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Research article

Association between provincial sunshine duration and mortality rates in China: Panel data study ☆

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ABSTRACT

Background: mortality rates are usually influenced by the variations of environmental factors. However, there are few studies on the impact of sunlight duration induced mortality. In this study, we examine provincial level associations between the sunshine duration and crude mortality rates.
Methods: we use China mortality data from the National Bureau of Statistics of China combined with China census data and data from the China Meteorological Data Service Centre. Annual mortality rates for 31 provinces, autonomous regions, and municipalities in China from 2005 to 19. Data are analyzed at the provincial level by using panel regression methods. The main outcome measures are the mortality rates associated with average daily sunshine duration. Then we perform a series of sentimental analyses.
Results: the average daily sunshine duration ratio cubed is positively associated with provincial level mortality rates ($\beta = 11.509$, 95% confidence interval 1.869 to 21.148). According to this estimate, increasing 2.895 h of additional daily sunshine is associated with an estimated 1.15% increase in the crude mortality rates. A series of sensitivity analyses show a consistent pattern of associations between average daily sunshine duration ratio cubed and mortality rates.
Conclusions: more sunshine duration is associated with increased mortality rates. While the associations documented cannot be assumed to be causal, they suggest a potential association between increased sunshine duration and increased mortality rates.

1. Introduction

Previous studies have reported the association between sunshine duration and different types of mortality, but the associations are inconsistent or even reversed [1,2]. To our best knowledge, sunshine duration impacts humans in many ways. (1) Sun exposure. We know that sun exposure is positively associated with sunshine duration, and some studies have shown that sunshine duration is associated with mortality [1,2]. (2) Circadian rhythms. Photoperiod is not calculated according to sunshine hours, but generally, it is positively associated with sunshine duration. Day length enhances or suppresses diverse aspects of immune function, giving rise to mortality [3]. The daily light-dark cycle also entrains circadian rhythms in immunity [3]. Photoperiod is positively associated with influenza mortality and has a significant impact on maternal health [4]. (3) Psychological factors. Sunlight may produce positive

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mental activity, which helps maintain the homeostasis of the internal environment [5,6]. But for patients with mental diseases or psychological disorders, the results may be different [7]. Therefore, from the perspective of the interaction between sunshine hours and the human body, it is reasonable that there are differences between sunshine hours and different types of mortality. It is also important to investigate the association between sunshine duration and mortality rates.

We perform this analysis to investigate the association between sunlight duration and crude mortality in China. Fig. 1 shows mortality rates at the provincial level under examination in 2005, 2009, 2013, and 2017. And Fig. 2 shows the annual average daily sunshine duration between 2005 and 2019. Our hypothesis is that sunshine duration is associated with mortality through sunshine exposure, circadian rhythms, and psychological factors.

2. Materials and methods

We investigate the association between sunshine duration and mortality for the 31 provinces, autonomous regions, and municipalities in China. Data on daily sunshine duration, mortality, demographics, and weather conditions are all available for these provinces.

The mortality data are from the National Bureau of Statistics of China. Since 2005, the regional population data are based on the resident population, and considering the impact of COVID-19, we only collected data between 2005 and 2019. The mortality data released by the National Bureau of Statistics did not take population mobility into account. Therefore, considering the population mobility rates of counties and cities were higher than those of provinces, autonomous regions, or municipalities, we investigate the association between sunshine duration and mortality at the provincial level.

Daily sunshine duration data are collected from China Meteorological Data Service Centre, which reports the daily, monthly, and annual sunshine duration in all the Chinese provinces. Sunshine duration is a climatological indicator, measuring the duration of sunshine in a given period (usually, a day or a year) for a given location on Earth. Considering sunshine duration impacts humans in many ways, we define daily sunshine duration rate as the proportion of daily sunshine duration, then calculate the average daily sunshine duration rate according to daily sunshine duration in each year.

Crude Mortality refers to the ratio of the number of deaths to the average population during a year. Mortality data comes from the National Bureau of Statistics of China. The national population census is conducted in the year ending with 0; the national 1% population sample survey is conducted in the year ending with 5; sample surveys on population changes are conducted in the rest of the years which cover about 1 per thousand of the total population of the country. The sample survey on population change takes the whole nation as the population and each province, autonomous region, or municipality as sub-populations, and the stratified multistage systematic sampling scheme is used.

Maternal Mortality come form “China Health Statistical Yearbook” compiled by the National Health Commission. Maternal Mortality Rate refers to number of maternal deaths per 100,000 maternal. It generally refers to maternal mortality from the start of pregnancy to 42 days after parturition, due to pregnancy or any treatment of pregnancy. However, accidental deaths are not included. According to internationally accepted approach, the live births are used to represent the total number of maternity.

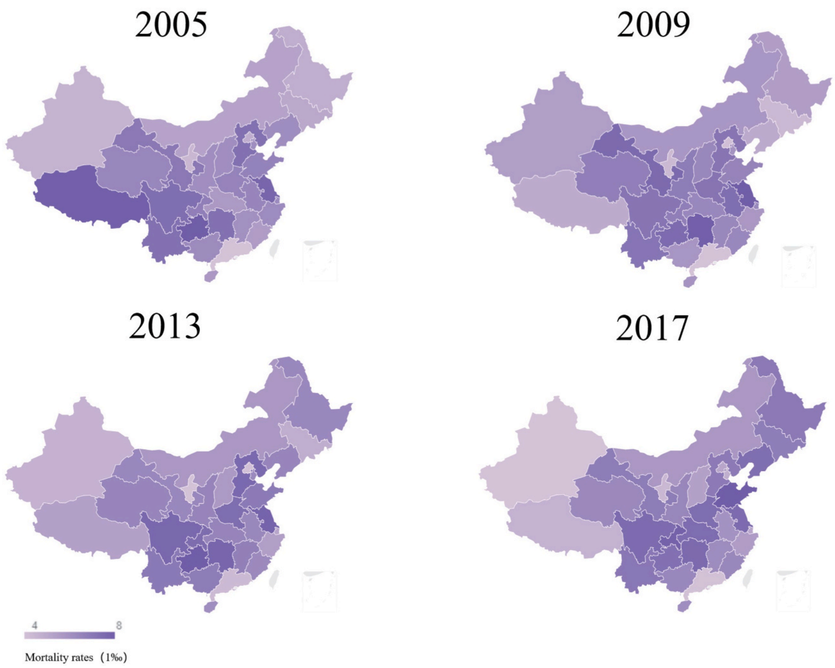

Fig. 1. Mortality rates at the provincial level under examination in 2005, 2009, 2013, and 2017.

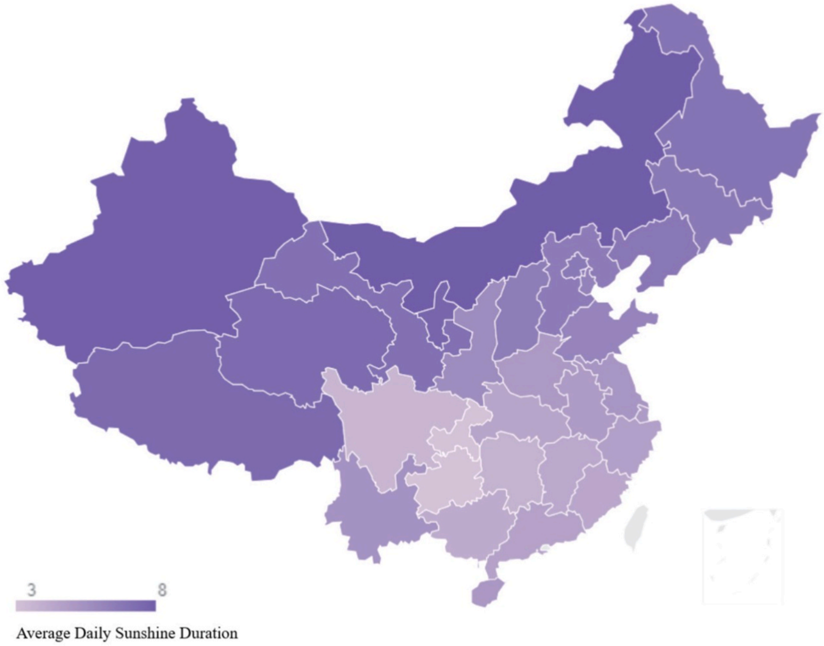

Fig. 2. The annual average daily sunshine duration between 2005 and 2019.

We obtain demographics and gross domestic product (GDP) data between 2005 and 2019 from the National Bureau of Statistics of China. These variables include gender ratio, age composition, illiterate population aged 15 and over [8], population, and per capita GDP. Additionally, we also obtain grain output per hectare. Grain output refers to the total output of grains produced within a calendar year. It includes summer crops, early rice, and autumn crops by harvest seasons. Considering the link between sunshine hours and grain output per hectare, we set grain output per hectare as an instrumental variable.

We included average daily temperature and fine particulate matter (PM2.5) concentration as control variables in the analysis. Because some literature has reported the association between the two variables and mortality, sunshine hours are also correlated with the two variables [9–11]. Average daily temperature data are also collected from China Meteorological Data Service Centre, which reports the daily, monthly, and annual sunshine duration in all the Chinese provinces. Then we extract the monthly average PM2.5 concentration of Chinese cities from 2005 to 2019 by annual global satellite-based estimates of PM2.5 data [12].

In the statistical analysis section, we used two-way fixed effects panel-data models to estimate the provincial level association of average daily sunshine duration rate with mortality for 2005–19. Our models specify fixed effects at the provincial level and year according to previous studies [13]. We first controlled for demographic characteristics and the log-transformed GDP per capita, then for daily average temperature and daily average PM2.5 concentration. In the regression analysis, we lag the average daily sunshine duration rate, average daily PM2.5 concentration, and daily average temperature by one year. Across all models, Driscoll Kraay, Rogers, and White standard errors were reported to account for cross-sectional independence, autocorrelation, and heteroskedasticity. The level of significance was 0.05. Statistical analyses were performed with Stata version 16.0.

Then we perform several sensitivity analyses, mainly for heterogeneity and endogeneity. First, to assess the heterogeneous effects and control potential climate confounding factors of sunshine duration rate on mortality, we divide the full sample into three sub-groups, North China, South China, and other regions (Northwest China and Qinghai-Tibet Region), and re-do the analysis. Second, to test and resolve endogeneity (Mainly refers to unobserved confounding factors and measurement error), we use two methods, one is the instrumental variable method, and the other is that we use two year lag of sunshine duration rate to-do the analysis. Third, to assess the seasonal effects, we examine the regression association between different seasonal average daily sunshine duration rates and mortality by dominance analysis. Dominance analysis is a brute force method where sub-models reflecting all possible combinations of the independent variables being included or excluded are estimated from the data and the fit statistic associated with each sub-model is collected [14]. It can rank the relative contribution of each independent variable to prediction. Four, due to the disparity in area, the four municipalities may not be comparable with the other 27 provinces and autonomous regions. Therefore, we deleted data from four municipalities and analyzed it with data from the remaining 27 provinces and autonomous regions. Finally, we used the maternal mortality rate to replace the crude mortality rate and re-do the analysis.

3. Results

3.1. The sunshine duration and mortality rates

Table 1 summarizes the within, between, and overall statistical indicators. The average daily sunshine duration is 5.68 h overall.

Table 2 presents estimated effects of average daily sunshine duration rate cubed (the main variable) on the following year's mortality. We find that the main variable is statistically significant and positively related to mortality in all three specifications. In column (1), the estimated main variable coefficient is 11.762 (1.386–22.138) and statistically significant at the 5% level. In column (2), we control the daily average temperature and daily average PM2.5, and find statistically significant at the 5% level. In the most restrictive specification, column (3), where province fixed effects, year fixed effects, demographics, per capita GDP, daily average temperature, and daily average PM2.5 were included, then the estimated coefficient is 11.509 (95% CI, 1.869 to 21.148) and statistically significant at the 5% level. According to column (3), increasing the main variable from 0.1 to 0.2 (approximately equal to 2.895 h of additional daily sunshine) is associated with a 1.15% increase (100% × 11.509 × 0.1 = 1.1509%) in mortality.

3.2. Sensitivity analysis

According to the Chinese Geographical Division, we divided the 31 provinces, autonomous regions and municipalities into three subgroups, North China, South China, and other regions (Northwest China and Qinghai-Tibet Region). North China and South China by the Huai River and Qin Mountains, which approximates the 0°CJanuary isotherm and the 800 mm (31 in) isohyet in China [13]. Therefore, there are obvious differences in topography, climate and river flow between northern China and southern China.

Table 2 column (4)–(6) shows the regression results of the two-way fixed effects model separately for northern provinces (column (4)), southern provinces (column (5)), and other regions (column (6)). It suggests that the increased mortality associated with the main variable mainly occurred in Northern China ($P < 0.001$). In northern cities, a 2.895 h change in the daily average sunshine duration is associated with a change in the mortality rate by 2.836% (95% CI, 1.322 to 4.445) per 1000 people, and statistically significant at the 0.1% level. In Northwest China and Qinghai-Tibet Region, a 2.895 h change in the daily average sunshine duration is associated with a change in the mortality rate by 4.795% (95% CI, 1.918 to 7.567) per 1000 people and statistically significant at the 5% level, but the region includes only four provinces and autonomous. Interestingly, the corresponding estimates for Southern China are not statistically significant.

We use grain output as instrumental variable and find no endogeneity (Hausmann endogeneity test, $P = 0.54$). Then we lag the

Table 1
The mortality rate and its explanatory variables within, between, and overall statistical indicators.

Variable		Mean	Std. Dev.	Min	Max	Observations
Mortality	overall	6.00	0.74	4.21	7.57	N = 465
	between		0.67	4.52	7.02	n = 31
	within		0.35	4.88	7.89	T = 15
ASSD	overall	5.68	1.35	2.70	8.15	N = 465
	between		1.35	3.23	7.91	n = 31
	within		0.27	4.89	6.66	T = 15
PM2.5	overall	40.69	15.69	4.66	85.69	N = 465
	between		14.94	5.44	73.07	n = 31
	within		5.44	18.64	53.30	T = 15
Temp	overall	13.57	5.40	2.58	25.45	N = 465
	between		5.47	3.38	24.41	n = 31
	within		0.43	12.39	14.64	T = 15
SexR	overall	104.38	3.97	94.65	123.17	N = 465
	between		2.52	99.77	110.75	n = 31
	within		3.09	94.73	121.77	T = 15
Age 15	overall	0.17	0.04	0.08	0.28	N = 465
	between		0.04	0.09	0.24	n = 31
	within		0.01	0.13	0.22	T = 15
Age 65	overall	0.10	0.02	0.05	0.17	N = 465
	between		0.02	0.06	0.13	n = 31
	within		0.01	0.05	0.14	T = 15
pGDP	overall	39920.41	25998.58	5218.00	161776.00	N = 465
	between		19368.21	20363.00	96963.60	n = 31
	within		17666.84	−9861.19	104732.80	T = 15
edu	overall	0.07	0.07	0.01	0.46	N = 465
	between		0.06	0.02	0.38	n = 31
	within		0.02	−0.01	0.17	T = 15
pop	overall	4361.44	2801.59	280.00	12489.00	N = 465
	between		2833.83	316.13	10925.33	n = 31

ASSD, average daily sunshine hours. PM2.5, average daily PM2.5 concentrations(micrograms per cubic meter). Temp, average daily temperature (degree centigrade). SexR, sex ratio(Female = 100). Age 15, aged 0–14. Age 65, aged 65 and over. pGDP, per capita Gross Domestic Product(100 million yuan). edu, Illiterate population aged 15 and over. pop,population(10000 persons).

Table 2
The association between average daily sunshine duration rate cubed and mortality.

	(1)	(2)	(3)	(4)	(5)	(6)
ASSD cubed	11.762** (2.23)	11.928** (2.14)	11.509** (2.35)	28.836*** (3.65)	−9.094 (−1.47)	44.795*** (2.96)
PM2.5	NO	YES	YES	YES	YES	YES
Temp	NO	YES	YES	YES	YES	YES
Demographics	NO	NO	YES	YES	YES	YES
pGDP	NO	NO	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	434	434	434	168	210	58
R^2	0.14	0.14	0.35	0.58	0.45	0.68

ASSD, average daily sunshine hours. PM2.5, average daily PM2.5 concentrations(micrograms per cubic meter). Temp, average daily temperature (degree centigrade). pGDP, per capita Gross Domestic Product(100 million yuan).
t statistics in parentheses.
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

main variable by two year, find a consistent positive association with $P < 0.05$ (Table A1).

We use four seasonal sunshine duration instead of annual sunshine duration to generate regression models and find that the impact of the main variable on mortality is different in different seasons (Table A2 column (1)–(3)). We find that, with or without controls, the main variables in autumn and summer were consistently higher than those in spring and winter, suggesting that autumn and summer daily average sunshine duration rate had a greater impact on mortality in the following year. We then analyze seasonal effects in the south and north of China (Table A2 column (4)–(5)). In southern China, the main variable in autumn and summer still had a greater impact on the mortality of the following year, while in northern China, the main variable in the autumn and winter had a greater impact. Overall, the main variable in autumn has a greater impact on mortality in the following year.

After removing the four municipalities, the regression results also show a significant positive association between the main variable and mortality (Table A3).

Finally, we also find that the main variable is statistically significantly and positively related to maternal mortality rate. This is consistent with our main conclusions (Table A4).

4. Discussion

From a mathematical point of view, mortality is associated with average daily sunshine duration rate cubed, so it is associated with average daily sunshine duration rate. The crude mortality rate includes all the deaths, some of which may have no significant association or positive association with sunshine hours rate, or the relationship is complicated. Therefore, it is reasonable that the average daily sunshine hours cubed is associated with mortality.

Our findings suggest that average daily sunshine duration rate is associated with an increase in crude mortality in China, and that this association also applies to maternal mortality. The association also held after controlling for average daily temperature, average daily PM2.5, GDP per capita, and some demographic characteristics.

Our study has several advantages. First of all, panel regression analysis combines the advantages of time series analysis and cross-sectional analysis. Second, according to the report of China National Bureau of Statistics, population mobility is not taken into account when calculating mortality rates. Therefore, relative to counties or other administrative regions, population mobility is the smallest at the provincial level. Therefore, in order to express the mortality rate more accurately, we took the provincial mortality rate as the research object. Third, the study focuses on the often-neglected factor of sunshine duration, analyzes its potential correlation with mortality rates, and provides new ideas and evidence for public health policies. Fourth, despite controlling for a series of confounding factors, our study still found a significant correlation between sunshine duration and mortality rates, indicating that this relationship does not only rely on the influence of other factors, and thus the study results are relatively reliable. Fifth, our study's methods and results can be useful for other regions and countries to consider when exploring the correlation between sunshine duration and mortality rates, and for the development of public health policies. Moreover, we assessed sensitivity using a variety of methods, and the results were consistent with previous studies.

For the ecological study has also several limitations. First, the sunshine duration rate data is reported at the city level, whereas mortality data is at the provincial level, so the sunshine duration data is averaged across all the monitoring stations within a province. Therefore, our estimates of mortality may have different bias for different provinces, autonomous regions, and municipalities. Second, PM2.5 concentration has been shown to be related with sunshine hours, but the PM2.5 concentration we used is a set of estimates [12]. Third, the crude mortality rate provided by the National Bureau of Statistics may be overstated or understated due to differences in population mobility and population density in different provinces, autonomous regions and municipalities. Fourth, the sample survey methods used to describe mortality and demographic characteristics vary from year to year, most of which are one-thousandth samples. Fourth, this study focused on some macro-level factors affecting mortality, and did not consider micro-level and individual/family level factors. Additionally some potential confounding variables and unknown errors cannot be included in our analysis. Overall, our panel regression analysis may be biased in estimating mortality coefficients, but the positive association between average daily sunshine duration rate and mortality should be correct.

There are several similar studies. An ecological regression analysis showed a negative correlation between the number of hours of sunlight and coronary heart disease mortality in the UK, but the study was based on a sample of patients on hospital wards [15]. A time series study analyzed the association between hospitalization for acute myocardial infarction and summer sunshine hours in Beijing, China, and found a significant U-shaped association between sunshine duration and acute myocardial infarction incidence, and both short and long daylight hours may increase the risk of hospitalization for acute myocardial infarction [16]. A retrospective study of a 40-year suicide data set in Austria found a significant correlation between the number of hours of daily sunlight and the frequency of suicide over a short period of time, after adjusting for seasonal effects. The study also suggested that the chronic effects of sunshine hours were beneficial in reducing suicide rates [17]. In addition to reflecting an association between short-term exposure hours and mortality, these studies also point to a chronic effect of sunshine hours on mortality [16,17].

The chronic effect of sunshine hours on mortality may be manifested first in disease incidence. Sunlight affects people's emotions and appearance. A global study showed that the annual sunshine hours were significantly negatively correlated with the incidence of alcoholic cirrhosis. This indicates that the impact of sunshine hours on mortality is also reflected in human behaviors, such as diet and exercise [5,6]. An ecological study on the incidence of scarlet fever in Mainland China from 2004 to 17. The incidence of scarlet fever increased by 1.41% for every 10 h of sunshine per month. But the regression controlled for only three meteorological factors [18]. Additionally, sunshine duration is also associated with the incidence of hand, foot and mouth disease [19–21], COVID-19 [21–24], and acute urinary stones [25]. Generally, there is a positive association between disease incidence and mortality, so from the perspective of disease incidence, the chronic influence of sunshine duration may be an important and easily overlooked factor.

Considering the limitations of ecological research, our research results need to be further refined. Future studies will need to investigate the relationship between sunshine hours and mortality using longitudinal follow-up data. At the same time, sunshine duration is associated with photoperiod, and future studies need to distinguish the difference between the two in terms of mortality.

5. Conclusions

Our results suggest that average annual sunshine duration is associated with an increase in crude mortality, and average daily sunshine hours in summer have the greatest effect. The findings are important because policy makers may develop relevant preventive measures to reduce mortality. Clinicians may also make personalized recommendations for patients based on sunshine duration.

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Author contribution statement

Weidong Wang: Conceived and designed the experiments; Wrote the paper.

Yu Fu: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e15862.

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