Temperature, Air Pollution and Fatal Unintentional Injuries in Jiangsu Province China, 2015-2017

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Abstract

Background The correlation of unintentional injury mortality to rising temperatures found in several studies could result from changes in behavior that increases exposure to hazards or risk when exposed. An increase of .82 degrees (C) daily maximum temperature in Jiangsu Province, China from 2015 through 2017 provides the opportunity to study further this phenomenon including a potential effect of air pollution. Air pollutants may cause symptoms and distractions that increase risk and avoidance behavior that reduces risk. This study examines data that allows estimates of the potential effects of temperature, precipitation and five air pollutants on injury mortality risk, each corrected statistically for the potential effects of the others.

Methods Daily data on unintentional injury deaths and exposures to temperature, precipitation and pollutants from 9 cities in Jiangsu Province, China during 2015-2017 were analyzed using logistic regression. Application of the regression equations to 2016 and 2017 data substituting 2015 values for each of the predictor variables respectively was used to estimate year-to-year changes in deaths related to changes in the risk factors.

Results Unintentional injury death risk was unrelated to temperature when temperatures were below 25 degrees (C) but increased substantially in relation to higher temperatures. The correlations mainly occurred for non-transport injuries. Fatal injury risk was higher in relation to higher concentrations of PM10, NO2 , and SO2 in certain temperature ranges but lower in relation to higher concentrations of CO in the lowest and highest temperature ranges. Lower risk was associated with O3 at low temperatures but higher risk at high temperatures. Risk was lower on weekends but higher on holidays when temperatures were moderate.

Conclusions The increase in fatal unintentional injuries from 2015 through 2017 was substantially related to the rise in average maximum daily temperature. Negative associations of certain pollutants, particularly O3, with injury risk suggests the possibility that changes in behavior to avoid those pollutants also results in lower injury risk. Most pollutants, however, are related to increased risk.

Background

From January, 2015 through 2017 the average maximum temperature measured daily among nine major cities in Jiangsu Province, China rose near 0.82 degrees (C) from 20.24 degrees in 2015 to 20.59 degrees in 2016 and 21.06 degrees in 2017. This event provided the opportunity to explore further the correlation of temperature, precipitation and air pollution to unintentional injury mortality found in previous research and the extent to which temperature increases and pollution control may affect fatal injury rates.

Temperature, precipitation and air pollution may affect risk of injury in two ways: increased or decreased exposure to potentially injurious energy or increased risk if exposed. A review of the literature on the correlation of various types of injuries to ambient temperature noted that most studies focused on the association of injuries with extreme temperatures but those that studied temperature in normal ranges also found increased injury incidence and mortality rates associated with warmer temperatures (Kampe, et al., 2016). Comparisons among U.S. states indicate increased injury mortality risk associated with warmth above normal (Parks, et al., 2020). Research on police-reported road collisions in Spain found a 2.9 percent increase during heat waves (Basagana, 2015). While peoples' attention to tasks at hand may be distracted by extreme temperatures, the more likely explanation for much of the correlation is changes in human activity based on temperature and precipitation that expose them to greater or less environmental hazards. Although certain recreational activities, such as skiing, are more frequent on colder days, many others, such as swimming and boating are warm and dry weather activities. Outdoor construction and other projects are sometimes suspended because of inclement weather. Higher temperatures increase risk for cocaine users (Marzuk, et al., 1998) but not as high as once thought (Bohnert, et al., 2010). The correlation of temperature to drug overdoses could also partly be the result of addicts being more often under the watch of families or other persons who care for them on cold or wet days that inhibit freedom of movement.

A study of road deaths among urban cities and counties in the U.S. found that reversal of the decreasing road death trend during 2015 was mainly associated with increased temperatures in that year (Robertson, 2018a). An alternative hypothesis that economic recovery from the Great Recession of 2008-2009 explained the reversal was not confirmed by comparing data among U.S. states during 2000-2016 (Robertson, 2019b). In both studies, increases in vehicle travel were found in relation to increasing temperature. Use of roads by pedestrians and bicyclists likely increased as well. Researchers noting the increase in injury deaths in Chinese cities during the latter half of the 20th Century repeated without evidence the conventional wisdom that they are mainly the result of activities associated with rapid economic growth (Zhou, et. al., 2012). From 2010 to 2015, however, injury death rates in Chinese cities were substantially lower than in the 1980s and 1990s while economic growth remained high (Ozanne-Smith and Li, 2018).

Environmental conditions other than temperature and precipitation may increase or decrease injury risk to those exposed and may also alter the probability of exposure (Sager, 2019). Air pollution is irritating to the eyes and may impair vision as well as lead to coughing spasms and breathing problems especially among the asthmatic, all of which would distract from alertness. Sleepiness has been associated with air pollutants (Heyes, A. and Zhu, 2019). Performance on verbal and mathematics tests is reduced among those exposed to higher ranges of air pollutants (Zhang, et al., 2018). Attempts to reduce exposure to pollutants may lead to more sedentary activities that lower risk of injury (Bresnahan, et al., 1997). Studies of avoidance behavior in relation to pollution find that some people stay indoors when the air has higher concentrations of pollutants, particularly when there are broadcast, print and internet warnings of hazard to health. Smog alerts in California were related to less attendance at studied outdoor venues (Neidell, 2008). School absences in Texas were found related to higher concentration of air pollutants (Curry, 2009) which could be due to both increased illness and avoidance behavior.

The purpose of this paper is to report analysis of the extent to which daily fluctuations in temperature, precipitation and air pollution are related to the risk of fatal injury during 2015 through 2017 in Jiangsu Province, China and predict the year-to-year trend in the aggregate. While the analysis of injury death rates in correlation with these factors does not specify the extent of avoidance behavior versus risk when exposed, the analysis does quantify the likely net effect of these two factors and, in the instances of negative correlations, suggests that avoidance behavior reduces the risk.

Methods

Daily injury deaths during 2015-2017 in each of 11 cities in Jiangsu Province, China were provided by the Jiangsu Provincial Center for Disease Prevention and Control. Two cities were included that did not have data for all three years. These were excluded from the analysis. The deaths were specified as occurring in transport or other circumstances. This classification was based on the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) codes V00-V99 for transport cases and W00-W99 for other unintentional cases (ICD10Data.com, 2019). As of 2013, 96.5 percent of transport deaths in China were from road injuries (Zhou, et al., 2016).

Daily meteorological data from each city, including daily maximum, minimum and average temperatures, and precipitation, were obtained from the China Meteorological Data Sharing Service System. Daily city-level air pollution data during 2015-2017 were collected from the National Air Pollution Monitoring System, whose quality was assured by the Ministry of Ecology and Environment of China. A tornado in Yancheng June 23, 2016 killed about 100 people in one day. These were excluded to prevent a skewed death distribution from a rare event. Data on the yearly population of each city was obtained from the Jiangsu Statistical Yearbooks (2015-2017).

Graphs of death rates per billion person days of exposure to each degree of maximum daily temperature were examined for evidence of nonlinearity. Graphs of frequency of daily deaths in each city were viewed to assist in the selection of a statistical model to use. The distribution of deaths per day in Nanjing is shown in Figure 1. The median is between 4 and 5 and the distribution is quasi-normal. Distributions for the other cities were similar but with higher medians. Tests of goodness of fit found that the distributions of transport deaths, other injury deaths or all injury deaths are significantly different from the Poisson distribution ($P<0.001$) thus ruling out the use of models based on the assumptions in the Poisson regresson model. The logistic regression model for aggregated binary data (SAS,2013) was used to estimate the associations, if any, between the predictor weather and pollution variables and odds of death per population.

Based on the nonlinearity of deaths in relation to temperature, shown in the results section, and the frequency distributions of deaths, separate logistic regression models were tested for temperatures below 25 degrees, 25-34 degrees and 35+ degrees (C). To reduce the skew of the distributions of precipitation, particulates (PM_{10}), sulfur dioxide (SO_2), nitrous oxide (NO_2), carbon monoxide (CO) and ozone (O_3), the square root of precipitation and the natural logarithm of the pollutants except CO were used in the analysis.

The form of the regression equation is:

Log odds of death per population = Intercept + (b_1 x temperature) + (b_2 x $\sqrt{}$ precipitation) + (b_3 x log (PM_{10})) + (b_4 x log (SO_2) + (b_5 x log (NO_2)) + (b_6 x CO) + (b_7 x log (O_3)) + (b_8 x weekend) + (b_9 x holiday)

where weekend is 1 if a Saturday or Sunday that is not indicated as a workday on the Chinese holiday calendar (timeanddate.com, 2020), and holiday is 1 if a holiday, otherwise zero. The calendar indicates a few weekend days as workdays. The weekend and holiday variables were added to adjust for the likelihood that travel is different and workplace exposures are reduced on non-workday weekend days and holidays.

To estimate the annual number and percent change in injury deaths related to changes in each of the predictor variables, the regression equations were used to estimate deaths that would have occurred if each predictor in 2016 and 2017 had remained the same as in 2015 during the same days of the year in each city. This was accomplished by substituting in the regression equations the value of the variables in 2015 on the same day of the year during 2016 and 2017 for each variable while allowing the others to take their 2016 or 2017 values. This procedure produces the number of deaths on each day in 2016 and 2017 that would have been expected if the variable did not change from the 2015 value. The expected number of deaths on a given day is 1/(1+EXP(-X)) times the population where X is the regression equation (Selvin, 1991), The expected numbers for each of the days are added to get the expected injury deaths expected in 2016 and 2017.

Results

Table 1 presents the injury deaths per million inhabitants per year by external cause (transport vs. other) and in total for each city. The data show a remarkable variation among the 9 cities in injury mortality per population. In many instances, Nanjing's rate is less than half that of 8 of the 9 other cities. The three year upward trend in total injury death rates in several cities is mainly due to unintentional injuries other than those experienced in transport.

Table 1. Annual Transport and Other Fatal Unintentional Injuries Per Million Inhabitants Among Cities in Jiangsu Province, China, 2015-2017

City	Transport			Other Injury			Total		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Nanjing	81	79	80	120	147	138	202	226	218
Wuxi	115	115	112	273	315	314	387	430	426
Xuzhou	228	224	221	183	197	231	411	421	452
Changzhou	150	168	170	246	295	301	395	463	471
Nantong	187	214	232	274	365	380	461	579	612
Lianyungang	212	212	227	295	320	338	507	532	565
Huaian	210	196	189	218	241	244	428	437	433
Yancheng	206	218	261	199	289	282	404	508	543
Suqian	162	179	183	137	151	180	299	330	364

Totals are not always the sum of transport and other deaths because of rounding.

Table 2. Means and Standard Deviations of the Transformed Predictor Variables By City in Jiangsu Province, China, 2015-2017

	Temperature		Precipitation		PM10		SO2		NO2		O3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nanjing	21.2	9.1	1.3	2.7	4	0.5	2.5	0.4	3.7	0.5	4.6	0.4
Wuxi	21.5	9.1	0.4	2.6	4.4	0.5	2.9	0.5	3.4	0.5	4.6	0.5
Xuzhou	20.5	9.6	0.9	1.9	4.2	0.6	2.9	0.5	3.3	0.4	4.5	0.4
Changzhou	21.4	9.2	1.5	2.6	4.3	0.5	2.8	0.5	3.7	0.4	4.5	0.5
Nantong	20.9	8.9	1.4	2.6	4.2	0.5	2.7	0.4	3.8	0.4	4.5	0.5
Lianyungang	19.6	9.4	0.8	1.9	4.2	0.5	3.1	0.5	3.4	0.6	4.6	0.4
Huaian	20.3	9.2	1.1	2.2	4.4	0.5	2.8	0.6	3.3	0.5	4.6	0.4
Yancheng	20	9.1	1.2	2.4	4.4	0.6	2.7	0.5	3.1	0.6	4.6	0.4
Suqian	20.4	9.3	0.9	2.1	4.2	0.5	2.7	0.5	3.1	0.5	4.6	0.3

Table 2 gives the means and standard deviations of the weather and pollution variables by city. Nanjing has somewhat lower average particulates and sulphur dioxide than the averages for the other cities but is not consistently higher or lower on the other variables.

Figure 2 shows the transport related deaths per billion person days of exposure to specific maximum temperatures. Each data point is the sum of the deaths on the days that the maximum temperature reached the indicated temperature divided by the sum of the approximate number of people residing in a given city each day the temperature reached the indicated temperature adjusted to billions of person days. A maximum daily temperature at freezing or below in Jiangsu Province is rare. Person days when the maximum temperature was zero (C) or less were two tenths of one percent of the total so deaths on those days and the person years are included in the zero category in the graphs. There does not appear to an association of transport death risk with maximum temperatures other than a dip at the highest temperatures. In contrast, Figure 3 indicates that unintentional injuries other than in transport declined slightly up to about 25 degrees maximum daily temperature, accelerated upward at higher temperatures and did so extraordinarily at temperatures above 34 degrees.

The logistic regression equations for transport deaths and other unintentional deaths separately did not accurately predict actual total deaths for each in a given year so they could not be used for the purpose of estimation of the deaths attributable to changes in the variables. The prediction of the equation for total unintentional injury deaths in 2016 was higher by 3.5 percent (25428 expected vs. 24,567 actual) in 2016 but very similar in 2017 (25737 expected vs. 25666 actual). The odds ratios from the exponentiated regression coefficients are presented in Table 3.

Table 3. Exponentiated Logistic Regression Coefficients (odds ratios) and 95 Percent Confidence Intervals (CI): Unintentional Injury Fatalities Per Population Per Day

Temperature	Cool (< 25)		Moderate (25-34)		Hot (> 34)	
	Odds ratio	95% CI	Odds ratio	95% CI	Odds Ratio	95% CI
Temperature	1.00	(0.999, 1.002)	1.02	(1.015, 1.025)	1.34	(1.301, 1.378)
Precipitation	0.99	(0.988, 0.999)	1.00	(0.998, 1.009)	1.01	(0.991, 1.027)
Log(PM10)	1.05	(1.018, 1.082)	1.02	(0.979, 1.068)	1.33	(0.897, 1.526)
Log(SO2)	1.08	(1.0533, 1.111)	1.12	(1.088, 1.166)	1.00	(0.937, 1.065)

Log(NO2)	1.01	(0.991, 1.039)	0.97	(0.944, 1.002)	1.01	(0.929, 1.097)
CO	0.95	(0.905, 0.989)	0.99	(0.900, 1.042)	0.73	(0.584, 0.908)
Log(O3)	0.86	(0.836, 0.887)	0.96	(0.920, 1.009)	1.25	(1.101, 1.423)
Weekend	0.97	(0.951, 1.007)	0.96	(0.930, 0.985)	0.96	(0.903, 1.020)
Holiday	0.99	(0.095, 1.025)	1.05	(1.007, 1.104)	0.66	(0.545, 0.810)

Corrected for the estimated effects of other factors, when temperatures are less than 25 degrees, risk of fatal injury is unrelated to temperature but increases in relation to degrees of moderate and high temperatures. Precipitation has no apparent effect. The association of pollutants and injury risk varies depending on temperature range, evidence of what is called "effect modification" also found in research on non-injury mortality in relation to temperature and air pollutants (Chen, et al., 2018). Higher risk is associated with higher PM_{10} at cool but not moderate or hot temperatures. SO_2 is related to increased risk at cool and moderate but not hot temperatures. NO_2 is related to higher risk only at cool temperatures. Risk decreases with higher CO at cool and hot temperatures and O_3 when temperatures are cool but that correlation reverses at hot temperatures. Risk is lower on non-workday weekends although significantly so only at moderate temperatures. Holidays are not associated with risk at cool temperatures but risk is higher on holidays when temperatures are moderate and lower when temperatures are hot.

The substantially lower injury death rate in Nanjing compared to the other cities may be partly the result of lower average concentration in its atmosphere of particulates and sulphur dioxide that are predictive of higher injury risk on a daily basis. A regression that added Nanjing as a separate predictor variable did not produce a good fit to the distribution of summed predicted versus actual injury deaths per year.

Of concern in use of regression coefficients is the degree to which the predictor variables are correlated. Excessive collinearity distorts the coefficients. While there is no consensus among statisticians regarding the threshold for such concern, if the squared correlation coefficients among the predictors exceed 0.60, the regression coefficients are likely to be unreliable (Allison, 2012). The squared OLS correlation coefficients among the weather and pollution variables are displayed in Table 4. Although the pollution variables are intercorrelated in many cases, none of the squared coefficients exceed 0.50. O_3 is a greenhouse gas that influences temperature but it is only moderately correlated with temperature at cool temperatures in this study. The correlation of the weekend and holiday variables with the others (not shown) was trivial.

Table 4. Squared OLS Correlation Coefficients Among Transformed Daily Weather and Pollution Predictor Variables At Cool, Moderate and Hot Temperatures, Jiangsu Province, China. 2015-2017

[Please see the supplementary files section to view the table.]

Table 5. Difference in Predicted Unintentional Injury Deaths in 2016-2017 if Predictors Had Remained at 2015 Levels While Others Changed, Jiangsu Province, China

	2016			2017		
	If 2015	Difference	%	If 2015	Difference	%
Temperature	22764	2664	10.5	22513	3224	12.5
Precipitation	25491	-64	0.0	25783	-47	0.0
PM_{10}	24144	346	1.4	23715	370	1.4
SO_2	25195	233	0.1	24244	-182	-0.1
NO_2	25289	138	0.1	25571	166	0.1
CO	25590	-163	-0.1	25436	-126	0.0
O_3	27442	-2015	-8.0	26407	-2245	-9.0

Table 5 shows the difference in total unintentional injury fatalities attributable to changes of the predictor variables in time. Rising temperatures in 2016 and 2017 were associated with a 10.5 percent increase in deaths during 2016 and a 12.5 percent increase during 2017 from what would have been expected if temperatures had remained at 2015 levels while the other variables changed. The changes in actual versus expected numbers of deaths related to changes in pollutants were marginal with the exception of O_3 which was associated with 8 percent fewer deaths in 2016 and 9 percent fewer than expected in 2017.

Discussion

These results are mostly consistent with previous studies showing increased risk of unintentional injury mortality as temperatures rise, particularly when maximum daily temperatures are above 25 degrees (C). A major exception in Jiangsu Province is that the risk of death in relation to rising temperatures is mainly confined to people engaged in activities other than transport. While the results are associations with the usual concern that they may not represent causation, the cited literature in the introduction suggests that people adjust their activities to pollution and it is common knowledge that they do so in response to weather. That said, the lack of correlation of precipitation with odds of injury mortality is surprising. The available data are inadequate to examine the possibility that avoidance behavior during rainy days offsets the higher risk of vehicle-related fatalities in wet weather.

Why would warmer temperatures be related to transport casualties in Spain and fatalities in U.S. cities much more strongly than in cities in Jiangsu Province, China? One possible reason is the difference in cultures regarding vehicle use. U.S. road deaths are substantially higher on Friday and weekend days than on other weekdays (Bureau of Transportation Statistics, 2019). In contrast, transport deaths in Jiangsu Province are three percent less on Saturday and six percent less on Sunday than on the average weekday. This suggests that vehicles are used less for discretionary travel in Jiangsu Province. Also, a substantial proportion of the correlation of temperature and road death risk in the U.S. is due to the apparent lack of use of bicycles and motorcycles at subfreezing temperatures (Robertson, 2019b). Such temperatures are extremely rare during daytime in Jiangsu Province.

Unfortunately, we have no data on kilometers travelled per vehicle in China or pedestrian volume and bicycle use in the U.S. and Chinese cities. If there were major road injury prevention efforts during 2015-2017 in Jiangsu Province, they could have offset the effect of temperature. According to one report, China has made little use of “traffic calming” road designs that have reduced fatality rates in other countries but does have engineering standards for vehicle crashworthiness, child safety seats and school bus seats (Fayard, 2017). A seat belt use law was imposed throughout China in May, 2004. A study if belt use observed in traffic in Nanjing soon after the law indicated about 67 percent use by drivers and 19 percent by front seat passengers (Routley, et al., 2007). During 2005-2007, belt use by drivers in Nanjing had declined to 39 percent and that of front seat passengers to 3 percent leaving substantial room for improvement (Routley, et al., 2008). A study of road deaths in Jiangsu Province during 2012 found that more than half the deaths occurred to pedestrians and that the risk of pedestrian deaths per population increased dramatically with age (Ding, Y. et al. , 2017) but the age distribution of the population would not have changed enough in three years to affect the results reported here. A search of Chinese laws and regulations aimed at childhood injury prevention relative to laws and regulations recommended by the United Nations Children’s Fund, the World Health Organization or the European Child Safety Alliance found that 10 of 27 were not found in Chinese statutes and regulations (Li, et al., 2015).

The results regarding the possible effects of pollution are complicated but overall suggest that whatever avoidance behavior may reduce injury risk, the net effect of more pollution is increased injury risk. The major exception is increased CO and O_3 which appears to affect avoidance behavior at certain temperatures. More research is needed on observed behavior in relation to concentration of pollutants at different temperatures.

Conclusions

Warming temperatures are associated with increased risk of unintentional injury mortality. Burning fossil fuels that contribute to warming continues to grow, outpacing the adoption of sustainable energy sources (United Nations Environment Programme, 2019). Although the association of warming and injury mortality varies from country to country depending on the temperature ranges experienced, cultural factors and behavioral responses to temperatures and air pollution, without further efforts at prevention based on data regarding the types of injuries affected, climate warming and possibly some forms of pollution control will likely contribute to an upward trend in injury mortality.

Declarations

Ethics approval and consent to participate: The data are from statistical resources and no contact with individuals occurred.

Consent for publication: The authors agree on submission for publication.

Availability of data and materials: Jiangsu CDC does not permit posting of daily mortality data for public access.

Competing interests: The authors have no financial or other interests that would be altered by publication of this study.

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Authors' contributions: Lian Zhou and Kai Chen assembled the data. Leon Robertson analyzed the data and drafted the manuscript. Kai Chen contributed analysis, revisions, and edited the manuscript.

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Figures

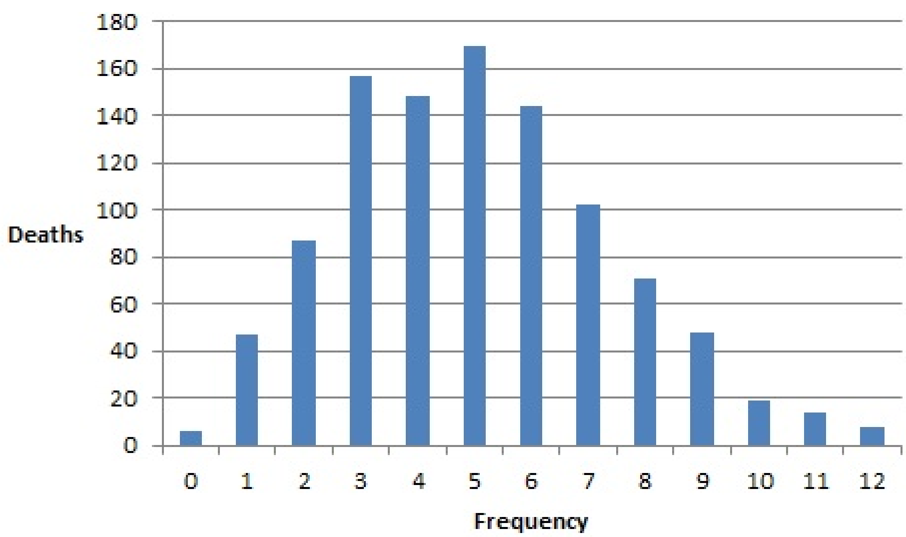

Figure 1

Frequency Distribution of Daily Injury Deaths During 2015-2017 in Nanjing, China

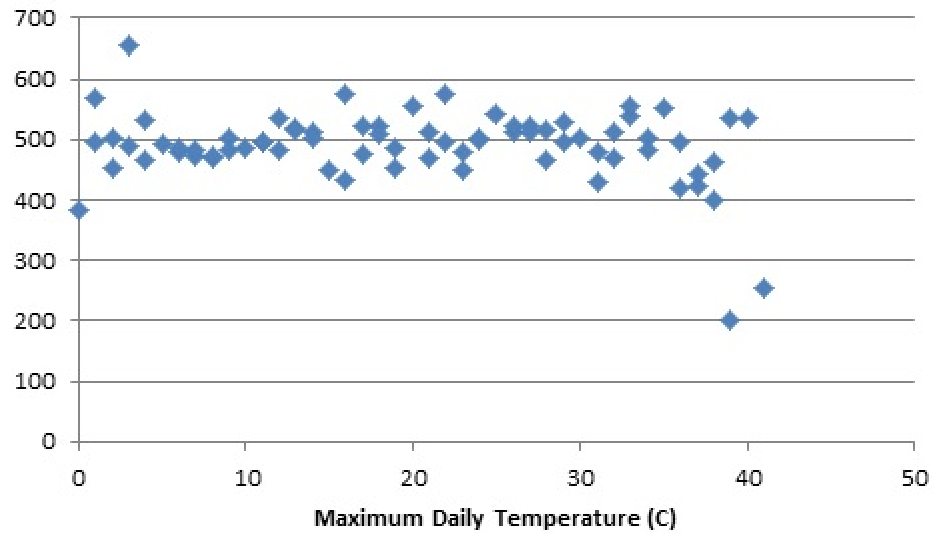

Figure 2

Maximum Daily Temperature (C) and Transport Deaths Per Billion Person Days of Exposure, Jiangsu Province, China, 2015-2017.

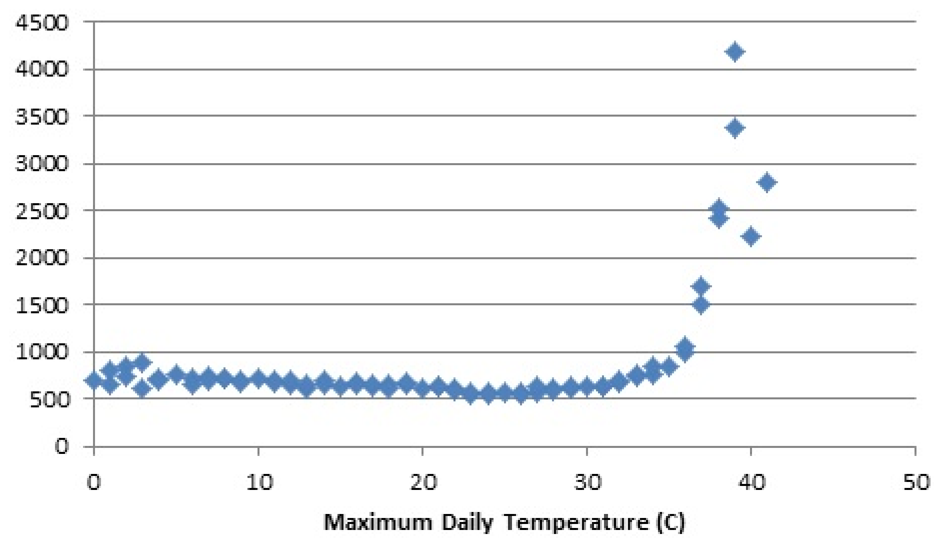

Figure 3

Maximum Daily Temperature (C) and Unintentional Injury Deaths Other Than Transport Per Billion Person Days of Exposure, Jiangsu Province, China, 2015-2017

Supplementary Files

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- Table4.docx