable that could explain seasonal variations in suicide rates. Several studies from the 1980s–1990s (15–17) reported associations between temperature and suicide, but these analyses were based on monthly and weekly data, threatening the validity of the results since the effect of temperature on suicide-related behavior has been reported to be im-

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mediated (18). During the 2000s, a number of studies using daily data were published. Positive associations between suicide and temperature on the same day and a day before were found in Germany (19), while temperatures on the same day only were associated with suicides in England and Wales (8), Taiwan (20), and Japan (21). Moreover, Lin et al. studied temperature, humidity, atmospheric pressure, rainfall and sunshine, but only temperature was significantly associated with suicide rates (20). However, no association between meteorological variables and suicides was found in other studies (22).

Given heterogeneity of the findings on the associations between temperature and suicides, studies in other regions are warranted (19). Moreover, most of the studies were performed in economically stable countries with temperate, subtropical, and tropical climates, while the evidence from transitional countries, particularly with arid- or semiarid climates is nonexistent to the best of our knowledge.

As in many other former Soviet Republics, suicide rates in Kazakhstan (25.6 per 100 000 in 2008) are much greater than in other countries with similar economic indicators. Male and female suicide rates in 2008 were 43.0 per 100 000 and 9.3 per 100 000, respectively, placing Kazakhstan among the top 5 countries with the highest suicide rates in the world (23). However, no studies on suicide and its association with climatic factors originating from Kazakhstan or other Central Asian republics of the former USSR have been published internationally.

The capital of Kazakhstan — Astana — is one of the fastest growing capitals in the world. Its population increased from 281 thousand in 1999 to 709 thousand in 2010. According to the Köppen-Geiger classification, Astana is located in the steppe region on the border between a humid continental and a semiarid climate and has cold winters and warm summers (24). Mean temperatures for January and July are −17.3°C and 20.2°C, respectively. However, winter temperatures below −30°C and summer temperatures above 30°C are not uncommon providing vast opportunities for studying the effects of temperature on various health outcomes (25–27).

A unique geographic location of this relatively large city with one of the greatest range of temperatures across the world combined with rapid economic changes and an initially high level of suicides make the population of Astana particularly vulnerable to the effects of climatic factors and provides a rare opportunity to study associations between temperature and suicide in a semiarid climate in a country undergoing a rapid social and economic transition.

The aim of this study was to assess the relationship between air temperature and daily suicide counts in Astana, Kazakhstan.

Material and Methods

This is an ecological study using daily data on climatic factors and suicide counts in Astana. Data on all suicides (ICD-10 codes X60–X84) from February 11, 2005, to December 31, 2010, were obtained from the Municipal Bureau of Forensic Medicine. Data on mean and maximum daily temperatures, humidity, barometric pressure, and wind speed were obtained from the Kazakhstan Hydrometeorological Service (Kazhydromet). In addition to traditionally used mean and maximum daily temperatures, we applied mean and maximum apparent temperatures as the indices of discomfort related to the individual’s perceived air temperature since it combines the effects of temperature and humidity and is associated with body’s ability to cool by perspiration and evaporation during hot days (28). Mean and maximum apparent temperatures were calculated using the following formula:

\[
AT = -2.653 + 0.994 \times T + 0.0153 \times DT^2,
\]

where T is the mean or the maximum daily temperature and DT is the dew point temperature (29).

Daily suicide counts were used as a discrete dependent variable. The mean daily temperature was the primary independent variable. An exploratory analysis using the countfit function in the Stata software (30) was used to select the best fitting model for a dependent variable. Autocorrelations and partial autocorrelations of the dependent variable were used to find the appropriate autoregressive term for the regression models. A negative binomial regression model with no autoregressive terms provided the best fit. Moreover, it accounts for the overdispersion of the data. Robust standard errors were used to additionally account for heterogeneity as described elsewhere (30). Months, years, and holidays were included in the models as dichotomous variables. The analyses were repeated using a maximum daily temperature as well as mean and maximum apparent temperatures. Additional adjustment was performed for barometric pressure, wind speed, and humidity.

First, a curvilinear relationship between temperature and each of the outcomes was modeled by fitting cubic splines with knots spaced every 5°C across the whole temperature spectrum using the mksrs function in the Stata software with a linear adjustment for covariates (31). Then the most parsimonious model was selected by the stepwise reduction of the number of knots to the minimum using a 5% level of alpha error. The best fitting models were linear models (no knots) across the whole temperature spectrum. SPSS v. 17 was used for basic data processing (SPSS Inc., Chicago, IL, USA). Modeling was performed using the Stata 10.0 software (Stata Corp, TX, USA).
**Results**

Altogether, 685 cases of suicide occurred in Astana between February 11, 2005, and December 31, 2010. Daily suicide counts varied between 0 and 4 with a mean of 0.32 (SD, 0.58). A clear seasonal pattern of suicides in Astana was observed: 0.40 suicides on the average occurred during summer months while the corresponding numbers for spring, autumn, and winter were 0.37, 0.26, and 0.23, respectively. Basic data on daily suicides and climatic variables are summarized in Table 1. Altogether, 32% and 30% of all the suicides occurred during summers and springs, respectively. The mean numbers of suicides per day are presented in Fig. 1.

No clear pattern between the 4 temperatures and daily suicides counts were revealed (Fig. 2), and statistically, the linear model provided the best fit to the data. In crude analyses, all 4 temperatures were positively and significantly associated with the outcome. After adjustment for the effects of years, months, and holidays, the coefficients remained significant for all temperatures but daily maximum temperature. Further adjustment for wind velocity, humidity, and barometric pressure resulted in the fact that only mean apparent and maximum apparent temperatures remained significantly associated with daily suicide counts (Table 2). An increase in 1°C in the mean apparent temperature was associated with an increase in the number of suicides by 2.1% (95% CI, 0.4–3.8). A corresponding increase in the maximum apparent temperature was 1.2% (95% CI, 0.1–2.3). Moreover, when seasons were included in the model with any of the studied temperatures, the coefficients for seasons were reduced to nonsignificant values (data not shown) suggesting that the temperature is likely to explain seasonal variations in suicide counts in the study setting.

**Discussion**

This is to our knowledge the first study on the associations between air temperature and suicides in Central Asia. Moreover, this is one of the first studies that assessed the effect of 4 different temperature estimates on the daily suicide counts. Both mean, maximum, mean apparent and maximum apparent temperatures were associated with the number of suicides in crude analyses, but after controlling for seasonal, long-term effects and other climatic variables, only mean apparent and maximum apparent temperatures remained significantly related to the outcome. Moreover, we did not find any threshold for the effect of temperature that suggests a linear relationship between all the temperature and daily suicide counts in Astana.

### Table 1. Basic Statistics for Daily Suicide Counts and Climatic Variables in Astana, Kazakhstan, in 2005–2010

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suicide counts</td>
<td>0.3</td>
<td>0.6</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Mean temperature, °C</td>
<td>4.6</td>
<td>14.2</td>
<td>−36.2</td>
<td>31.7</td>
</tr>
<tr>
<td>Maximum temperature, °C</td>
<td>10.1</td>
<td>15.1</td>
<td>−32.7</td>
<td>40.1</td>
</tr>
<tr>
<td>Mean apparent temperature, °C</td>
<td>4.1</td>
<td>12.4</td>
<td>−16.2</td>
<td>30.7</td>
</tr>
<tr>
<td>Maximum apparent temperature, °C</td>
<td>11.2</td>
<td>17.0</td>
<td>−15.7</td>
<td>52.6</td>
</tr>
<tr>
<td>Relative humidity, %</td>
<td>64.9</td>
<td>16.4</td>
<td>14</td>
<td>98</td>
</tr>
<tr>
<td>Wind velocity, m/s</td>
<td>3.0</td>
<td>1.6</td>
<td>0</td>
<td>13.4</td>
</tr>
<tr>
<td>Barometric pressure, hPa</td>
<td>977.8</td>
<td>9.3</td>
<td>951.2</td>
<td>1010.7</td>
</tr>
</tbody>
</table>

### Table 2. A Percentage Increase in the Number of Suicide Cases Associated With an Increase in Mean, Maximum, Mean Apparent, and Maximum Apparent Temperatures by 1°C in Astana, Kazakhstan, in 2005–2010

<table>
<thead>
<tr>
<th>Variable</th>
<th>Crude</th>
<th>95% CI</th>
<th>Adjusted</th>
<th>95% CI</th>
<th>Adjusted</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temperature</td>
<td>1.42</td>
<td>0.84; 2.00</td>
<td>1.53</td>
<td>0.15; 2.92</td>
<td>1.37</td>
<td>−0.21; 2.94</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>1.25</td>
<td>0.71; 1.78</td>
<td>1.11</td>
<td>−0.02; 2.38</td>
<td>0.91</td>
<td>−0.58; 2.39</td>
</tr>
<tr>
<td>Mean apparent temperature</td>
<td>1.62</td>
<td>0.98; 2.25</td>
<td>2.01</td>
<td>0.39; 3.62</td>
<td>2.11</td>
<td>0.42; 3.79</td>
</tr>
<tr>
<td>Maximum apparent temperature</td>
<td>1.12</td>
<td>0.66; 1.58</td>
<td>1.11</td>
<td>0.03; 2.19</td>
<td>1.19</td>
<td>0.07; 2.31</td>
</tr>
</tbody>
</table>

1Each temperature was studied using separate models.
2Adjusted for years, months, and holidays.
3Adjusted for years, months, holidays, wind velocity, humidity, and barometric pressure.
4Apparent temperatures reflect the effects of both temperature and humidity; therefore, humidity was excluded from the model.

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The main strength of this study is the use of the data on daily counts and meteorological variables from one setting that reduces the likelihood of geographical bias, which might threaten the validity of the findings is several previous studies where average temperatures for the whole country were used. Moreover, all cases of suicide as registered in the Municipal Bureau of Forensic Medicine during the study period minimized selection bias. However, the data from January 1, 2005, to February 10, 2005, were unavailable. This limitation results in a slight underestimation of the proportion of suicides in winter. However, the degree of underestimation is small. Moreover, our finding on a greater mean number of suicides per day by month (Fig. 1) remains unaffected as well as the associations between the temperature and the outcome. Another strength is that we adjusted for other meteorological variables, such as wind velocity, barometric pressure, and humidity (the latter was not used for the analysis of apparent temperatures), which have a potential to confound associations between the temperature and suicide.

Another limitation of the study is a relatively small number of suicides that occurred during the study period resulting in limited statistical power for stratified analyses. Given that the male-to-female ratio of suicides in Kazakhstan is more than 4 to 1, our results mostly reflect the pattern of suicide among men, while the models for women did not converge due to a low number of cases.

One more limitation, which is typical of most similar studies on climatic factors and health outcomes, is its ecological design, i.e., the use of aggregated data on both exposure and outcome with no possibility to assess an association between the temperature and suicide at the individual level. However, it is reasonable to assume that those who died were at least to the same degree exposed to the effects of temperature as the rest of the population.

Misclassification of the cause of death has been mentioned as a potential limitation of several simi-
lar studies (19–22). In our study, we used the data from the Municipal Bureau of Forensic Medicine, which generally provide more valid data on the external causes of death than the official statistics in the post-Soviet states (32), although no evaluation of the validity of the registration of suicides in Kazakhstan has been performed. However, even there is the potential for the underestimation of the number of suicides in this study, it is unlikely that the quality of registration is related to the temperature. Thus, if present, this bias is nondifferential and would influence the width of the confidence intervals, but not the point estimates.

Our main results are in line with most previous studies showing a clear seasonal pattern of suicides (3, 5–7, 12, 13, 21). However, while the peak of suicide mortality occurs in spring in several countries (4, 21), our results clearly show that although there are more suicides in spring than autumn and winter, summer months, particularly June and July, are the months with the highest numbers of suicides per day (Fig. 1). Interestingly, in multivariable analyses, the introduction of the temperature in the model attenuates the effect of the season, which becomes close to zero and nonsignificant. Thus, we can speculate that air temperature or other factors closely associated with air temperature may at least partly explain the observed seasonal variation in Astana. However, the effects of temperature were found in other settings even in the absence of the seasonal patterns of suicide (8). In the latter study, contrary to our findings, a nonlinear relationship between the temperature and suicides was found. An increase in the temperature above 18°C was associated with a 3.8% increase, on the average, in the daily suicide counts. In our study, a linear model provided the best fit, although given the low number of cases, a nonlinear relationship could not be detected due to limited power. However, looking at Fig. 2, one may suspect thresholds at 25°C for mean and mean apparent temperatures and at 35°C for maximum and maximum apparent temperatures. We attempted to repeat our analyses for the parts of the temperature range above the thresholds, but the number of cases was too small for the models to converge.

Most studies reported associations between the temperature and the number of suicides with no delayed effects. Muller et al. found an association between suicide counts and the temperature not only at the day of the event, but also with a lag of one day. We repeated our analyses using temperatures with lags 0–3, but did not find a significant association between suicide and lagged variables supporting the hypothesis that the effect of temperature seems to be immediate (18).

Several other studies reported positive associations between the temperature and suicide counts, but direct comparisons are difficult due to differences in the data collection methods, statistical modeling techniques, and environmental variables, which were used for adjustment. Most studies (8, 10, 12, 13), although not all (19–22), used the data at the national level ensuring adequate statistical power, although at the expense of geographical bias, i.e., the geographical differences between the place where the temperature was measured and where suicide took place. In our study, the distance between the meteorological station and the place of suicide is less than 10 km, but at the expense of statistical power. Modeling techniques vary considerably among studies. Our approach is similar to the ones widely used in studies on the associations between cardiovascular, cerebrovascular, and respiratory diseases with first modeling curvilinear relationships and comparing them with linear models (28). The main difference is that we used dichotomous “dummy” variables for months and years, while other researchers used various smoothing functions to control for secular and seasonal trends (8, 21).

Nearly all previous studies used a mean temperature as the main exposure variable (15–22). Our study seems to be among the first to evaluate the effect of not only the mean temperature, but also mean apparent, maximum, and maximum apparent temperatures. Interestingly, only apparent temperatures remained significantly associated with the outcome after adjustment for seasonal effects and other meteorological variables. Moreover, after adjustment for other factors, the effect of mean and maximum temperatures was slightly reduced, but the association with apparent temperatures strengthened. However, the coefficient for the mean temperature decreased only marginally, and the loss of significance can be attributed to limited power. Apparent and maximum apparent temperatures were used in studies on cardiovascular or respiratory diseases, but not suicides (28). The apparent temperature is an index of discomfort related to the individual’s perceived air temperature since it combines the effects of temperature and humidity and is associated with the body’s ability to cool by perspiration and evaporation during hot days. Biological mechanisms behind the observed associations between apparent temperatures, particularly the mean apparent temperature and suicide, in Astana require further research.

Mechanisms through which suicide counts are greater during the days with a higher temperature remain unknown. Several mechanisms were discussed and summarized in 3 groups: sociological, biological, and psychological (8). Kazakhstan as many other former Soviet Republics has a high per capita consumption of alcohol particularly among men, and one may speculate that more alcohol could be consumed in warmer days (8), although there is no evidence that this might be the case in
Kazakhstan. Anderson et al. showed that high temperatures may influence the level of aggressiveness and violence (33), and Page et al. suggested that this may increase the likelihood for committing suicide in these days, because in their study, the strongest association with temperature was observed for violent suicides (8). Several studies have shown alterations in the noradrenergic, dopaminergic systems and particularly serotonin systems in the pathogenesis of suicide (34). Lower serotonergic activity increases aggressive behavior and impulsiveness and thus may induce suicidal behavior (35). However, it remains unknown whether an increase in temperature is associated with a decrease in serotonin levels and requires further research.

Conclusions
The results from Astana, Kazakhstan, are in line with findings from other settings and suggest a linear relationship between daily suicide counts and mean apparent and maximum apparent temperatures with no thresholds. Factors and mechanisms behind this association warrant further research with a further going aim to develop mitigation strategies in the period of climate change.

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Statement of Conflict of Interest
The authors state no conflict of interest.

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