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The Hidden Cost of Pollen: Empirical Analysis of the Association Between Pollen Exposure and Mental Health

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The Hidden Cost of Pollen: Empirical Analysis of the Association Between Pollen Exposure and Mental Health

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Abstract

This study examines the association between pollen exposure and monthly suicide mortality in Japan. It combines prefecture-level daily pollen counts with monthly suicide mortality data for 2009-2020 and estimates panel models with prefecture and year-by-month fixed effects. The estimates indicate that additional high-pollen days are positively associated with overall suicide mortality. The association is statistically significant in several specifications for women, although the female-specific estimates are sensitive to model specification and the difference between women and men is not directly tested. Results from the pollen-season sample support the main overall association. Because the estimated relationship is not monotonic across pollen categories and the age-specific analysis entails multiple testing, the heterogeneity and mechanism results should be viewed as exploratory.

Keywords: pollen exposure; suicide mortality; mental health; seasonal allergies; Japan

JEL Classification: I12, I18, Q51, Q54

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1. Introduction

Pollen allergy, a common chronic condition, has become a significant public health issue in Japan, primarily due to cedar and cypress pollen. These allergens, a consequence of extensive post-war afforestation policies, have led to a substantial increase in the prevalence of seasonal allergic rhinitis, which now affects over 40% of the population. In response, the Japanese government has implemented measures such as logging planted cedar forests and replanting these areas with lower-pollen cedar seedlings. To evaluate the necessity and effectiveness of these measures, it is critical to understand the actual social and economic costs of pollen allergy.

The effects of pollen allergy extend beyond physical symptoms, affecting economic burdens, human behaviour, and cognitive functions. Previous studies have demonstrated increased medical costs (Sheffield, 2011), declines in academic performance (Marcotte, 2017), decreased consumption (Kuroda, 2022), and a rise in traffic accidents (Akesaka & Shigeoka, 2024). These economic burdens, impaired cognitive function and losses of productivity, combined with the physical stress of allergic symptoms, collectively lower quality of life and negatively impact mental health.

While clinical studies have explored the association between allergies and mental health, there is limited economic research on this topic. This study addresses this gap by investigating the relationship between pollen exposure and suicide mortality in Japan. By combining daily pollen counts with monthly suicide data from 2009 to 2020, this study provides quantitative evidence that an increase in high-pollen days is associated with an increase in suicide mortality. The estimated association is statistically significant in several specifications for women but not for men; however, the difference between the male and female estimates is not directly tested.

The remainder of the paper is organized as follows: Section 2 describes the background and literature review, Section 3 details the data, Section 4 presents the empirical model, Section 5 reports the main results, and Section 6 presents the discussion and conclusions.

2. Background and literature review

Pollen and seasonal allergies

Seasonal allergic rhinitis (SAR), often called "Pollen Allergy," is an allergic reaction to airborne allergens, typically pollen from trees, grasses, or weeds. When an individual with this condition is exposed to these allergens, their immune system overreacts, leading to allergic symptoms like runny nose, nasal congestion, sneezing and itchy eyes. Symptoms generally appear or worsen during specific seasons, depending on which type of pollen triggers the allergy (Greiner et al., 2011).

SAR symptoms are often considered mild and not fatal. However, for individuals with severe allergic predisposition, SAR can lead to more intense complications, such as bronchitis, bronchial asthma, and cardiovascular issues. In rare cases, it may even trigger life-threatening reactions like anaphylaxis (Nathan, 2023).

Pollen allergy has become increasingly severe in Japan over recent years. An extensive epidemiological survey was conducted by the Japanese Society of Immunology and Allergology in Otolaryngology among otolaryngologists and their families in 1998, 2008, and 2018. As is shown in Figure 1, the overall prevalence of pollen allergy rose from 19.6% in 1998 to 29.8% in 2008, and further increased to 42.5% in 2018, representing a 10-percent point rise every decade. The prevalence rate has increased dramatically among younger individuals (Matsubara, 2020).

The dominant pollen sources in Japan are cedar (Sugi) and cypress (Hinoki) trees. Cedar is extensively planted across a wide area from the southern part of Hokkaido to Kyushu, covering approximately 4.5 million hectares, while cypress is primarily planted in various regions of Honshu, particularly in western Japan (Forestry Agency, 2024). Since cedar and cypress are both members of the Cupressaceae family, and due to the structural similarities of the major antigens found in their pollen, it is common for individuals to exhibit concurrent allergic reactions to both types of pollen (Ministry of Environment, 2022).

The prevalence and severity of pollen allergy in Japan are closely linked to post-World War II forest policies. In response to extensive logging during the war, the Japanese government undertook reforestation projects, prioritizing coniferous species such as cedar and cypress. These endemic species were favoured due to their well-established cultivation techniques, rapid growth rates, high yields, and application versatility. During the rapid economic growth period of the 1950s to the 1970s, the demand for timber increased, resulting in a significant expansion of cedar plantations. Cedar forests account for over 40% of Japan's planted forests, while cypress comprises approximately 25%.

As these cedar forests matured, a significant portion of the cedar reached an age of 20 years older—the time at which trees start producing a large amount of pollen. Consequently, this proliferation of cedar pollen has substantially contributed to the rise in the incidence of pollen allergy among the Japanese population (Forestry Agency, 2024).

To address the unforeseen social problem of pollen allergy, the Japanese government has implemented various measures across relevant ministries, agencies, and local governments. To mitigate pollen sources, the Forestry Agency is accelerating the logging of planted cedar forests and replanting these areas with lower-pollen cedar seedlings. This approach reduces pollen production and aligns with broader goals of sustainable resource use, enhancing forest functionality, and contributing to Japan’s commitment to achieving carbon neutrality by 2050.

In addition, for measures against pollen exposure, the Ministry of the Environment and the Ministry of Health, Labour and Welfare widely promote preventive behaviours against pollen exposure. Additionally, the Ministry of Economy, Trade, and Industry is advancing initiatives to support flexible working arrangements, such as remote working, to reduce pollen exposure in daily life (Forestry Agency, 2024).

Social cost of pollen allergies

To accurately assess the necessity and effectiveness of such policies, clarifying the actual social costs associated with pollen is essential. Pollen allergy can be a significant burden on Japan's national healthcare budget. According to the Ministry of the Environment, the medical expenses for allergic rhinitis, including SAR, are estimated to be approximately 360 billion yen. This figure comprises 190 billion yen for consultations and related services, 170 billion yen for prescription medications for insured treatments in fiscal year 2019, and 40 billion yen for over-the-counter medications (Ministry of Health, Labour and Welfare, 2023).

Empirical studies underscore the relationship between daily pollen levels and medical expenses. For instance, Johnston et al. (2009) found that an interquartile range increase in Poaceae pollen concentration was associated with a 5% rise in medication sales in Darwin, Australia. Similarly, Ito et al. (2015) observed that higher mid-spring pollen concentrations in New York City increased medication sales and emergency department visits for asthma-related symptoms. Furthermore, Sheffield et al. (2011) identified a strong correlation between peaks in tree pollen concentration and surges in over-the-counter allergy medication sales in the New York City metropolitan area.

However, the economic burden of pollen allergy extends beyond direct medical costs. Clinical studies indicate the adverse effect of SAR on cognitive performance, resulting from antibodies generated by the immune response that adversely affect brain function and sleep disruption caused by allergic symptoms, such as nasal congestion. For instance, research has reported reduced spatial working memory in children with allergies, longer response times, slower computational abilities, and diminished capacity for divided attention in adults with allergies (Papapostolou et al., 2020; Wilken, 2002).

Empirical studies documented some behavioural outcomes arising from allergic-induced cognitive impairment. For example, Marcotte (2015), Marcotte (2017) and Bensnes (2016) provide evidence that children's test performance declines on higher pollen days. For the broader population, Akesaka and Shigeoka (2024) investigate the association between pollen exposure and accidents, including traffic accidents and work-related incidents—some of the most severe consequences of cognitive impairment. Their analysis revealed that a 100% increase in the daily pollen count increases 0.231 daily accidents per million people.

In addition to impairing cognitive function, SAR poses a threat to mental health through multiple interrelated mechanisms. At first, chronic physical symptoms, such as nasal congestion and itchy eyes, can lead to substantial psychological stress by diminishing comfort and quality of life. These symptoms often disrupt sleep, exacerbating fatigue and emotional instability. From a biological perspective, the release of cytokines as immune responses associated with SAR has been shown to activate brain regions involved in mood regulation, increasing the risk of depression and anxiety (Gudis et al., 2023). Furthermore, the economic burden of managing pollen allergy, including medical expenses and reduced productivity, can intensify financial stress. Anxiety about prospects may also arise from work absenteeism and productivity losses, while reduced academic performance due to allergy-related impairments can adversely affect long-term educational and career opportunities (Marcotte, 2017). These interconnected factors explain the broader psychological implications of SAR and highlight the need for a comprehensive approach to mitigate its complex impact.

Medical studies suggest a significant association between SAR and psychiatric disorders such as mood disorders, anxiety disorders and eating disorders, as well as a history of suicidal ideation (Hans Oh et al., 2018; Messias et al., 2010). Furthermore, Stickley et al. (2017) revealed that during the airborne pollen season, high-pollen days were associated with a nearly 50% increase in the odds of suicide among women compared to pollen-free days. These findings underscore the adverse effect of pollen exposure on mental health.

Climate change and pollen allergies

Climate change is expected to increase pollen concentration and the duration of the pollen season through the expansion of plant distribution and extension of the growing season. Increased pollen counts and a longer duration of the pollen season have been observed worldwide.

According to Anderegg et al. (2021), in the United States from 1990 to 2018, the pollen concentration increased by 20.9% annually, and the duration of the pollen season increased by 8 days. Such a relationship is also shown in Japan's data. Akesaka and Shigeoka (2024) examined the relationship between the daily pollen counts and the temperature in the previous summer. They found that 1℃ increases in maximum temperature in the previous summer could increase 167 grains/m^3 of daily pollen counts, and an additional 10 hot days are associated with a 237 grains/m^3 increase.

These studies suggest that climate change makes pollen allergy more severe, and these trends are expected to progress further due to global warming in the coming decades (Lake et al., 2017; Zhang and Steiner, 2022), followed by the increase in social costs. Akesaka and Shigeoka (2024) estimated that an additional 1,823 pollen-induced accidents under the IPCC's "business-as-usual" scenario, which forecasts a 4.1°C rise in summer temperatures between 2076 and 2095, with a lower-bound social cost of approximately $236 million annually. These simulations indicate that increasing pollen and longer seasons will increase the likelihood of seasonal allergies.

Suicide in Japan

Globally, over 720,000 people die by suicide annually, and many more than that make attempts. Suicide can affect individuals at any stage of life and is prevalent in all regions. In 2021, it was the third leading cause of death among 15–29-year-olds worldwide (WHO, 2024). In Japan, the number of suicides has remained over 20,000 over 40 years (Ministry of Labour, Health and Welfare, 2024), and the suicide mortality rate is the highest among G7 nations.

Suicide is closely tied to individual circumstances, but its impacts extend to society. The incidence of suicide can have severe psychological and emotional impacts on bereaved family members and friends, potentially increasing their risk of suicide. On a macroeconomic scale, suicide represents a significant loss of human capital and potential contributions to society. A 2010 study by the National Institute of Population and Social Security Research estimated that in Japan, the total potential earnings in 2009 would have been 1,903 billion JPY higher if suicides had been prevented. Furthermore, eliminating suicide and depression was projected to boost GDP by approximately 1,700 billion JPY.

Factors of suicide in Japan

According to the National Police Agency, health problems are the leading reported cause of suicide, followed by economic and livelihood issues and family problems. Mental health conditions, a significant driver of health-related suicides, are often exacerbated by socioeconomic factors, such as unemployment, financial instability, and work-related stress.

In recent years, research has revealed that even small environmental shocks can exacerbate existing vulnerabilities and contribute to suicide risk when combined with major factors. For example, studies document that air pollution and climate change contribute to mental health deterioration and increased suicide risk. Persico and Marcotte (2022) found that in the U.S., a 1 μg/m³ increase in daily PM2.5 concentrations is associated with a 0.49% rise in daily suicides. Similarly, Molitor et al. (2023) reported that wildfire smoke exposure increases suicide risk, with rural counties experiencing 0.11 additional suicides per million residents for each additional day of smoke exposure. Chen et al. (2024) expanded on this by highlighting the broader mental health impacts of air pollution in China, demonstrating that a 1 sd increase in PM2.5 concentrations raises the likelihood of severe mental illness symptoms by 7.58 percentage points. Indirect pathways, such as reduced physical activity and impaired physical health, were identified as contributors to these effects.

3. Data

Pollen and weather data

Airborne pollen data is obtained from the Japanese Ministry of the Environment's pollen monitoring system, "Hanako-san"[3]. Automatic pollen counters at each station report hourly pollen counts of Japanese cedar and cypress per cubic meter (grains/m^3). This system includes 120 pollen monitoring stations across Japan, averaging two to three per prefecture. Notably, Okinawa prefecture has no monitoring stations due to its distinct climate. This monitoring system operates annually from February to May, except in Hokkaido, where it operates from March to June. Data are available on the Ministry's website. The pollen monitoring stations are mainly located in urban areas with high population density but also in some mountainous regions, which are sources of pollen dispersion (Wakamiya et al., 2019).

To align the pollen data with suicide mortality data, which are available at the prefectural level, I calculated the daily average pollen counts for each prefecture. This was done by aggregating the hourly pollen counts over 24 hours for each monitoring station within a prefecture and then averaging these daily totals across all stations within the same prefecture. The pollen count values for periods without observation (June to January) were set to zero. This decision reflects the absence of cedar and cypress pollen, the primary contributors to pollen allergies in Japan, during this time. Although other pollen sources, such as grasses and weeds, may be present, their counts, prevalence, and associated symptoms are significantly less pronounced compared to cedar and cypress (Kishikawa 2020). Consequently, this analysis prioritizes the dominant sources of allergenic pollen, using the off-season as a baseline to account for the negligible influence of these minor allergens.

Weather data is obtained from the Japan Meteorological Agency's Automated Meteorological Data Acquisition System, AMeDAS[4]. I extracted data from the nearest AMeDAS monitoring site to each pollen monitoring station and aggregated these data to the prefecture level using the same averaging approach as for pollen data. The weather variables include precipitation, temperature, wind speed, and sunlight hours.

[3] https://www.env.go.jp/page_00209.html
[4] https://www.data.jma.go.jp/obd/stats/etrn/

Suicide mortality data

The suicide data come from the "Vital Statistics" by the Japanese Ministry of Health, Labour and Welfare[5]. These statistics include the number of deaths by suicide for each month by sex and age group, as well as the suicide mortality by sex at the prefecture level. The suicide mortality is defined as the number of deaths by suicide per 100,000 population.

To calculate the monthly suicide mortality rate by age group, I combined the number of suicides with population data by age group for each prefecture. The dataset exclusively records suicides among Japanese citizens within Japan, and the prefecture of death corresponds to the individual's place of residence.

Figure 2 shows the distribution of daily pollen counts between 2009 and 2020 during the pollen season (February to May; March to June in Hokkaido). Panel A displays the raw daily pollen counts, which exhibit a right-skewed distribution. Panel B illustrates the logged values of the pollen counts.

Figure 3 presents the average daily pollen counts by prefecture from 2009 to 2020, highlighting that while all prefectures experience pollen exposure, the concentration levels vary across prefectures.

Figure 4 shows the daily pollen counts in Miyagi prefecture in 2020, illustrating temporal variations in pollen exposure during the pollen season.

Figure 5 displays the distribution of monthly suicide mortality from 2009 to 2020, by overall, male and female categories.

Finally, Table 1 presents summary statistics. The overall monthly suicide mortality rate is 1.64 per 100,000 population, while the corresponding rates for men and women are 2.36 and 0.97 per 100,000, respectively. The average daily pollen count during the pollen season is 1,101 grains/m³, with a standard deviation of 3,297.

4. Empirical model

The base model to examine the relationship between pollen exposure and suicide mortality is expressed as follows:

$$\log[Suicide]_{it} = \sum_{j\in J}\sum_{k\in K}\beta_k^j[Pollen]^j{}_{i,t-k} + r[Weather]_{it} + \delta[Socioecon_{it}] + \alpha_i + \mu_t + \varepsilon_{it} \quad (1),$$

where the dependent variable represents monthly suicide mortality in a prefecture and month. For pollen exposure, I use bin variables that count the number of days in each month falling into each pollen category. Following the Japanese Ministry of the Environment, daily pollen counts are classified as low (≤10 grains/m³), moderately high (>10 to ≤30), high (>30 to ≤50), very high (>50 to ≤100), and extremely high (>100). The omitted category in the main specification is days with pollen counts of 30 grains/m³ or less. This construction permits daily pollen measurements to be linked to monthly suicide mortality data.

Though the allergic reaction typically lasts four to eight hours (Skoner, 2001), pollen allergy continues over several months. Chronic physical discomfort, impaired sleep quality, reduced productivity, and economic burdens from pollen exposure can lead to accumulated stress over time.

[5] https://www.mhlw.go.jp/toukei/list/81-1.html

To capture these cumulative effects, I include lagged pollen exposure terms $K = 0, 1$ and 2 in the model.

The $[Weather_{it}]$ term accounts for weather covariates that may influence both pollen dispersion and mental health. I include the number of rainy days per month since precipitation can significantly mitigate pollen dispersion. Sunlight is another crucial factor, as prior research highlights a strong association between sunlight exposure and mental health, particularly its effects on mood and depression, even on incidents of suicide (Kadotani et al., 2014). To capture this, I include the number of days per month with at least five hour of sunlight. Additionally, I incorporate the monthly average wind speed as wind transports pollen across regions.

As discussed in the previous section, various factors influence suicide mortality, so it is essential to include socioeconomic controls in the analysis. I include prefectural annual income per capita and the quarterly unemployment rate to represent economic conditions. Household composition is represented by the rates of single mothers, single fathers, and welfare recipients. I also control for population demographics, including the proportion of elderly individuals (aged 65 and older) and young people (aged under 15). Additionally, I control for the impact of disasters by including the number of deaths and the number of people affected by disasters over the past three years.

FE (α_i) controls for unobserved, time-invariant heterogeneity across units, such as regional or demographic factors. Year-by-month FE (μ_t) accounts for macroeconomic conditions, seasonality, and other temporal factors that could influence the dependent variable across all units in the same period.

5. Main Results

Basic results

Table 2 presents the main estimation results on equation (1). Columns (1)-(3) display the baseline result without lagged pollen variables ($K = 0$), while columns (4)-(6) include one-month lagged variables ($K = 1$), and columns (7)-(9) include two-month lagged variables ($K = 2$) for the overall population, as well as separately for men and women.

An additional high-pollen day (>30 to ≤50 grains/m^3) and an extremely high-pollen day (>100 grains/m^3) are associated with approximately 0.6% and 0.2% higher monthly suicide mortality, respectively; both estimates are statistically significant at the 5% level. The estimated association is statistically significant for women but not for men. For women, an additional high-pollen day is associated with approximately 0.9% higher monthly suicide mortality. This comparison does not by itself establish that the pollen coefficients differ statistically between women and men, because a formal cross-group test is not reported.

Regarding lagged pollen exposure, an additional very-high-pollen day (>50 to ≤100 grains/m^3) is associated with approximately 0.5% higher monthly suicide mortality for women. The lagged estimates are generally weaker than the contemporaneous estimates. This pattern is consistent with a relatively short-lived association, but the current design does not identify the precise timing of a causal response.

Robustness

The results are broadly similar across several alternative constructions of pollen exposure. Using the logarithm of monthly average pollen counts (Table 3), the coefficient for overall suicide mortality remains positive and statistically significant, whereas the female-specific coefficient is not statistically significant. A two-bin categorization and a finer six-bin categorization are reported in Tables 4 and 5. Taken together, these checks suggest that the positive association for the overall population is relatively stable, while the female-specific estimates are more sensitive to specification. Table 6 restricts the sample to the pollen season, when pollen is actually monitored. This is an important check because pollen counts in unmonitored months are assigned a value of zero in the full-year sample. In the pollen-season sample, the high-pollen coefficient remains positive and statistically significant for the overall population and for women. The similarity of the overall estimate to the baseline result indicates that the main association is not driven solely by the treatment of unmonitored off-season months.

Lastly, I introduce an interaction term between the number of rainy days and the pollen bin variables to examine how precipitation may influence the relationship between pollen exposure and suicide mortality (Table7). The coefficient of the "high" bin variable becomes larger in both the overall and female suicide mortality analyses. For women, the coefficient of the interaction term is negative and statistically significant at the 10% level, suggesting that on rainy days, the effect of pollen exposure on suicide mortality is slightly reduced. In general, however, the association between pollen exposure and suicide mortality remains largely unaffected by precipitation.

Heterogeneity

I conducted an analysis using age-specific monthly suicide mortality as the outcome variable, categorized in 10-year intervals, ranging from 10 years old to 80 years old and beyond. Figure 8, 9 and 10 show the average age-specific suicide mortality rates for males and females. For individuals aged 20 and above, the suicide rate for men exceeds that of women. Suicide mortality in teens is relatively low compared to other age groups.

Tables 8, 9, and 10 report age-specific estimates. Some coefficients are statistically significant for people in their 50s, but significant estimates also appear in other age groups and pollen categories. Because these tables involve many simultaneous hypothesis tests across sex, age, and pollen categories, isolated significant coefficients may arise by chance and should be interpreted as exploratory evidence. One possible explanation for age and sex heterogeneity is variation in biological responses, including hormonal mechanisms around menopause. However, hormones are not observed in the present data, and the age-specific pattern is not sufficiently systematic to identify this mechanism.

Additionally, I divided the prefectures into two groups based on the median of average daily pollen counts in the season and conducted separate analyses for each group. Table 11 presents the results. Columns (1)-(3) show the estimates for prefectures where the daily average pollen dispersion is below the median, while columns (4)-(6) show the estimates for prefectures where it is above the median. No significant results were found for prefectures with lower pollen dispersion, while significant results were observed for those with higher pollen dispersion.

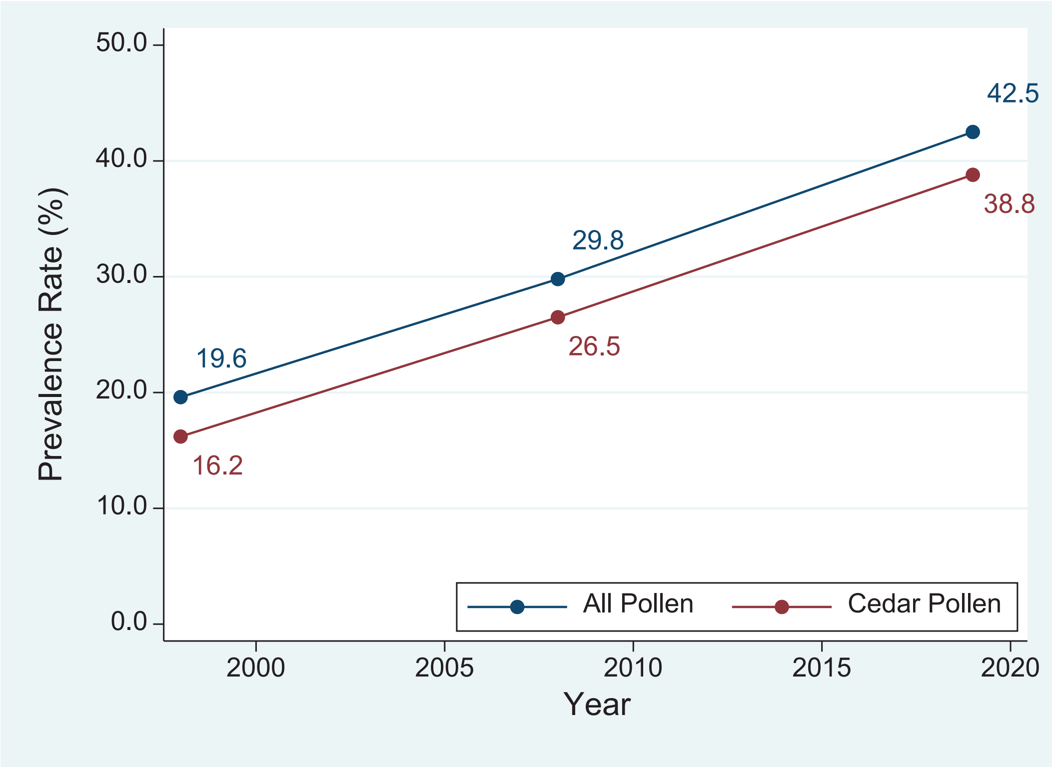
6. Discussion and Conclusion

This study provides a quantitative assessment of the association between pollen exposure and monthly suicide mortality in Japan using suicide records and pollen counts from 2009 to 2020. The estimates indicate that more high-pollen days are associated with higher overall monthly suicide mortality. The association is statistically significant in several specifications for women but not for men, although the difference between the two groups has not been formally tested. These findings are consistent with clinical evidence linking seasonal allergies to mental-health challenges, but the fixed-effects design should be interpreted as documenting conditional associations rather than definitive causal effects.

The estimates do not display a monotonic dose-response pattern across pollen categories: in the baseline specification, the coefficient for high-pollen days (>30 to ≤50 grains/m^3) exceeds those for the very-high and extremely-high categories. Therefore, the estimates should not be interpreted as showing that progressively higher pollen levels necessarily generate progressively larger changes in suicide mortality. One possible explanation is avoidance behaviour: on days with especially high pollen forecasts, individuals may stay indoors, use masks or medication, or otherwise reduce exposure. This mechanism is plausible but cannot be tested with the current data. A second limitation concerns the aggregation of pollen counts. Pollen levels can vary substantially within a prefecture, and prefectural averages may obscure local exposure variation. Future research could link outcomes to individual monitoring stations or finer spatial units.

The age-specific estimates require additional caution because the large number of comparisons raises the risk of false-positive findings. Future work should pre-specify key subgroups, report formal tests of differences across sex and age groups, and consider adjustments for multiple hypothesis testing. In addition, the present study uses suicide mortality as an indicator of mental health. Suicide represents an extreme outcome and does not capture more prevalent problems such as mood disorders, anxiety, and sleep disturbance. Future studies could use medical claims, survey measures, or other mental-health outcomes and develop a more explicit identification strategy to assess causality and distinguish biological responses from behavioural adaptation.

Figure 1 – Transition of pollen allergy prevalence rates

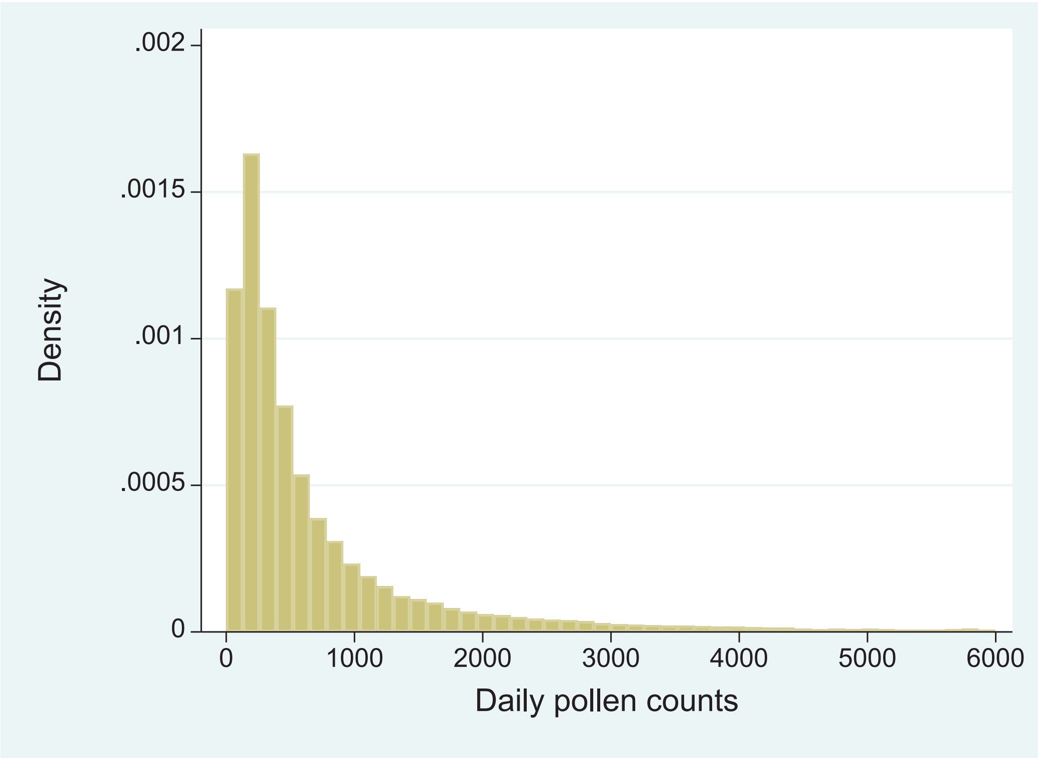


Data source: (Matsubara, 2020)

Notes: This graph represents the transition of the prevalence rate of overall pollen allergy and cedar pollen allergy.

Figure 2 – Distribution of daily pollen counts

A. Level



B. Logged

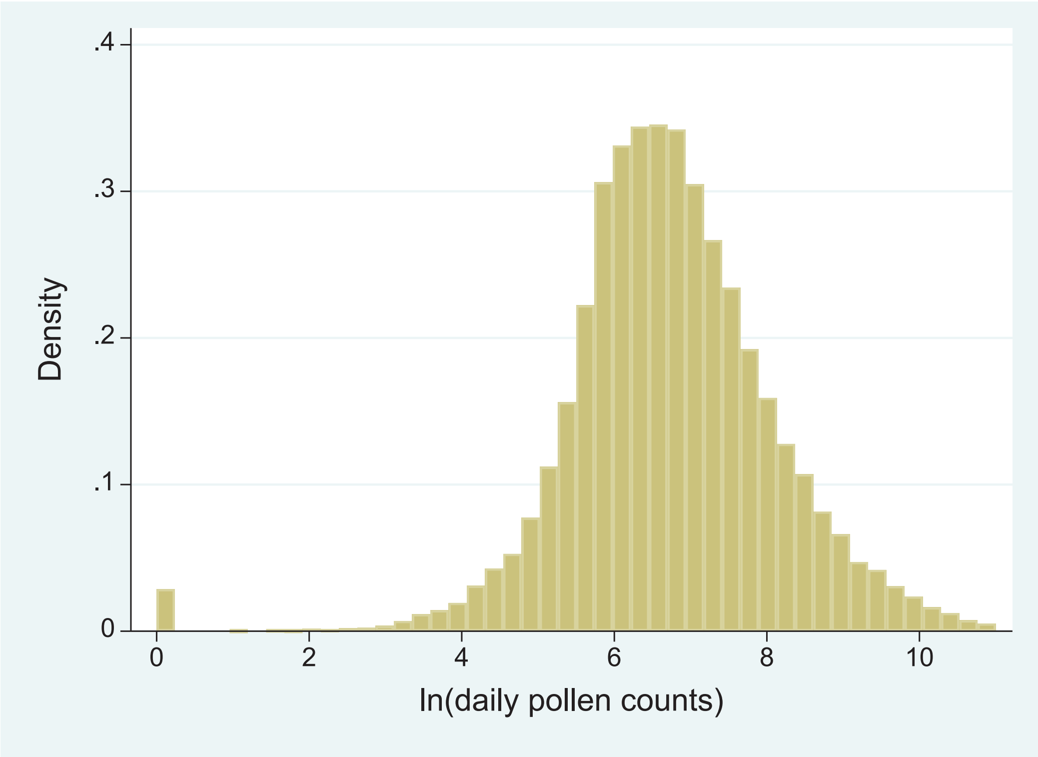
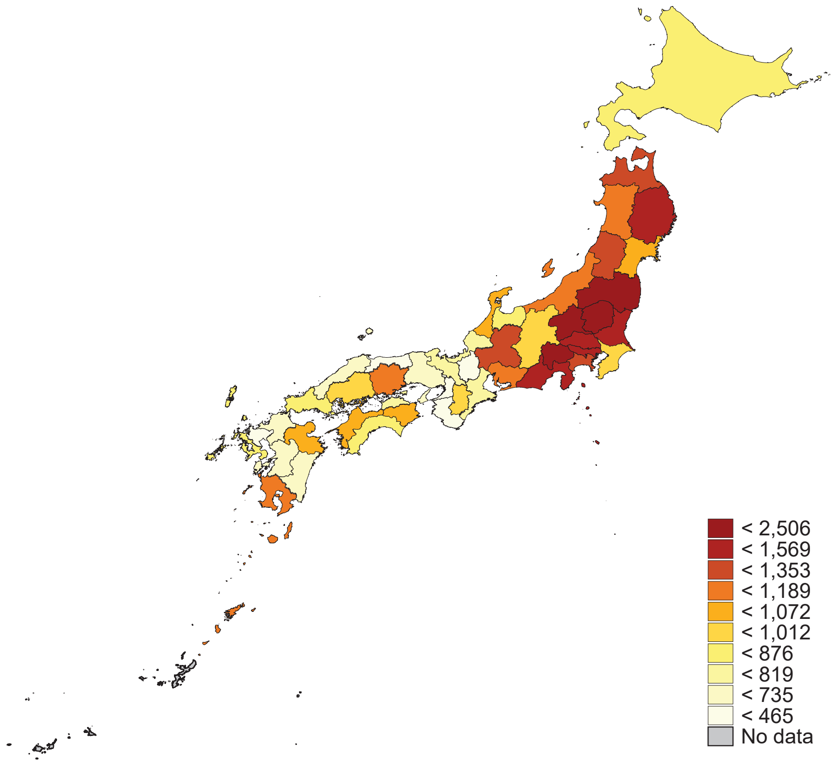
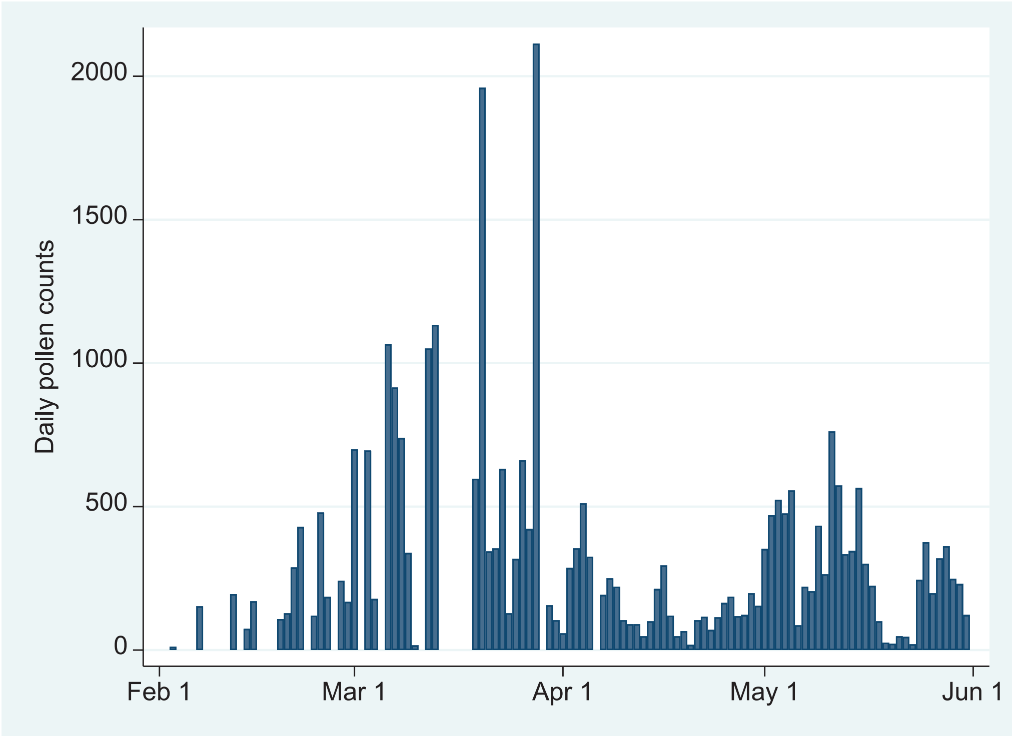


Figure 3 – Pollen counts across prefectures



Notes: This graph represents the average daily pollen counts during the pollen season by prefecture from 2009 to 2020.

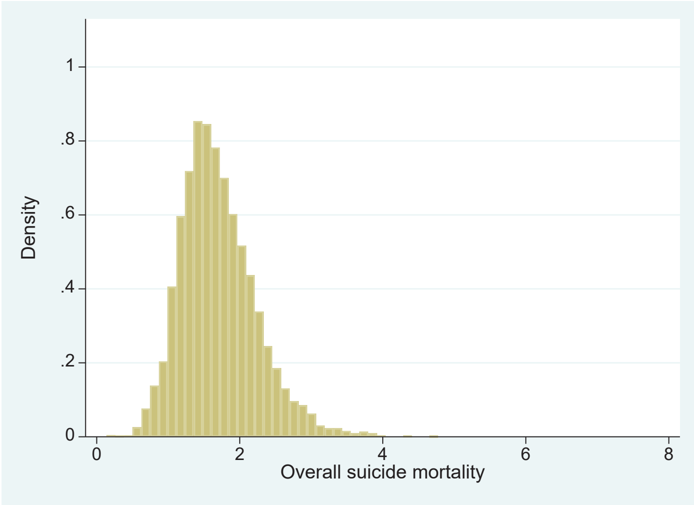
Figure 4 – Pollen counts in Miyagi prefecture in 2020



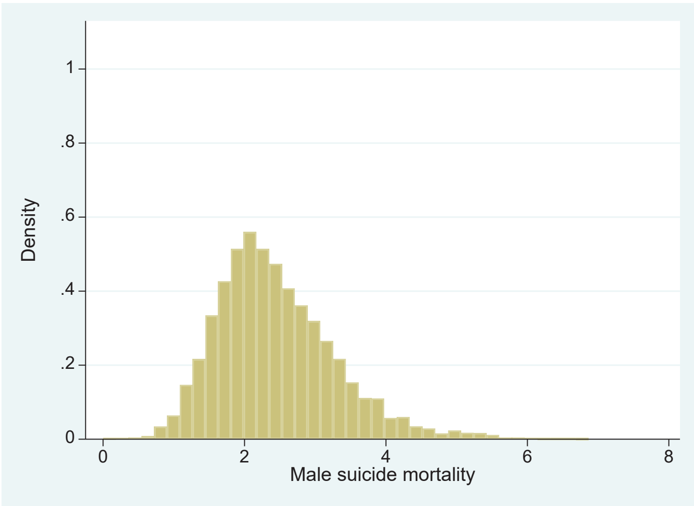
Notes: This graph represents the daily pollen counts in Miyagi prefecture in 2020.

Figure 5 – Distribution of suicide mortality

A. Overall



B. Male



C. Female

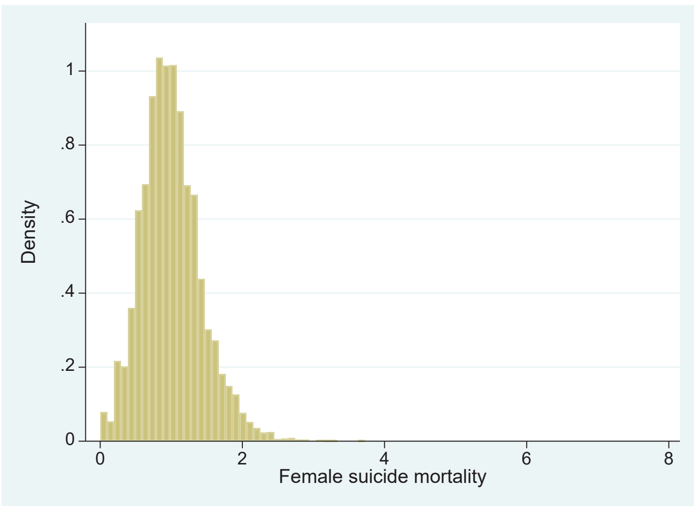


Figure 8 - Average Age-Specific Suicide Mortality: Overall

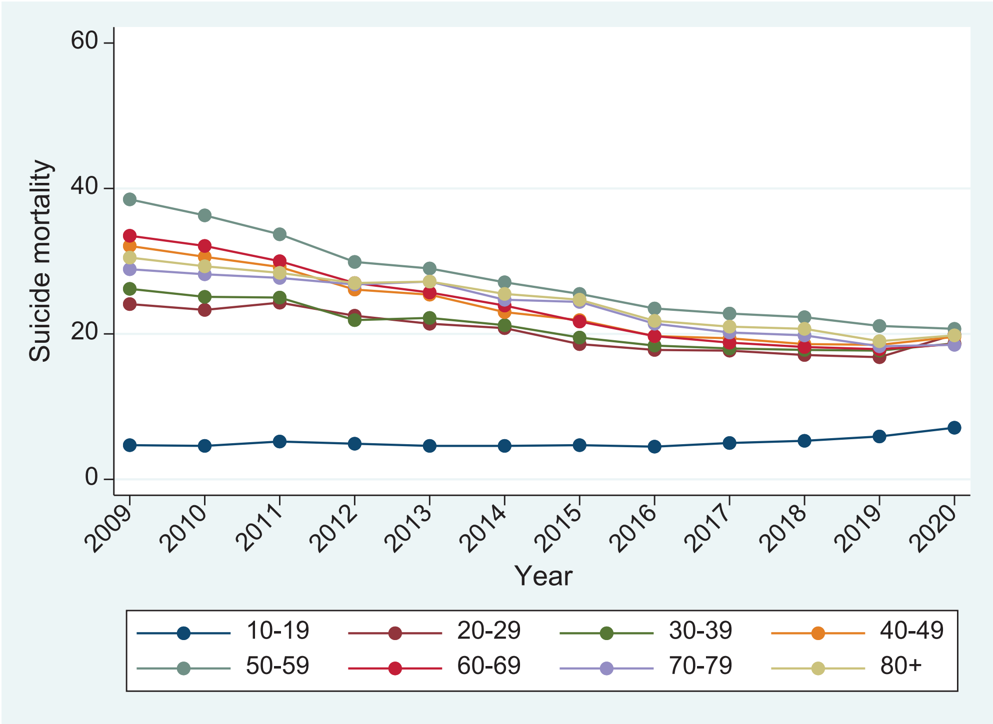


Figure 9 - Average Age-Specific Suicide Mortality: Male

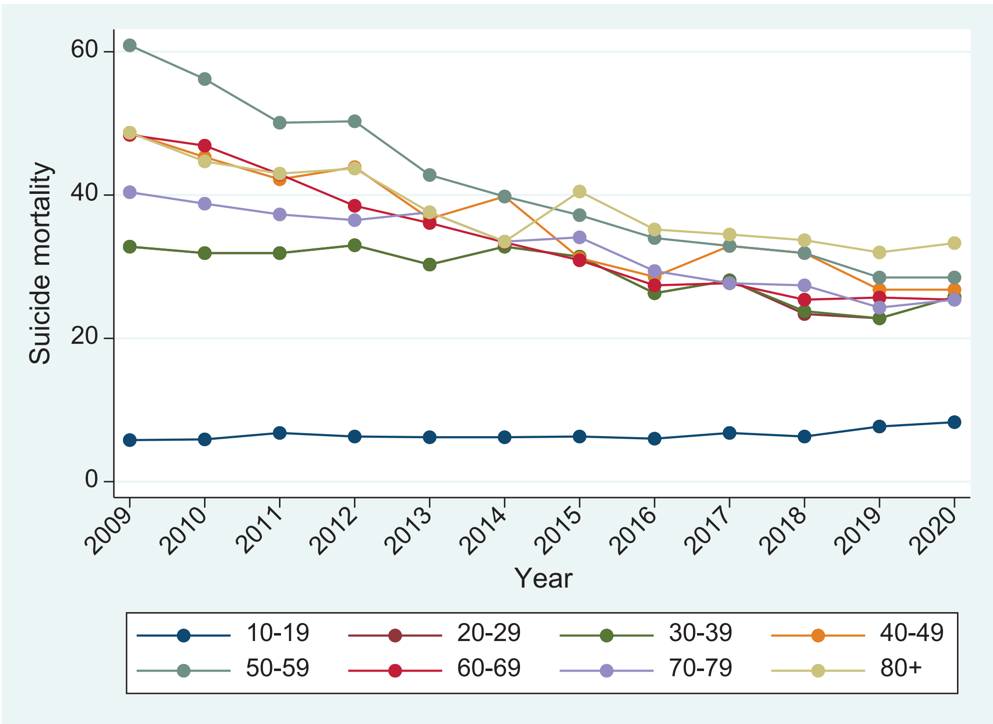
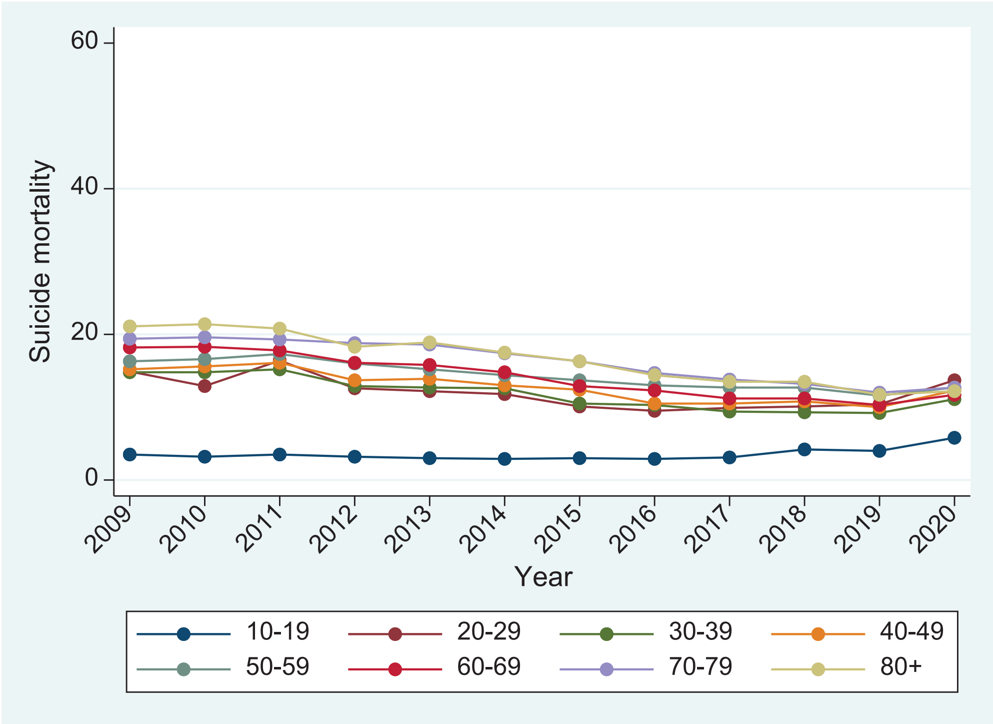


Figure 10 - Average Age-Specific Suicide Mortality: Female



Data source: Ministry of Health, Labour and Welfare. (2021). *Suicide prevention white paper 2021.*

Notes: These graphs represent the average age-specific suicide mortality.

Table1 – Summary statistics

	(1) N	(2) Mean	(3) Std. dev.	(4) Min	(5) Max
A. Monthly suicide mortality					
All	6,624	1.640	0.510	0.137	4.470
Male	6,624	2.362	0.820	0	6.866
Female	6,624	0.968	0.411	0	3.488
B. Regressors					
Daily pollen counts (grains/m^3)	181,746	285.478	1,741.528	0	399,667
Daily pollen counts in pollen season (grains/m^3)	46,825	1,101.106	3,297.473	0	399,667
Pollen bin 0	6,624	20.492	14.223	0	31
Pollen bin (0, 10]	6,624	0.069	0.415	0	10
Pollen bin (10, 30]	6,624	0.299	1.099	0	23
Pollen bin (30, 50]	6,624	0.369	1.122	0	13
Pollen bin (50, 100]	6,624	0.884	2.094	0	18
Pollen bin >100	6,624	8.324	12.264	0	31
Precipitation (mm)	201,618	5.053	13.66	0	396.7
Average temperature (°C)	201,618	14.632	8.650	-11.47	33.57
Average wind speed (m/s)	201,618	2.290	0.996	0	11.20
Sunlight (hours)	201,618	4.933	3.794	0	14.35
Population	552	2162.232	2487.412	80	13,768
Natural disaster death	552	34.551	482.1	0	10,154
Natural disaster affected	552	886.002	4,740.173	0	78,755
Income per capita (1,000 yen)	552	2,834.683	513.883	2,082	5,931
Single-mother household ratio	552	1.510	0.027	0.735	2.150
Single-father household ratio	552	0.172	0.029	0.083	0.283
Unemployment rate	2208	3.272	1.132	0.600	7.700
Welfare recipient ratio	552	28.982	36.545	2.558	231.562

Table 2 – Main results

Outcome: logged monthly suicide mortality

	K=0			K=1			K=2		
	all	male	female	all	male	female	all	male	female
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Pollen (30, 50]	0.0055**	0.0027	0.0090**	0.0056**	0.0028	0.0091**	0.0064**	0.0036	0.0097**
	(0.0027)	(0.0036)	(0.0040)	(0.0027)	(0.0036)	(0.0040)	(0.0028)	(0.0036)	(0.0041)
Pollen (50, 100]	0.0012	0.0000	0.0034	0.0008	-0.0002	0.0027	0.0008	-0.0002	0.0027
	(0.0014)	(0.0019)	(0.0028)	(0.0014)	(0.0019)	(0.0027)	(0.0015)	(0.0019)	(0.0025)
Pollen >100	0.0017**	0.0010	0.0029	0.0018**	0.0011	0.0029	0.0023**	0.0016	0.0033**
	(0.0007)	(0.0009)	(0.0013)	(0.0008)	(0.0010)	(0.0018)	(0.0009)	(0.0010)	(0.0013)
k=1									
Pollen (30, 50]				0.0042	0.0047	0.0030	0.0044*	0.0048	0.0032
				(0.0026)	(0.0032)	(0.0031)	(0.0026)	(0.0033)	(0.0040)
Pollen (50, 100]				0.0011	-0.0010	0.005**	0.0008	-0.0013	0.0046*
				(0.0017)	(0.0021)	(0.002)	(0.0017)	(0.0021)	(0.0024)
Pollen >100				0.0001	0.0001	-0.0000	0.0001	0.0001	-0.0001
				(0.0010)	(0.0011)	(0.0010)	(0.0009)	(0.0011)	(0.0013)
k=2									
Pollen (30, 50]							0.0057**	0.0059*	0.0055
							(0.0024)	(0.0032)	(0.0040)
Pollen (50, 100]							-0.0022	-0.0024	-0.0010
							(0.0017)	(0.0019)	(0.0024)
Pollen >100							0.0002	0.0004	0.0004
							(0.0008)	(0.0008)	(0.0013)
Prefecture FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6624	6624	6624	6578	6578	6578	6532	6532	6532
R-squared	0.5467	0.4734	0.3046	0.5458	0.4722	0.3046	0.5430	0.4683	0.3044
Adj R-squared	0.5330	0.4576	0.2836	0.5318	0.4559	0.2833	0.5287	0.4517	0.2827
F	3.50***	2.14*	2.14*	3.81***	1.57	2.19**	3.54***	2.72***	1.99**

Notes: Robust standard errors clustered at the prefectural level in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3 – Robustness: Logarithmic form
Outcome: logged monthly suicide mortality

	all (1)	male (2)	female (3)
ln (pollen counts)	0.0072** (0.0029)	0.0072** (0.0035)	0.0083 (0.0058)
Prefecture FE	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes
N	6624	6624	6624
R-squared	0.5466	0.4736	0.3040
Adj R-squared	0.5330	0.4578	0.2832
F	3.50**	3.38**	1.81

Notes: Robust standard errors clustered at the prefectural level in parentheses.
Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 – Robustness: Two-Bin Categorization
Outcome: logged monthly suicide mortality

	all (1)	male (2)	female (3)
Pollen >30	0.0015** (0.0007)	0.0009 (0.0009)	0.0028* (0.0016)
Prefecture FE	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes
N	6624	6624	6624
R-squared	0.5465	0.4734	0.3042
Adj R-squared	0.5330	0.4577	0.2834
F	3.80**	2.36*	2.09*

Notes: Robust standard errors clustered at the prefectural level in parentheses.
Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5– Robustness: Six-Bin Categorization
Outcome: logged monthly suicide mortality

	all (1)	male (2)	female (3)
Pollen <10	-0.0074*	-0.0065	-0.0152**
	(0.0043)	(0.0073)	(0.0073)
Pollen (10, 30]	-0.0020	0.0032	-0.0091**
	(0.0029)	(0.0033)	(0.0039)
Pollen (30, 50]	0.0065**	0.0021	0.0124***
	(0.0028)	(0.0037)	(0.0037)
Pollen (50, 100]	0.0007	-0.0001	0.0021
	(0.0013)	(0.0019)	(0.0022)
Pollen >100	0.0011*	0.0011	0.0010
	(0.0005)	(0.0009)	(0.0012)
Prefecture FE	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes
N	6624	6624	6624
R-squared	0.5468	0.4735	0.3058
Adj R-squared	0.5330	0.4575	0.2847
F	3.54***	1.70	5.90***

Notes: Robust standard errors clustered at the prefectural level in parentheses.
Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6– Robustness: Limiting Sample to Pollen Season
Outcome: logged monthly suicide mortality

	all (1)	male (2)	female (3)
Pollen (30, 50]	0.0078***	0.0051	0.0105**
	(0.0029)	(0.0040)	(0.0043)
Pollen (50, 100]	0.0015	0.0006	0.0031
	(0.0019)	(0.0027)	(0.0033)
Pollen >100	0.0018	0.0013	0.0026
	(0.0012)	(0.0019)	(0.0023)
Prefecture FE	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes
N	2208	2208	2208
R-squared	0.5560	0.4824	0.3153
Adj R-squared	0.5354	0.4584	0.2835
F	3.50***	2.16*	1.51

Notes: Robust standard errors clustered at the prefectural level in parentheses.
Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7– Robustness: Rainfall
Outcome: logged monthly suicide mortality

	all	male	female
	(1)	(2)	(3)
Pollen (30, 50]	0.0165*	0.0103	0.0253***
	(0.0088)	(0.0122)	(0.0086)
Pollen (50, 100]	0.0045	0.0044	0.0046
	(0.0041)	(0.0058)	(0.0059)
Pollen >100	0.0010	0.0006	0.0018
	(0.0009)	(0.0012)	(0.0019)
Pollen (30, 50] ×rain days	-0.0007	-0.0005	-0.0011*
	(0.0005)	(0.0008)	(0.0006)
Pollen (50, 100] ×rain days	-0.0003	-0.0003	-0.0001
	(0.0003)	(0.0004)	(0.0004)
Pollen >100 ×rain days	0.0000	-0.0000	0.0000
	(0.0000)	(0.0001)	(0.0001)
Prefecture FE	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes
N	6624	6624	6624
R-squared	0.5474	0.4739	0.3054
Adj R-squared	0.5335	0.4578	0.2841
F	2.74**	1.41	2.99***

Notes: Robust standard errors clustered at the prefectural level in parentheses.
Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8 - Heterogeneity in Age: Overall population
Outcome: logged monthly suicide mortality

Overall								
	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pollen (30, 50]	0.0003	0.0123	0.0009	0.0076	0.0179**	-0.0001	0.0048	-0.0062
	(0.0122)	(0.0141)	(0.0090)	(0.0106)	(0.0078)	(0.0096)	(0.0107)	(0.0107)
Pollen (50, 100]	0.0169**	-0.0055	0.0064	-0.0065	0.0046	0.0060	0.0051	-0.0013
	(0.0071)	(0.0065)	(0.0052)	(0.0066)	(0.0087)	(0.0056)	(0.0048)	(0.0057)
Pollen >100	0.0066	0.0006	0.0000	-0.0012	0.0053**	-0.0001	0.0032	0.0006
	(0.0046)	(0.0033)	(0.0029)	(0.0029)	(0.0022)	(0.0030)	(0.0020)	(0.0024)
Prefecture FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month by year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6624	6624	6624	6624	6624	6624	6624	6624
R-squared	0.2389	0.3349	0.4396	0.5217	0.5001	0.5494	0.4740	0.4508
Adj R-squared	0.2160	0.3148	0.4227	0.5073	0.4850	0.5358	0.4581	0.4342
F	1.13	0.78	1.28	2.16*	2.49**	0.42	0.92	0.33

Notes: Robust standard errors clustered at the prefectural level in parentheses. Significance level: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The age-specific estimates involve multiple hypothesis testing and should be interpreted as exploratory.

Table 9 - Heterogeneity in Age: Male
Outcome: logged monthly suicide mortality

Male	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pollen (30, 50]	0.0004	0.0001	-0.0057	0.0150	0.0054	-0.0055	0.0053	0.0010
	(0.0119)	(0.0161)	(0.0114)	(0.0107)	(0.0108)	(0.0092)	(0.0115)	(0.0144)
Pollen (50, 100]	0.0164**	-0.0089	0.0057	-0.0097	0.0041	0.0088	0.0133***	0.0003
	(0.0069)	(0.0070)	(0.0057)	(0.0066)	(0.0086)	(0.0063)	(0.0043)	(0.0085)
Pollen >100	0.0063	0.0015	-0.0017	-0.0007	0.0061**	0.0011	0.0010	-0.0006
	(0.0045)	(0.0036)	(0.0035)	(0.0032)	(0.0026)	(0.0031)	(0.0026)	(0.0040)
Prefecture FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6624	6624	6624	6624	6624	6624	6624	6624
R-squared	0.2443	0.2837	0.3828	0.4562	0.4231	0.4554	0.3672	0.2910
Adj R-squared	0.2215	0.2621	0.3641	0.4398	0.4057	0.4390	0.3482	0.2696
F	1.13	0.83	0.44	2.53**	1.29	0.56	2.79**	0.10

Notes: Robust standard errors clustered at the prefectural level in parentheses. Significance level: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The age-specific estimates involve multiple hypothesis testing and should be interpreted as exploratory.

Table 10 - Heterogeneity in Age: Female
Outcome: logged monthly suicide mortality

Female	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pollen (30, 50]	0.0003	0.0046	0.0057	-0.0050	0.0218*	0.0057	0.0131	-0.0077
	(0.0126)	(0.0134)	(0.0117)	(0.0110)	(0.0114)	(0.0125)	(0.0094)	(0.0111)
Pollen (50, 100]	0.0174**	0.0033	0.0030	0.0066	0.0061	0.0020	-0.0031	0.0026
	(0.0073)	(0.0066)	(0.0062)	(0.0069)	(0.0077)	(0.0060)	(0.0061)	(0.0075)
Pollen >100	0.0068	-0.0008	0.0041	0.0010	0.0038	-0.0009	0.0088***	0.0047
	(0.0047)	(0.0025)	(0.0033)	(0.0039)	(0.0037)	(0.0040)	(0.0025)	(0.0041)
Prefecture FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6624	6624	6624	6624	6624	6624.	6624	6624
R-squared	0.2339	0.1745	0.2019	0.2431	0.2679	0.2850	0.2906	0.3006
Adj R-squared	0.2108	0.1496	0.1778	0.2202	0.2458	0.2634	0.2692	0.2795
F	1.14	2.07*	2.17*	0.28	1.19	0.63	2.60**	1.10

Notes: Robust standard errors clustered at the prefectural level in parentheses. Significance level: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The age-specific estimates involve multiple hypothesis testing and should be interpreted as exploratory.

Table11 - Heterogeneity in pollen counts across prefectures
Outcome: logged monthly suicide mortality

	< median			≧ median		
	all	male	female	all	male	female
	(1)	(2)	(3)	(4)	(5)	(6)
Pollen (30, 50]	0.0053	0.0055	0.0037	0.0022	-0.0061	0.0154**
	(0.0033)	(0.0039)	(0.0057)	(0.0048)	(0.0060)	(0.0067)
Pollen (50, 100]	-0.0004	-0.0026	0.0034	0.0047*	0.0060*	0.0027
	(0.0015)	(0.0020)	(0.0035)	(0.0025)	(0.0034)	(0.0043)
Pollen >100	0.0015*	0.0012	0.0021	0.0029**	0.0020	0.0043
	(0.0008)	(0.0011)	(0.0017)	(0.0013)	(0.0021)	(0.0032)
Prefecture FE	Yes	Yes	Yes	Yes	Yes	Yes
Year-by-month FE	Yes	Yes	Yes	Yes	Yes	Yes
N	3312	3312	3312	3312	3312	3312
R-squared	0.5064	0.4367	0.2832	0.6015	0.5366	0.3492
Adj R-squared	0.4795	0.4060	0.2442	0.5798	0.5114	0.3138
F	1.57	1.08	2.65**	4.75***	5.32***	2.28***

Notes: Robust standard errors clustered at the prefectural level in parentheses. Significance level: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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