

The early impact of paraquat ban on suicide in Taiwan

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Abstract

Introduction: Pesticide ingestion is a leading method for suicide worldwide.

Paraquat is a highly lethal herbicide when ingested. We assessed the impact of the first-stage ban on the import and production of paraquat (from February 2018) on suicides by pesticide poisoning in Taiwan.

Methods: Suicide data by method (pesticide vs non-pesticide), pesticide (paraquat vs non-paraquat), and area/sex/age were extracted from the national cause-of-death data files (2011-2019). Negative binomial regression was used to estimate changes in suicide rates in 2019, compared to the expected rates based on pre-ban linear trends (2011-2017).

Results: The paraquat ban was followed by an estimated 37% (rate ratio [RR] = 0.63, 95% confidence interval [CI] 0.54-0.74) reduction in pesticide suicide rate (190 [95% CI 116-277] fewer suicides) in 2019, mainly due to a 58% (RR = 0.42, 95% CI 0.33-0.54) reduction in paraquat suicides (145 [95% CI 92-213] fewer suicides).

Larger absolute reductions in pesticide suicides were found in rural areas, males, and the elderly (aged 65+ years) than their counterparts. Except for a 10% (95% CI 3-18%) reduction in overall suicide rates in the elderly, there was no statistical evidence for a change in non-pesticide and overall (all-method) suicides.

Conclusion: The ban on the import and production of paraquat was followed by a fall in whole-population pesticide and paraquat suicides and elderly suicides in Taiwan.

Keywords: pesticide ban, pesticide suicide, suicide prevention, paraquat

Introduction

Pesticide ingestion is a leading method for suicide worldwide. Approximately 14-20% of global suicides, or 110,000-168,000 deaths a year, are from pesticide self-poisoning [1]. The prevention of pesticide suicides is a priority area of global suicide prevention strategies [2].

Paraquat, a commonly used herbicide, is amongst the pesticides **most frequently** involved in suicides. Paraquat is highly lethal when ingested [3], with an estimated case fatality of 55% in Taiwan [4]. Restricting access to paraquat may effectively prevent suicide from paraquat poisoning and reduce pesticide suicide rates [5], as few pesticides are as toxic as paraquat [3] and therefore even a shift to other pesticides is unlikely to result in higher case fatality. In Taiwan, a nationwide (first-stage) ban on the import and production of paraquat was implemented from February 2018, followed by a complete (second-stage) ban on its sale and use from February 2020. However, some have argued for a reversal of the policy and lifting the ban, citing the possibility of a shift to use other pesticides or methods for suicide that could lead to no effect of the ban on suicide [6]. Therefore, there is an urgent need to evaluate the ban's early effect on reducing deaths. We assessed the impact of the first-stage paraquat ban (i.e., ban on import and production) on suicide in Taiwan. We hypothesised that the impact on pesticide suicides would be most marked in rural areas, males, and the elderly (aged 65+ years), which were previously shown to have the largest burden of pesticide suicides in Taiwan [7,8].

Materials and methods

Suicide data (2011-2019) for people aged 15 years or above in Taiwan were extracted

from national cause-of-death data files, coded using the International Classification of Diseases, 10th Revision (ICD-10). A recent time trend analysis showed that Taiwan's suicide rates changed from a downward trend to a stable trend in 2011 [9]. Possible suicide deaths were identified using the following ICD-10 codes: X60-X84 (suicide), Y10-Y34 (undetermined intent), W75-W76, W83-W84 (accidental suffocation) and X48 (accidental pesticide poisoning), as a previous study from Taiwan indicated that many deaths classified as undetermined intent, accidental suffocation, or accidental pesticide poisoning were likely to be misclassified suicides [10]. Pesticide suicides were identified using ICD-10 X68 (suicide), Y18 (undetermined intent) and X48 (accident); all other suicides were classified as 'non-pesticide suicides'. Amongst pesticide suicides, suicides by paraquat poisoning were identified by searching 'paraquat' in the 'cause of death' field on the death certificate; all other pesticide suicides were classified as 'non-paraquat pesticide suicides'. Certified suicides accounted for the majority of all possible suicides; the percentage of certified suicides in all possible suicides (i.e., certified suicides and potential misclassified suicides combined) was 87.4%, 90.8%, and 88.8% for overall (all-method), pesticide, and paraquat suicides, respectively, during 2011-2019 (Appendix Table 1). To assess the impact of including potential misclassified suicides on our findings, we conducted sensitivity analyses based on deaths certified as suicides only. We used the term 'suicide' when referring to all possible suicides throughout the paper for simplicity.

Mid-year population data by sex, age group, and city/county were extracted from the Demographic Fact Books (2011-2019) published by the Ministry of the Interior. The 23 cities/counties were categorised into urban (n=11) and rural areas (n=12) based on whether their proportions of agricultural workers were below or above the median (5.4%), respectively. Sources for agricultural crop yield data are summarised in the

Appendix.

We calculated annual age-standardised suicide rates (2011-2019), overall and by method (pesticide vs non-pesticide) and pesticide (paraquat vs non-paraquat), for people aged 15 years or above, according to the 2000 World Health Organization World Standard Population. We calculated the percentage of pesticide suicides in all suicides, overall and by area/sex/age group, in 2011-2017 to investigate the contributions of pesticide suicide to the burden of suicide prior to the 2018 paraquat ban. Negative binomial regression models were used to estimate rate ratios (RRs), and their 95% confidence intervals (CIs) in 2018 and 2019, compared with the expected suicide rates based on the pre-ban linear suicide trends (2011-2017). We included year, sex, and age group (in 5-year bands) in the models to adjust for time trends as well as changes in population structure. The effect of the paraquat ban was investigated by including two dummy variables, one for 2018 and one for 2019. We focused on the results for 2019 (from 1st January to 31st December 2019) as it is the first complete year after the paraquat ban. Furthermore, official statistics showed that paraquat sale started to drop markedly from mid-2018 and became nearly zero in 2019 [11], enabling an assessment of the effect of no paraquat sale on suicide in that year.

Differences between areas (urban vs rural), sexes, and age groups (15-24, 25-44, 45-64 and 65+ years) were examined by including appropriate interaction terms (e.g., area * the dummy variable of year 2019) in the models. The reduced numbers and rates of suicide in 2019 were calculated based on the RR estimates, observed number of suicides, and population. Changes in rates of suicide were presented as rate differences (RDs), i.e., observed rates minus expected rates. The details of regression analyses and the calculation of changes in numbers and rates of suicide were provided in the Appendix. All regression analyses were performed using Stata 15.0 (StataCorp,

College Station, TX).

The study was approved by National Taiwan University Hospital Research Ethics Committee (201606036RINB).

Results

Figure 1 shows trends in suicide in Taiwan in 2011-2019. Figure 2 shows the forest plots of RRs (Figure 2A) and RDs (2B), overall and by subgroup. A marked reduction in pesticide suicide rates was found after the 2018 paraquat ban, compared with expected suicide rates based on pre-ban linear trends (2011-2017) – the pesticide suicide rate decreased by 37% (RR = 0.63, 95% CI 0.54-0.74) in 2019 (Figure 2A and Appendix Table 2). The corresponding estimated reduced number and rate of pesticide suicides was 190 (95% CI 116-277) and 0.93 (95% CI 0.57-1.35) per 100,000, respectively. The fall in pesticide suicide rate was mainly attributable to the reduction in paraquat suicides (RR = 0.42, 95% CI 0.33-0.54, 145 fewer suicides [95% CI 92-213]; a 0.71 [95% CI 0.45-1.04] per 100,000 reduction in rate). By contrast, non-paraquat pesticide suicides showed a small reduction (RR = 0.82, 95% CI 0.67-1.00; RD = -0.23, 95% CI -0.51 to 0.01 per 100,000). The age-standardised rates of non-pesticide and overall suicide were relatively stable over the study period (Figure 1B); there was no statistical evidence for a change in their rates in 2019 after the paraquat ban, although there is a suggestion of a small rise for non-pesticide suicides (RR = 1.05, 95% CI 0.99-1.10; RD = 0.89, 95% CI -0.17 to 1.89) (Appendix Table 2). The sensitivity analysis using certified suicides alone showed similar results; there was an estimated 40% (RR = 0.60, 95% CI 0.51-0.70) reduction in certified pesticide suicides in 2019 after the paraquat ban (Appendix Figure 1 and Appendix

Table 3).

In 2011-2017, prior to the paraquat ban, pesticide poisoning accounted for 12.1% of all suicides in Taiwan; the proportion was higher in rural than urban areas (21.8% vs 5.7%), in males than females (13.1% vs 10.2%), and highest in the elderly group (21.4%) (Appendix Table 2). Based on RRs, the falls in pesticide suicide rates were similar in urban and rural areas, and in males and females (p for interaction = 0.95 and 0.72, respectively) in 2019, whilst they appeared to be most marked in individuals aged 25-44 years and 45-64 years (p for age interaction < 0.001) (Figure 2A and Appendix Table 2). By contrast, the largest absolute reduction in pesticide suicide rates was found in older people aged 65+ years (1.17 and 1.58 per 100,000 for paraquat and pesticide suicides, respectively), which was also the only age group showing a decrease in all-method suicide rates (RR = 0.90, 95% CI 0.82-0.97; RD = -3.70, 95% CI -6.82 to -0.83 per 100,000) (Figure 2B and Appendix Table 2). A larger absolute reduction in pesticide suicide rates was found in rural (vs urban) areas and males (vs females).

No obvious change in the four major crop yields was found after the paraquat ban (Appendix Figure 2).

Discussion

Taiwan's ban on the import and production of paraquat from February 2018 was followed by a 37% reduction in pesticide suicides (190 fewer suicides) in 2019, mainly due to the 58% reduction in paraquat suicides (145 fewer suicides). No changes in non-pesticide and all-method suicides were found. In keeping with our

hypothesis, larger absolute reductions were found in rural areas, males, and the elderly population, with a 10% fall in all-method suicide rate in the elderly population, amongst whom pesticide poisoning accounted for 21.4% of all suicides before the paraquat ban. The paraquat ban was associated with no obvious changes in crop yields.

There are some limitations of the study. First, this is an ecological analysis and the observed reduction in pesticide suicides could be due to other factors, e.g., national suicide prevention programmes including gatekeeper training and the surveillance and aftercare projects for suicide attempters. However, these programmes were not specific to pesticide self-poisonings, and thus the specific effect that we observed on pesticide suicides makes this unlikely. Furthermore, our data showed that the reduction in pesticide suicides was mainly attributable to the decrease in paraquat suicides, suggesting a causal effect of the paraquat ban on reducing pesticide suicides. Second, this study examined only the short-term effect on suicide of the first-stage paraquat ban starting from February 2018. It was still legal to sell and use paraquat in 2019 before its complete ban from February 2020. Future research is needed to assess the longer-term effect of the complete paraquat ban. Finally, we included both certified and possible suicides (including accidental pesticide poisoning) in the analysis to address possible under-reporting of suicide, whilst possible suicides may not all be actual suicides. However, sensitivity analyses including certified suicides alone showed almost the same findings. Furthermore, accidental pesticide poisoning deaths may also be prevented by the paraquat ban.

Our finding is consistent with that found in South Korea, which observed a 37% fall in pesticide suicides in 2013 after the 2011-2012 ban on the sale of paraquat [5]. In Sri Lanka, a ban on three highly hazardous pesticides including dimethoate, fenthion, and

paraquat in 2008-2011 was followed by a 50% and 21% drop in pesticide and overall suicides in 2011-2015, respectively [12]. Individuals who consider ingesting pesticides to kill themselves may impulsively choose the most readily available products. Therefore, banning highly hazardous pesticides may contribute to reductions in suicide rates if lower lethality products are ingested instead [13,14].

We found no change in whole-population overall suicide rate after the paraquat ban. By contrast, a reduction in overall suicides was found in South Korea [5] and Sri Lanka [12] after the bans that involved paraquat. One reason for the difference in findings is the high proportions of pesticide suicides in all suicides in South Korea (21%) [15] and Sri Lanka (50%) [13] before the ban. By contrast, paraquat and pesticide ingestion accounted for only 5% and 12% of all suicides, respectively, in Taiwan before the paraquat ban [11], and thus the expected effect of the regulations on overall suicide rates is limited. By contrast, pesticide poisoning accounted for 21.4% of all elderly suicides in Taiwan (Table 1), in keeping with our finding of a reduction in both pesticide suicides and all-method suicides in the elderly population following the paraquat ban. Another factor that may have contributed to the lack of any impact of the paraquat ban on Taiwan's whole-population suicide rate is the increase in suicide rates in the younger (15-24 years) and middle-aged (45-64 years) groups in Taiwan in recent years [9].

We found limited evidence for method substitution, i.e., a shift from paraquat ingestion to fatal self-poisoning using other pesticides or other suicide methods after the paraquat ban. There was no change or a small decrease in non-paraquat pesticide suicides in the whole population and across age groups. With the exception of the elderly, there was a suggestion of an increase in non-pesticide suicides in the period

after the ban ($RR = 1.05$, 95% CI 0.99-1.10). Nevertheless, in those aged 65+ years, i.e., the age group with the highest burden of pesticide and paraquat suicides in Taiwan, there was no evidence of method substitution. Follow-up studies are needed to investigate the longer-term impact of paraquat ban and any method substitution.

In contrast to the concerns about the potential harmful effect on agricultural outputs due to pesticide bans, our results showed no obvious change in crop yields after the paraquat ban, in keeping with findings from South Korea [5], Sri Lanka [12,16], Bangladesh [17], and India [18].

In conclusion, the 2018 ban on the import and production of paraquat **was associated with** a reduction in pesticide suicide rates in Taiwan in 2019, with a fall in all-method suicide rates in older people, who had the greatest burden of pesticide suicides across all age groups. National and international policies restricting access to highly hazardous pesticides may prevent many pesticide suicides.

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Declaration of interest statement

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research Syngenta-funded trial meetings, and being an expert adviser to the first WHO consultation on best practices on community action for safer access to pesticides (2006), all outside the submitted work. ME is a WHO member of the FAO–WHO Joint Meeting on Pesticide Management, and reports receiving an unrestricted research grant from Cheminova (2012) and travel expenses from Syngenta to attend meetings (2005–06). DG and ME declare relevant grants from the Wellcome Trust and American Foundation for Suicide Prevention, were expert advisers to the WHO consultation on cost-effectiveness of suicide prevention interventions, including pesticide regulation (2019), provided technical assistance for the development and publication of “Suicide Prevention: A Resource Guide for Pesticide Registrars and Regulators” (2019). SSC is a reviewer of “Suicide Prevention: A Resource Guide for Pesticide Registrars and Regulators” (2019).

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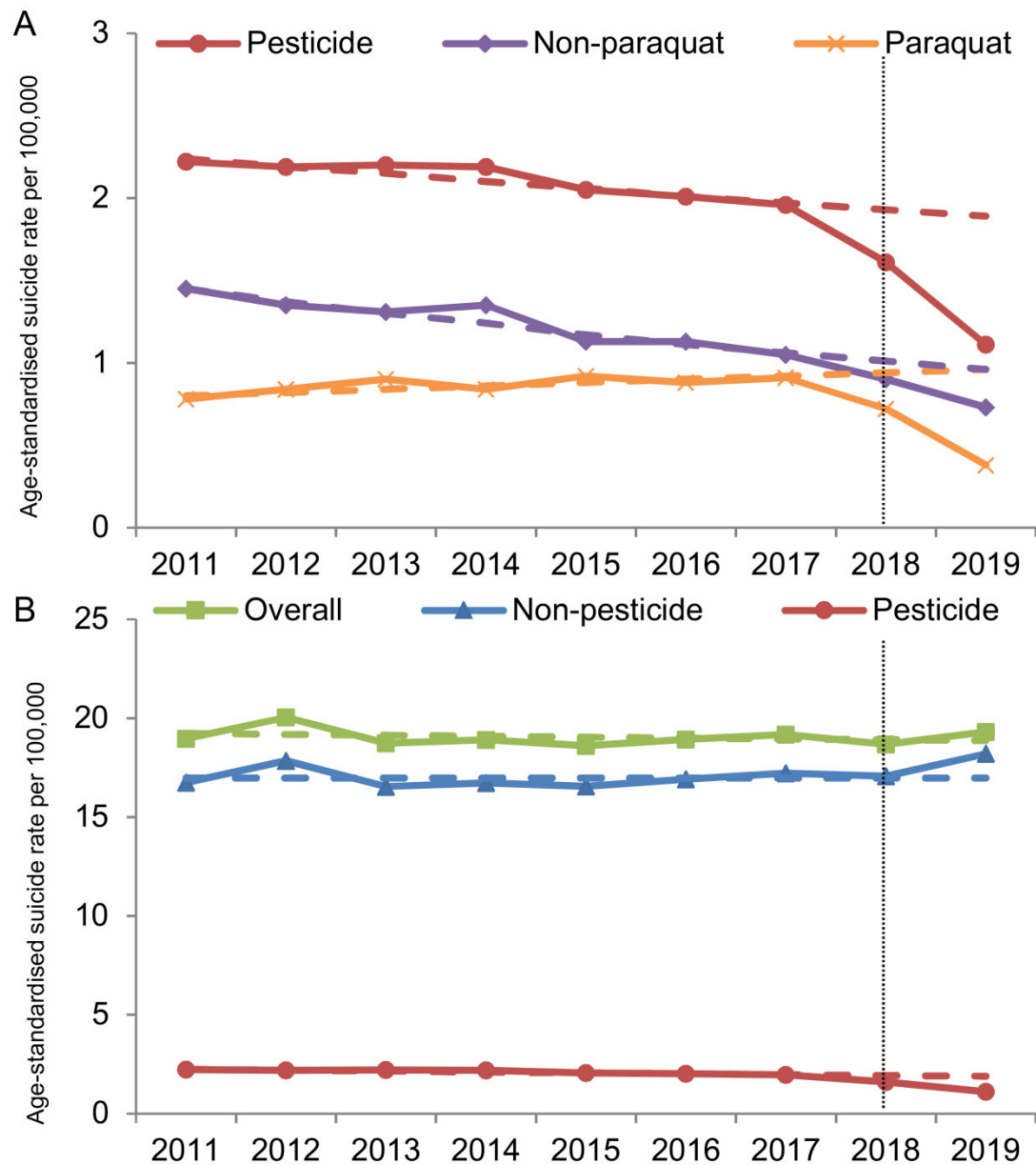
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Figure caption

Figure 1. Trends in age-standardised rates (per 100,000) of (A) pesticide, non-paraquat, and paraquat suicide and (B) overall, non-pesticide, and pesticide suicide (the dashed lines indicate the **estimated** suicide rates based on trend in 2011-2017) in Taiwan, 2011-2019. The vertical line indicates the year when the import and production of paraquat was banned (2018, or 1st February 2018 to be exact).

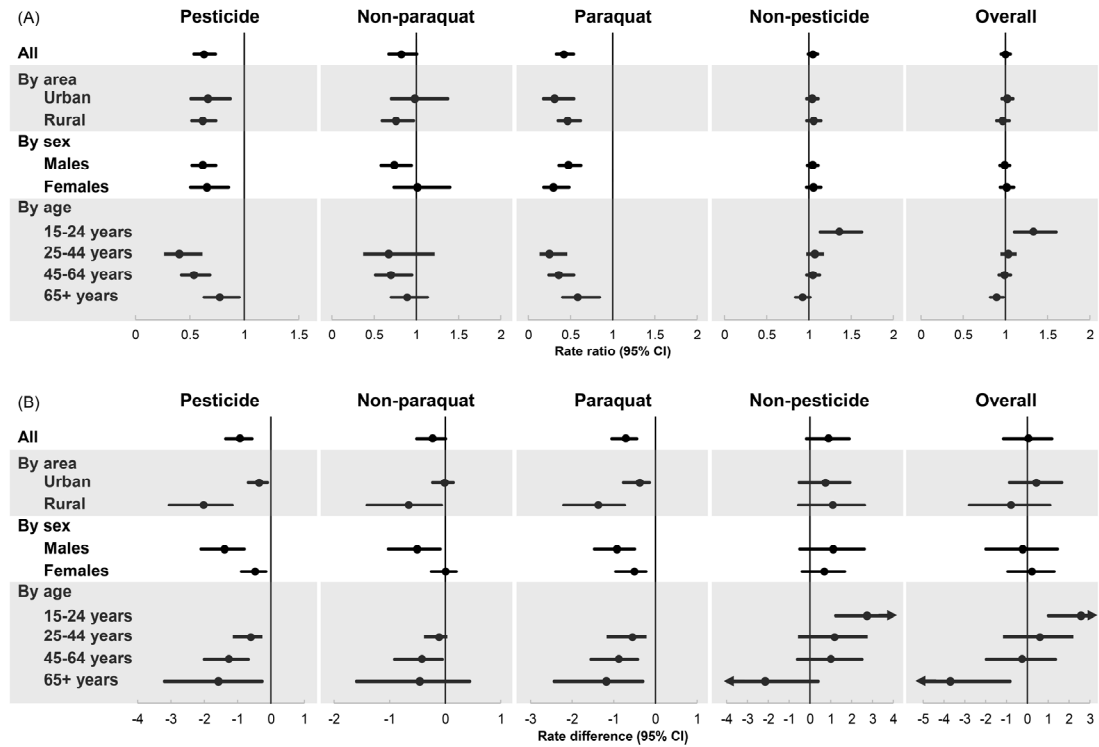
Figure 2. (A) Rate ratios (RRs) and (B) corresponding rate differences (RDs) per 100,000 based on RRs, and their 95% confidence intervals (CIs) of suicide by method (pesticide vs non-pesticide) and pesticide (paraquat vs non-paraquat) in 2019 after the paraquat ban in Taiwan. RRs are between the observed rates and the expected rates based on suicide trends 2011-2017 estimated using negative binomial regression models. The import and production of paraquat was banned from 1st February 2018.

Figure 1. Trends in age-standardised rates (per 100,000) of (A) pesticide, non-paraquat, and paraquat suicide and (B) overall, non-pesticide, and pesticide suicide^a (the dashed lines indicate the **estimated** suicide rates based on trend in 2011-2017) in Taiwan, 2011-2019. The vertical line indicates the year when the import and production of paraquat was banned (2018, or 1st February 2018 to be exact).



^a Including certified suicides and possible suicides (deaths certified as undetermined intent, accidental suffocation, or accidental pesticide poisoning).

Figure 2. (A) Rate ratios (RRs) and (B) corresponding rate differences (RDs) per 100,000 based on RRs, and their 95% confidence intervals (CIs) of pesticide (further grouped into non-paraquat and paraquat), non-pesticide, and overall suicides^a in 2019 after the paraquat ban in Taiwan. RRs are between the observed rates and the expected rates based on suicide trends 2011-2017 estimated using negative binomial regression models. The import and production of paraquat was banned from 1st February 2018.



Note: Rate ratios for pesticide (non-paraquat and paraquat) suicides could not be estimated in people aged 15-24 years due to no cases.

^a Including certified suicides and possible suicides (deaths certified as undetermined intent, accidental suffocation, or accidental pesticide poisoning).

Appendix

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1. Statistical methods

We used negative binomial regression models to estimate suicide rate ratios (RRs) and their 95% confidence intervals (CIs) in 2018 and 2019, compared with expected suicide rates based on linear suicide trends before the 2018 paraquat ban (2011-2017). There was evidence for overdispersion in suicide data and therefore negative binomial models were used instead of Poisson models. In the negative binomial regression models, the dependent variable was the number of suicides, with log-transformed population as the offset. The independent variables included two dummy variables, one for 2018 and one for 2019, to estimate changes in suicide rates in the two years, respectively, relative to those expected based on pre-ban suicide trends. The year variable was included in all models to adjust for linear time trend. Sex and age group (in 5-year bands) were also included to adjust for changes in population structure over time, in models using data not stratified by sex/age.

We focused on changes in suicide rates in 2019, as i) it is the first complete year after the first-stage paraquat ban, and ii) paraquat sale reduced to nearly zero in that year. The RR estimates were obtained using *nbreg* command specifying the *irr* option to investigate relative (i.e., proportional) changes in suicide rates. The expected number of suicides based on the RR estimates, all-method, by method (pesticide vs non-pesticide), and by pesticide (paraquat vs non-paraquat), was calculated by dividing the observed number of suicides by the RR estimate (formula 1). The corresponding 95% CIs of the expected number of suicides were calculated based on the 95% CIs of RRs (formulas 2 and 3). Rate difference (RD) was calculated by subtracting the expected suicide rate (based on the expected number of suicide) from the observed suicide rates (based on observed number of suicide); the 95% CIs of RD were based on the 95% CIs of the expected number of suicides derived from the 95%

CIs of RRs (formulas 4 to 6).

$$Expected = Observed/RR..... (1)$$

$$Expected \text{ upper limit of 95\% CI} = Observed/RR \text{ upper limit of 95\% CI}..... (2)$$

$$Expected \text{ lower limit of 95\% CI} = Observed/RR \text{ lower limit of 95\% CI}..... (3)$$

$$RD = (Observed-Expected)/population \times 10^5 (4)$$

$$RD \text{ upper limit of 95\% CI} = (Observed-Expected \text{ upper limit of 95\% CI})/population \times 10^5 (5)$$

$$RD \text{ lower limit of 95\% CI} = (Observed-Expected \text{ lower limit of 95\% CI})/population \times 10^5 (6)$$

Formula 7 shows how the reduced number of suicides in 2019 was estimated based on RR estimates, the observed number of suicides, and population.

$$Estimated \text{ change in suicide number based on RR} = Observed \times (1-1/RR) (7)$$

2. Descriptive statistics of the suicide data by manner of death

Appendix Table 1 shows the summary statistics for the distribution of the number and percentage of all possible suicides (certified suicides , deaths certified as undetermined intent, accidental suffocation, and accidental pesticide poisoning) by method (pesticide vs non-pesticide) and pesticide (paraquat vs non-paraquat) during the whole study period (2011-2019) and in the first complete year after the 2018 paraquat ban (2019 only).

Appendix Table 1. The total number and percentage of certified suicides, undetermined deaths, and accidental deaths, overall and by method (pesticide vs non-pesticide) and pesticide (paraquat vs non-paraquat), during the whole study period (2011-2019) and in the first complete year after the paraquat ban (2019 only).

	Overall		Non-pesticide		Pesticide		Non-paraquat		Paraquat	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
2011-2019										
All possible suicides ^a	38005	(100)	33708	(100)	4297	(100)	2581	(100)	1716	(100)
Suicide	33229	(87.4)	29329	(87.0)	3900	(90.8)	2376	(92.1)	1524	(88.8)
Undetermined death	4452	(11.7)	4253	(12.6)	199	(4.6)	105	(4.1)	94	(5.5)
Accidental death	324	(0.9)	126	(0.4)	198	(4.6)	100	(3.9)	98	(5.7)
2019 only										
All possible suicides ^a	4384	(100)	4062	(100)	322	(100)	216	(100)	106	(100)
Suicide	3838	(87.5)	3556	(87.5)	282	(87.6)	191	(88.4)	91	(85.8)
Undetermined death	497	(11.3)	483	(11.9)	14	(4.3)	10	(4.6)	4	(3.8)
Accidental death	49	(1.1)	23	(0.6)	26	(8.1)	15	(6.9)	11	(10.4)

^a Including certified suicides and possible suicides (deaths certified as undetermined intent, accidental suffocation, or accidental pesticide poisoning).

3. Detailed results of the negative binomial regression analyses

Appendix Table 2 show the estimates of rate ratios, rate differences, and change in number of suicides by method (pesticide vs non-pesticide) and pesticide (paraquat vs non-paraquat) in 2019, after the paraquat ban, between observed rates and those estimated based on the pre-ban trend (2011-2017), using all possible suicides.

Appendix Table 2. Rate ratios (RRs) and their 95% confidence intervals (CIs)^a, as well as estimated changes in the number and estimated rate differences (RDs) per 100,000 based on RRs, for pesticide (non-paraquat vs paraquat), non-pesticide, and overall suicide^b in 2019 after the paraquat ban in Taiwan. RRs are between the observed rates and the expected rates based on trend 2011-2017 from negative binomial regression models. The import and production of paraquat was banned from 1st February 2018.

	% of pesticide suicides in all suicides in 2011-2017	Observed number of suicides ^b	RR	(95%CI)	p	Estimated change in suicide number based on RR		Estimated rate difference based on RR	
						n	(95%CI)	RD	(95%CI)
All groups combined	12.1								
Pesticide		322	0.63	(0.54 , 0.74)	<0.001	-190	(-277 , -116)	-0.93	(-1.35 , -0.57)
Non-paraquat		216	0.82	(0.67 , 1.00)	0.056	-46	(-104 , 1)	-0.23	(-0.51 , 0.01)
Paraquat		106	0.42	(0.33 , 0.54)	<0.001	-145	(-213 , -92)	-0.71	(-1.04 , -0.45)
Non-pesticide		4062	1.05	(0.99 , 1.10)	0.097	182	(-34 , 385)	0.89	(-0.17 , 1.89)
Overall		4384	1.00	(0.95 , 1.06)	0.94	10	(-233 , 240)	0.05	(-1.14 , 1.17)
Urban	5.7								
Pesticide		96	0.67	(0.51 , 0.87)	0.003	-48	(-92 , -14)	-0.35	(-0.68 , -0.10)
Non-paraquat		73	0.98	(0.70 , 1.37)	0.92	-1	(-31 , 20)	-0.01	(-0.23 , 0.15)
Paraquat		23	0.31	(0.18 , 0.54)	<0.001	-51	(-104 , -20)	-0.38	(-0.77 , -0.15)
Non-pesticide		2614	1.04	(0.97 , 1.11)	0.24	100	(-70 , 260)	0.74	(-0.52 , 1.92)
Overall		2710	1.02	(0.96 , 1.09)	0.50	59	(-116 , 223)	0.44	(-0.86 , 1.65)
Rural	21.8								
Pesticide		226	0.62	(0.52 , 0.74)	<0.001	-140	(-210 , -80)	-2.02	(-3.05 , -1.16)
Non-paraquat		143	0.76	(0.60 , 0.97)	0.026	-45	(-97 , -5)	-0.66	(-1.41 , -0.07)

Paraquat		83	0.47	(0.35 , 0.62)	<0.001	-95	(-152 , -51)	-1.37	(-2.20 , -0.74)
Non-pesticide		1448	1.06	(0.97 , 1.14)	0.19	76	(-38 , 180)	1.09	(-0.55 , 2.61)
Overall		1674	0.97	(0.90 , 1.05)	0.42	-54	(-192 , 74)	-0.78	(-2.78 , 1.08)
Males	13.1								
Pesticide		228	0.62	(0.52 , 0.74)	<0.001	-140	(-211 , -81)	-1.39	(-2.10 , -0.80)
Non-paraquat		144	0.74	(0.58 , 0.94)	0.014	-51	(-103 , -9)	-0.50	(-1.02 , -0.09)
Paraquat		84	0.48	(0.36 , 0.62)	<0.001	-92	(-147 , -51)	-0.92	(-1.46 , -0.50)
Non-pesticide		2674	1.04	(0.98 , 1.11)	0.17	112	(-49 , 263)	1.11	(-0.49 , 2.61)
Overall		2902	0.99	(0.94 , 1.05)	0.80	-23	(-200 , 145)	-0.23	(-1.99 , 1.44)
Females	10.2								
Pesticide		94	0.66	(0.51 , 0.86)	0.002	-49	(-92 , -16)	-0.47	(-0.89 , -0.15)
Non-paraquat		72	1.01	(0.73 , 1.40)	0.94	1	(-26 , 20)	0.01	(-0.25 , 0.20)
Paraquat		22	0.30	(0.18 , 0.48)	<0.001	-52	(-99 , -23)	-0.50	(-0.95 , -0.23)
Non-pesticide		1388	1.05	(0.97 , 1.14)	0.20	71	(-39 , 173)	0.69	(-0.37 , 1.67)
Overall		1482	1.02	(0.94 , 1.10)	0.70	23	(-98 , 134)	0.22	(-0.94 , 1.29)
15-24 years	2.8								
Pesticide		0	-	- -		-	- -	-	- -
Non-paraquat		0	-	- -		-	- -	-	- -
Paraquat		0	-	- -		-	- -	-	- -
Non-pesticide		290	1.36	(1.14 , 1.63)	0.001	77	(35 , 112)	2.74	(1.24 , 3.99)
Overall		290	1.33	(1.11 , 1.60)	0.002	72	(28 , 109)	2.58	(1.01 , 3.89)
25-44 years	6.3								
Pesticide		29	0.40	(0.26 , 0.62)	<0.001	-43	(-81 , -18)	-0.60	(-1.14 , -0.25)
Non-paraquat		16	0.67	(0.37 , 1.22)	0.19	-8	(-27 , 3)	-0.11	(-0.38 , 0.04)
Paraquat		13	0.25	(0.13 , 0.46)	<0.001	-39	(-83 , -15)	-0.55	(-1.17 , -0.21)
Non-pesticide		1296	1.07	(0.97 , 1.18)	0.18	84	(-40 , 197)	1.18	(-0.57 , 2.77)
Overall		1325	1.03	(0.94 , 1.13)	0.49	43	(-83 , 157)	0.60	(-1.16 , 2.21)
45-64 years	12.5								
Pesticide		103	0.54	(0.42 , 0.68)	<0.001	-89	(-141 , -48)	-1.26	(-2.00 , -0.68)
Non-paraquat		68	0.70	(0.52 , 0.95)	0.021	-29	(-64 , -4)	-0.42	(-0.91 , -0.05)
Paraquat		35	0.36	(0.24 , 0.54)	<0.001	-62	(-109 , -30)	-0.88	(-1.55 , -0.43)
Non-pesticide		1560	1.05	(0.97 , 1.13)	0.22	70	(-42 , 175)	1.00	(-0.60 , 2.49)
Overall		1663	0.99	(0.92 , 1.06)	0.77	-18	(-138 , 95)	-0.25	(-1.97 , 1.35)
65+ years	21.4								
Pesticide		190	0.77	(0.63 , 0.95)	0.016	-55	(-112 , -9)	-1.58	(-3.19 , -0.27)

Non-paraquat	132	0.89	(0.70 , 1.13)	0.35	-16	(-56 , 15)	-0.46	(-1.60 , 0.44)
Paraquat	58	0.59	(0.41 , 0.84)	0.004	-41	(-85 , -11)	-1.17	(-2.43 , -0.30)
Non-pesticide	916	0.92	(0.84 , 1.02)	0.10	-75	(-173 , 14)	-2.16	(-4.95 , 0.39)
Overall	1106	0.90	(0.82 , 0.97)	0.010	-129	(-239 , -29)	-3.70	(-6.82 , -0.83)

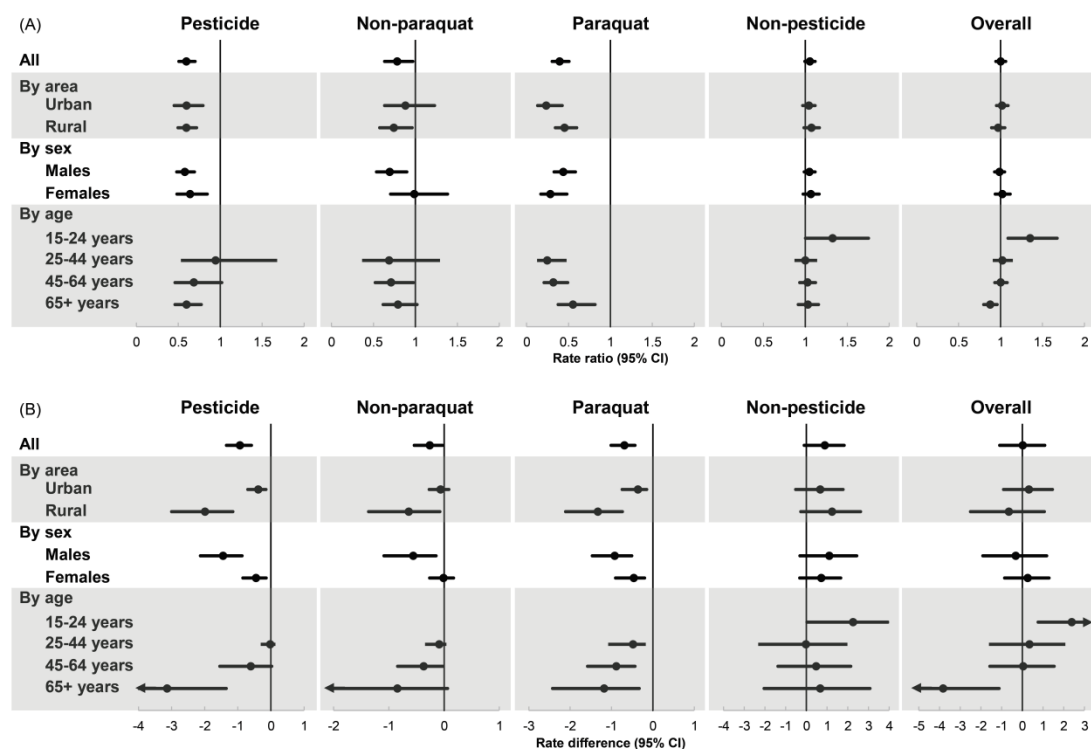
^a 95% confidence intervals of rate ratios that do not include one, and of changes in suicide number and rate differences that do not include null, are highlighted in bold.

^b Including certified suicides and possible suicides (deaths certified as undetermined intent, accidental suffocation, or accidental pesticide poisoning).

4. Results of sensitivity analyses

Appendix Figure 1 and Appendix Table 3 show the sensitivity analyses using certified suicides alone to estimate the rate ratios, rate differences, and change in number of suicides by method (pesticide vs non-pesticide) and pesticide (paraquat vs non-paraquat) in 2019, after the paraquat ban.

Appendix Figure 1. Sensitivity analyses including certified suicides alone: (A) Rate ratios (RRs) and (B) corresponding rate differences (RDs) per 100,000 based on RRs, and their 95% confidence intervals (CIs) of pesticide (further grouped into non-paraquat and paraquat), non-pesticide, and overall suicides in 2019 after the paraquat ban in Taiwan. RRs are between the observed rates and the expected rates based on trend 2011-2017 from negative binomial regression models. The import and production of paraquat was banned from 1st February 2018.



Note: Rate ratios for pesticide (non-paraquat and paraquat) suicides could not be estimated in people aged 15-24 years due to no cases.

Appendix Table 3. Sensitivity analyses including certified suicides alone: Rate ratios (RRs) and their 95% confidence intervals (CIs)^a, as well as estimated changes in the number and estimated rate differences (RDs) per 100,000 based on RRs, for pesticide (non-paraquat vs paraquat), non-pesticide, and overall suicides in 2019 after the paraquat ban in Taiwan. RRs are between the observed rates and the expected rates based on trend 2011-2017 from negative binomial regression models. The import and production of paraquat was banned from 1st February 2018.

	% of pesticide suicides in all suicides in 2011-2017	Observed number of suicide	Rate Ratio	(95%CI)	p	Estimated change in suicide number based on RR		Estimated rate difference based on RR	
						n	(95%CI)	RD	(95%CI)
All groups combined	12.7								
Pesticide		282	0.60	(0.51 , 0.70)	<0.001	-191	(-274 , -121)	-0.94	(-1.34 , -0.59)
Non-paraquat		191	0.78	(0.63 , 0.97)	0.024	-53	(-110 , -6)	-0.26	(-0.54 , -0.03)
Paraquat		91	0.39	(0.31 , 0.51)	<0.001	-140	(-207 , -89)	-0.69	(-1.01 , -0.44)
Non-pesticide		3556	1.05	(0.99 , 1.12)	0.078	181	(-21 , 372)	0.89	(-0.10 , 1.82)
Overall		3838	1.00	(0.94 , 1.06)	0.96	6	(-223 , 222)	0.03	(-1.09 , 1.09)
Urban	5.9								
Pesticide		78	0.60	(0.45 , 0.79)	<0.001	-52	(-95 , -20)	-0.39	(-0.70 , -0.15)
Non-paraquat		63	0.88	(0.63 , 1.23)	0.46	-8	(-36 , 12)	-0.06	(-0.27 , 0.09)
Paraquat		15	0.23	(0.13 , 0.42)	<0.001	-49	(-100 , -20)	-0.36	(-0.74 , -0.15)
Non-pesticide		2293	1.04	(0.97 , 1.12)	0.27	90	(-71 , 239)	0.66	(-0.52 , 1.77)
Overall		2371	1.02	(0.95 , 1.09)	0.60	43	(-122 , 197)	0.32	(-0.91 , 1.46)
Rural	22.8								
Pesticide		204	0.60	(0.50 , 0.72)	<0.001	-137	(-207 , -79)	-1.99	(-3.00 , -1.15)
Non-paraquat		128	0.74	(0.58 , 0.96)	0.023	-44	(-94 , -5)	-0.64	(-1.37 , -0.08)
Paraquat		76	0.45	(0.34 , 0.60)	<0.001	-92	(-146 , -51)	-1.33	(-2.11 , -0.74)
Non-pesticide		1263	1.07	(0.99 , 1.17)	0.11	85	(-19 , 181)	1.23	(-0.28 , 2.62)
Overall		1467	0.97	(0.89 , 1.05)	0.47	-45	(-173 , 73)	-0.65	(-2.50 , 1.06)
Males	13.7								
Pesticide		199	0.58	(0.48 , 0.69)	<0.001	-145	(-215 , -88)	-1.44	(-2.13 , -0.87)
Non-paraquat		127	0.69	(0.54 , 0.90)	0.005	-56	(-110 , -14)	-0.56	(-1.09 , -0.14)
Paraquat		72	0.44	(0.33 , 0.58)	<0.001	-93	(-147 , -52)	-0.92	(-1.46 , -0.51)
Non-pesticide		2339	1.05	(0.99 , 1.12)	0.13	111	(-32 , 245)	1.10	(-0.32 , 2.43)
Overall		2538	0.99	(0.93 , 1.05)	0.68	-32	(-192 , 118)	-0.32	(-1.91 , 1.17)
Females	10.7								

Pesticide	83	0.64	(0.49 , 0.85)	0.002	-47	(-88 , -15)	-0.45	(-0.85 , -0.15)
Non-paraquat	64	0.99	(0.70 , 1.38)	0.94	-1	(-27 , 18)	-0.01	(-0.26 , 0.17)
Paraquat	19	0.28	(0.17 , 0.48)	<0.001	-48	(-94 , -21)	-0.46	(-0.90 , -0.20)
Non-pesticide	1217	1.06	(0.97 , 1.16)	0.17	74	(-33 , 171)	0.71	(-0.32 , 1.65)
Overall	1300	1.02	(0.94 , 1.11)	0.63	27	(-88 , 133)	0.26	(-0.85 , 1.28)
15-24 years	2.7							
Pesticide	0	-	-	-	-	-	-	-
Non-paraquat	0	-	-	-	-	-	-	-
Paraquat	0	-	-	-	-	-	-	-
Non-pesticide	257	1.33	(1.00 , 1.75)	0.048	63	(1 , 110)	2.25	(0.03 , 3.94)
Overall	257	1.35	(1.09 , 1.68)	0.006	67	(21 , 104)	2.39	(0.76 , 3.70)
25-44 years	6.6							
Pesticide	25	0.95	(0.53 , 1.68)	0.85	-1	(-22 , 10)	-0.02	(-0.31 , 0.14)
Non-paraquat	14	0.69	(0.37 , 1.30)	0.25	-6	(-24 , 3)	-0.09	(-0.34 , 0.04)
Paraquat	11	0.24	(0.13 , 0.48)	<0.001	-34	(-77 , -12)	-0.48	(-1.08 , -0.17)
Non-pesticide	1128	1.00	(0.87 , 1.14)	0.98	-2	(-165 , 141)	-0.02	(-2.32 , 1.99)
Overall	1153	1.02	(0.91 , 1.15)	0.72	25	(-115 , 148)	0.35	(-1.61 , 2.09)
45-64 years	14.1							
Pesticide	93	0.69	(0.46 , 1.02)	0.061	-43	(-108 , 2)	-0.61	(-1.54 , 0.02)
Non-paraquat	64	0.71	(0.52 , 0.98)	0.034	-26	(-59 , -2)	-0.37	(-0.84 , -0.02)
Paraquat	29	0.32	(0.21 , 0.49)	<0.001	-62	(-111 , -30)	-0.88	(-1.58 , -0.43)
Non-pesticide	1383	1.02	(0.93 , 1.12)	0.61	33	(-97 , 150)	0.46	(-1.38 , 2.14)
Overall	1476	1.00	(0.93 , 1.08)	0.96	3	(-110 , 108)	0.04	(-1.57 , 1.53)
65+ years	24.8							
Pesticide	164	0.60	(0.46 , 0.78)	<0.001	-110	(-190 , -47)	-3.13	(-5.44 , -1.35)
Non-paraquat	113	0.79	(0.62 , 1.02)	0.071	-30	(-70 , 2)	-0.84	(-2.01 , 0.06)
Paraquat	51	0.55	(0.38 , 0.82)	0.003	-41	(-85 , -12)	-1.18	(-2.43 , -0.33)
Non-pesticide	788	1.03	(0.92 , 1.16)	0.62	23	(-72 , 108)	0.66	(-2.05 , 3.07)
Overall	952	0.88	(0.80 , 0.96)	0.005	-134	(-237 , -39)	-3.82	(-6.78 , -1.12)

^a 95% confidence intervals of rate ratios that do not include one, and of changes in suicide number and rate differences that do not include null, are highlighted in bold.

5. Agricultural crop yields

Data on the crop yields of paddy rice, brown rice, vegetables, and fruits (the four major crop groups in Taiwan based on the annual yields in 2019) during 2011-2019 were from the Agricultural Statistics Yearbook published by the Council of Agriculture. Graphic examination showed no obvious change in the four major crop yields (i.e., paddy rice, brown rice, vegetables, and fruits) after the 2018 paraquat ban (Appendix Figure 2).

Appendix Figure 2. Trends in the yields of four major crop groups (10 ton per ha) in Taiwan, 2011-2019. The vertical line indicates the year when the import and production of paraquat was banned (2018, or 1st February 2018 to be exact).

